Intraoperative Duplex Ultrasound During Carotid Endarterectomy

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The purpose of this study was to examine the technical aspects of intraoperative duplex ultrasound (DUS) following carotid endarterectomy (CEA), suggest criteria to differentiate significant lesions requiring immediate surgical revision from normal or benign defects, and evaluate how frequently intraoperative DUS provides useful or unsuspected information. A retrospective study was performed on all patients who had both CEA and intraoperative carotid DUS between January 1, 1990, and January 1, 1995. A total of 155 DUS examinations were performed in 149 patients. Findings were grouped into three categories: normal; minor/insignificant lesions; and hemodynamically significant lesions based on the presence or absence of elevated peak systolic velocities, visible stenosis/thrombus, or intimal flap/dissection. Postoperative status was correlated with intraoperative DUS findings.

Ninety-one (59%) examinations performed on 87 patients produced normal findings. Forty-seven (30%) examinations performed on 45 patients showed minor abnormalities consisting of insignificant residual plaque, residual external carotid artery stenoses, small intimal flaps, elevated velocities with no associated anatomic lesion, or an arterial kink. Fourteen patients (9%) had significant findings requiring immediate surgical revision. These consisted of large intimal flaps or dissection in six patients, marked residual plaque and significant stenosis in five patients, thrombus in two patients, and a kink in one patient. Three additional patients (2%) had significant findings but were not revised for various reasons. No significant difference was identified in morbidity or mortality rates between those patients with normal findings, those patients with minor technical defects, and those patients with significant abnormalities undergoing immediate surgical revision. However, two of three patients who had significant abnormalities within the common carotid artery that were not revised suffered perioperative ipsilateral strokes.

Intraoperative DUS is a safe and accurate method to assess the technical adequacy of CEA. Intraoperative DUS showed significant lesions in 11% of patients. Identification and immediate repair of significant technical defects may decrease perioperative complication rate and long-term restenosis rate.

Introduction

Stroke remains the third most common cause of death in the United States. In 1992, more than 143,000 people died of stroke, and it is estimated that more than 3,800,000 patients who have had a stroke are alive but suffer residual adverse effects.[1] At least 50% of all strokes are thought to arise from carotid artery narrowing secondary to intraluminal plaque in the region of the carotid

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bifurcation.[2] Surgical attempts to remove this plaque date back to 1953, when DeBakey performed the first carotid endarterectomy (CEA).[3] Eastcott[4] was the first to describe carotid reconstruction for transient ischemic attacks in 1954. Since then, CEA has become one of the most common vascular procedures performed in the United States with 107,000 operations performed in 1985.[5]

Carotid endarterectomy is currently the recommended treatment for patients with symptomatic high-grade carotid artery stenosis (70–99%) and may be indicated in many asymptomatic patients as well.[6,7] The major complication rate for this procedure is low, occurring in approximately 5% of cases performed at all centers, and approaching 2% in tertiary centers.[6] Owing to the significant neurologic morbidity and mortality involved with a failed CEA, however, various intraoperative methods to assess the immediate technical adequacy of this procedure have been developed: continuous-wave Doppler,[8] pulsed Doppler,[9,10] electromagnetic blood flow measurement,[11] angiography,[12,13] and ultrasound.[14,15] More recently, duplex ultrasound (DUS), combining B-mode ultrasound imaging with pulsed Doppler spectral analysis, was introduced in an effort to identify lesions following CEA that could lead to perioperative thrombosis and stroke or long-term restenosis.[16-19] This imaging technique is safe, portable, and noninvasive; requires no contrast media; and allows for the immediate correction of significant technical defects. Its sensitivity in detecting technical defects has been shown to be similar to that of intraoperative angiography,[20,21] and with routine use, long-term restenosis rates appear to be decreased.[18,19]

The objectives of this study were to examine the technical aspects of intraoperative carotid DUS, to define criteria for differentiating between significant lesions and minor insignificant defects, to evaluate the impact of intraoperative DUS on perioperative neurologic complication rate, and to assess how frequently DUS provides useful information.

Patients and Methods

A retrospective chart and film review was performed for each patient who had an intraoperative duplex ultrasound following carotid endarterectomy between January 1, 1990, and January 1, 1995. Operations were performed by one of four vascular surgeons, and the intraoperative DUS examinations were performed by one of 11 staff radiologists. All patients were operated on under general anesthesia with EEG monitoring throughout the procedure. An Acuson

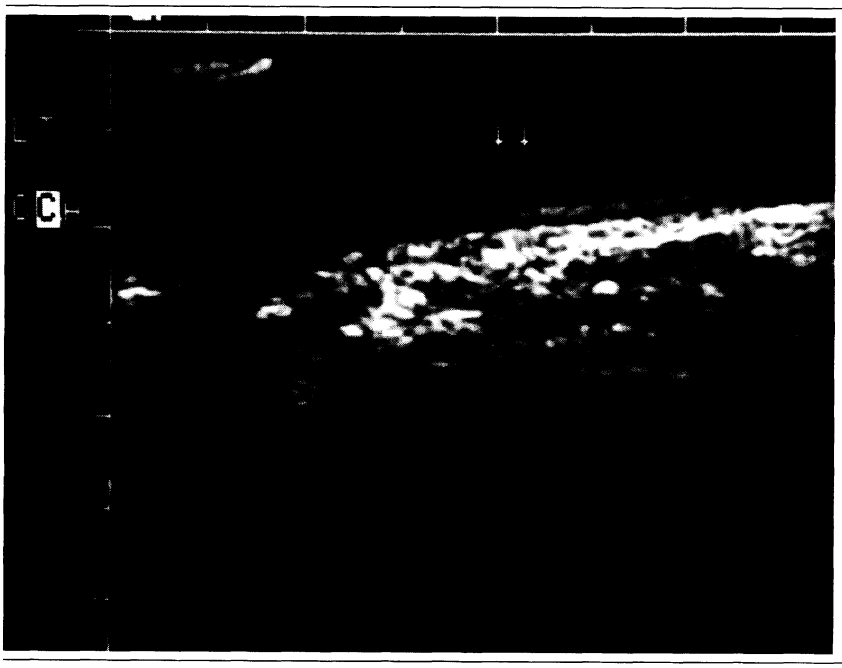

Figure 1. Normal longitudinal gray-scale image of distal CCA and proximal carotid bulb. Arrows indicate interruption of intima at proximal endarterectomy end point.

128 or XP-10 (Acuson Corporation, Mountain View, CA) with duplex and color Doppler capability was used for all examinations, as was a 7.5 MHz linear array transducer, which was inserted into a sterile plastic sheath. Imaging was performed primarily in the longitudinal plane. Transverse images were acquired to further evaluate any suspected abnormalities. The exposed distal common carotid artery (CCA), proximal internal carotid artery (ICA), and proximal external carotid artery (ECA) were evaluated. Care was taken to evaluate the CCA from a level proximal to the proximal endpoint of the endarterectomy through the mid ICA and ECA above the distal endpoint of the endarterectomy. Color Doppler was used initially to screen the exposed vessels for flow disturbance. In general, color Doppler was helpful in identifying sites of increased velocity or stenosis but tended to obscure fine detail such as small intimal flaps and dissections. These defects were better visualized by gray-scale imaging. Velocities were measured in all three arteries (CCA, ICA, ECA) and at segments proximal and distal to the endarterectomy endpoints or to the B-mode image abnormality if present. The duration of the DUS examination was between 10 and 20 minutes.

Intraoperative DUS findings were classified into three categories based on peak systolic velocity (PSV) and the presence or absence of visible stenosis, thrombus, intimal flap, or dissection (Table I). The normal category had PSV less than 1.25 m/sec, no or minimal visible stenosis or thrombus, and no intimal flap or dissection (Figure 1). A PSV greater than 1.25 m/sec has been shown to represent a significant (greater than 50%) stenosis and is one of the values used in our evaluation of patients preoperatively.[22] The insignificant category also had a PSV less than 1.25 m/sec but had either a moderate amount of visible plaque or a small intimal flap of less than 3 mm (Figure 2). Residual external carotid artery stenoses that were present on the preoperative imaging workup and still present but unchanged on the intraoperative DUS were also considered insignificant. The significant category consisted of studies with a PSV of greater than 1.25 m/sec, and either a marked amount of plaque, thrombus, or an intimal flap/dissection of greater than 3 mm (Figure 3). An examination with an elevated PSV but with no visible evidence of stenosis did not automatically constitute a major abnormality. Elevated PSV throughout the carotid system can also be seen in hyperdynamic states such as hyperthyroidism and with hyperperfusion after endarterectomy. Therefore, a discrete anatomic lesion had to accompany an elevated PSV in order to be assigned to the significant group.

During this study period, 333 carotid endarterectomies were performed at our institution. From this group, 155 intraoperative DUS examinations were performed in 149 patients, with six patients having staged bilateral carotid endarterectomies. One-hundred twelve were men with a mean age of 68.6 years, and 37 were women with a mean age of 68.9 years. Indications for CEA were symptomatic stenosis in 62% of patients and asymptomatic severe stenosis in 38%. Neurologic outcome was assessed postoperatively and after follow-up and correlated with intraoperative DUS findings. Mean follow-up was 5 months (range 1 day to 43 months). At follow-up, DUS examination was performed in 55% of all patients.

Table I. Classification of intraoperative duplex ultrasound findings during carotid endarterectomy.

Category	Gray Scale	Spectral Analysis
Normal	No or minimal plaque/thrombus	PSV < 1.25 m/sec
Insignificant	Moderate plaque/thrombus, small intimal flap, stable ECA stenosis	PSV < 1.25 m/sec
Significant	Marked plaque/thrombus or large intimal flap/dissection	PSV > 1.25 m/sec

PSV = peak systolic velocity; ECA = external carotid artery.

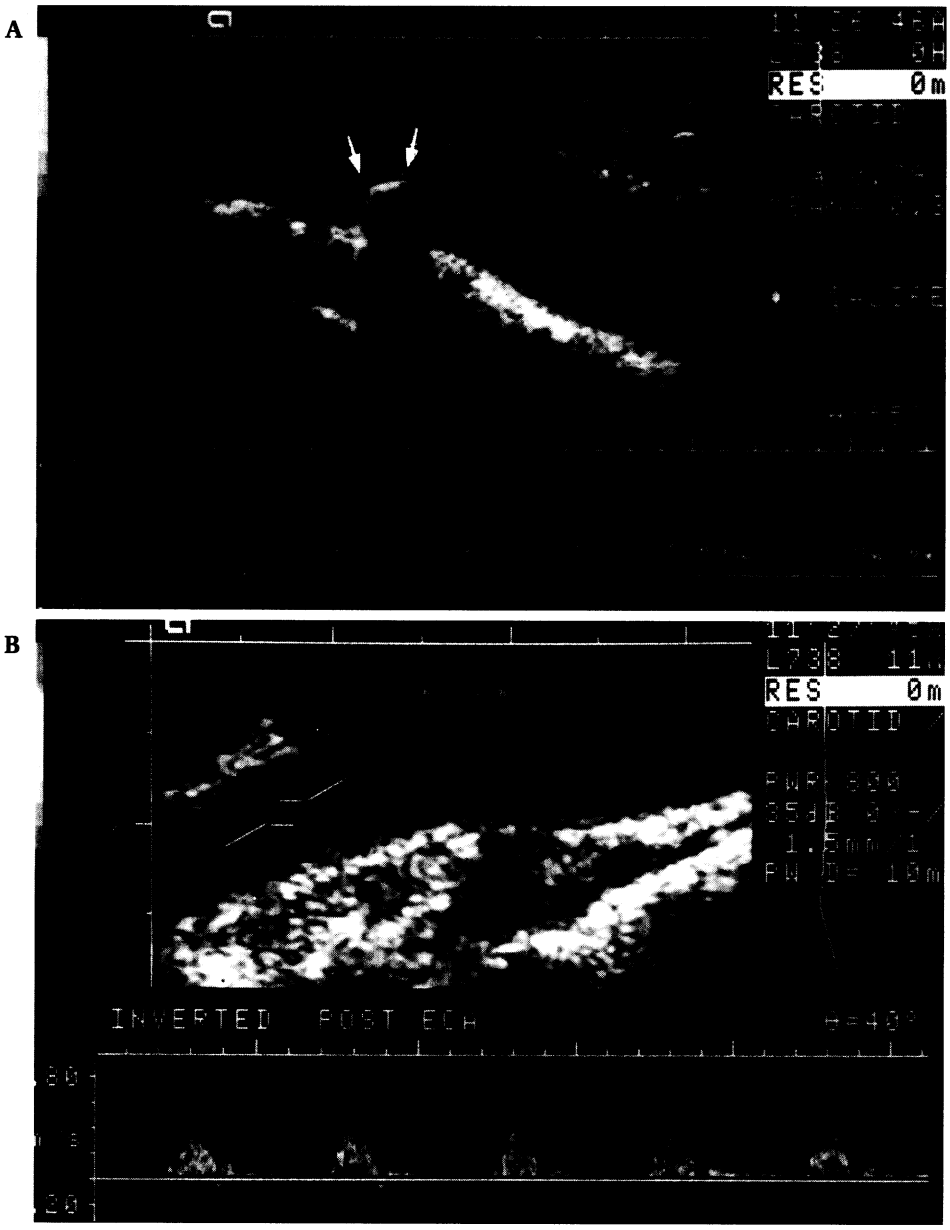

Figure 2.
A. Longitudinal gray-scale image of right CCA demonstrates a small amount of residual echogenic plaque at the proximal endarterectomy end point. Spectral analysis shows the PSV to be within the normal range (0.79 m/sec).
B. Longitudinal gray-scale image demonstrates a small intimal flap in the ECA. Spectral analysis shows the PSV within the normal range.

Results

The operative mortality rate was 0.7% (1/149). The cause of death for this patient was an ipsilateral stroke. The postoperative permanent stroke rate was 1.9% (3/155). Ninety-one (59%) DUS examinations in 87 patients yielded normal findings (Table II). Forty-seven (30%) examinations in 45 patients fell into the insignificant category (Table II). These minor defects were a residual plaque adjacent to the endarterectomy site (n = 30), residual ECA stenosis (n = seven), a small raised intimal flap (n = six), elevated PSV with no associated anatomic lesion (n = three), and one small kink. These minor lesions were located within the ICA in 11 CEAs, the CCA in 16 CEAs, the ECA in seven CEAs, and a combination of ICA and CCA or ECA involvement in three CEAs (Figure 2).

Significant abnormalities that were immediately revised were identified in 14 patients (9%) (Table II). These major defects were a marked

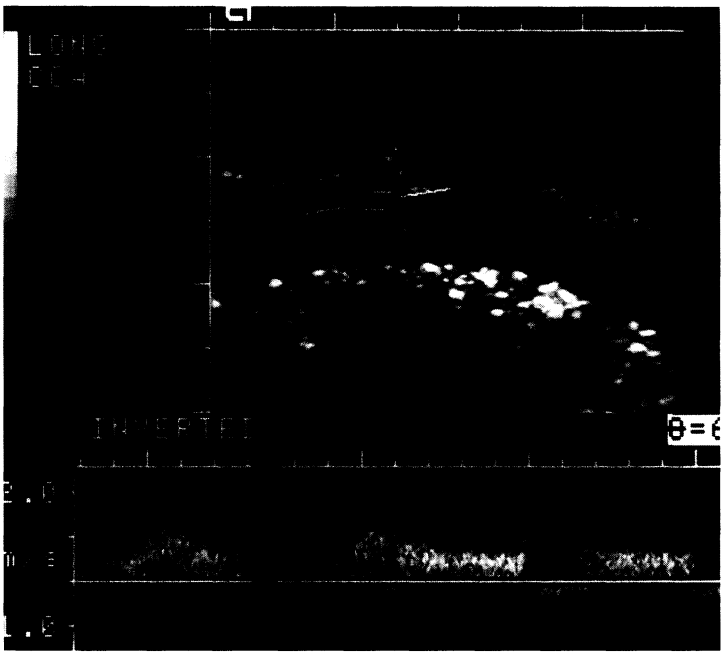

Figure 3. Longitudinal gray-scale image of distal CCA shows elevated plaque or intimal flap at the proximal endarterectomy end point. Spectral analysis demonstrates an elevated PSV (approximately 1.8 m/sec).

Table II. Postoperative outcome according to intraoperative DUS findings after carotid endarterectomy.

Category	N	%	Perioperative Stroke	
			Major	Minor/RIND
Total	155	100	3	2
Normal	91	59	1	2
Minor defects	47	30	0	0
Revised major defects	14	9	0	0
Unrevised major defects	3	2	2	0

DUS = duplex ultrasound; RIND = reversible ischemic neurologic deficit.

residual plaque adjacent to the endarterectomy site in five patients, a large intimal flap or dissection in six patients, an obstructing ICA/bulb thrombus in two patients, and an ICA kink in one patient (Figure 4). Three of these lesions were located in the ICA, two in the CCA, and nine within the ECA.

Three additional patients (2%) were identified as having significant abnormalities in intraoperative DUS but were not revised for various reasons (Table II). All three patients in this group had elevated PSV within the CCA associated with residual plaque (Figure 3). One of these lesions was felt to be nonhemodynamically significant by the surgeon and was not repaired. This patient had a normal postoperative course. The second patient had marked EEG changes, labile blood pressure, and a stormy operative course, and no revision was performed. This patient went on to develop an ipsilateral perioperative stroke, which eventually led to his death. The third patient within this category had

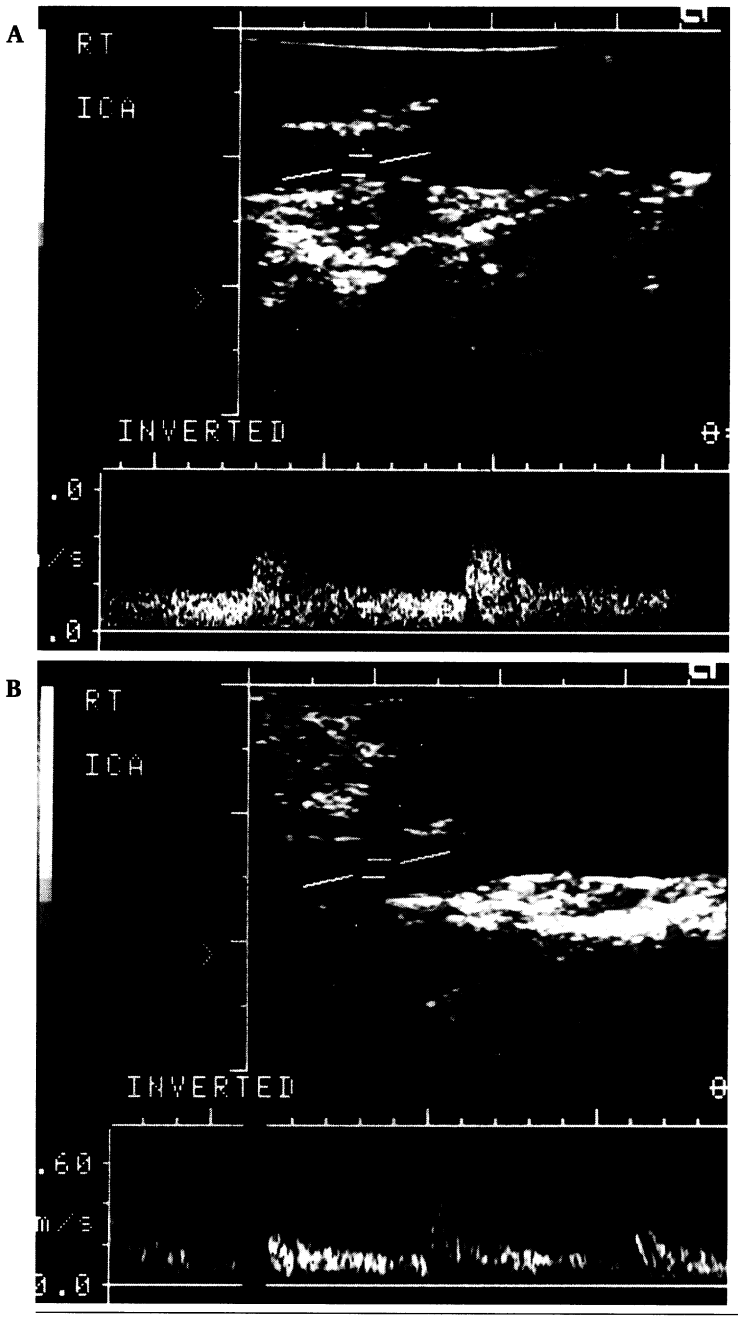

Figure 4.
A. Longitudinal gray-scale image of distal CCA and proximal ICA shows residual plaque, and spectral analysis confirms the hemodynamic significance of this residual stenosis with elevated PSV (approximately 2 m/sec).
B. After immediate surgical revision with patch angioplasty, longitudinal gray-scale image appears normal, and spectral analysis shows normal PSV (0.5 m/sec).

an intraoperative DUS interpreted as normal at the time of surgery. In retrospect, there was elevated blood velocity associated with moderate CCA plaque, consistent with a significant stenosis. This stenosis corresponded to findings found on the preoperative DUS and angiogram, but the endarterectomy did not extend proximally enough to include this site. This patient also went on to develop an ipsilateral perioperative stroke.

Of the 87 patients with 91 normal findings from intraoperative DUS examinations, 84 were neurologically normal in the postoperative period and at follow-up. Three patients suffered perioperative strokes (3/91, 3.3%). Two of these were reversible ischemic neurologic deficits (RIND). These two patients had recovered completely from their neurologic deficit by the sixth postoperative day. The third patient had residual dysarthria at 6 months. In this group

with normal findings from intraoperative DUS, there was a single case of an asymptomatic restenosis (> 50%) at 6 months. All 45 patients with insignificant intraoperative DUS findings (in 47 CEAs) were neurologically normal postoperatively and at follow-up. There was also one patient with an asymptomatic restenosis in this group. Of the 14 patients with significant abnormalities detected by intraoperative DUS who underwent surgical revision, all 14 were neurologically normal postoperatively and at follow-up and without restenosis. In this group, two patients at late follow-up died from causes unrelated to their CEA, one from an intraoperative myocardial infarction during a subsequent coronary artery bypass grafting procedure, and the other from renal failure at 13 months (Table II).

Discussion

The benefits of carotid endarterectomy for symptomatic or asymptomatic severe internal carotid artery stenosis have been well established by the NASCET and ACAS trials.[6,7] However, these benefits remain only if carotid endarterectomy can be performed with minimal postoperative neurologic risk. This has led to the need for intraoperative assessment of the technical adequacy of carotid endarterectomy over the past decades. Initially, intraoperative assessment of the technical adequacy of carotid endarterectomy was based on various methods such as continuous-wave Doppler, pulsed Doppler with spectral analysis, electromagnetic blood flow measurement, angiography, or B-mode ultrasound.[8-15] These methods were all recognized as being potentially useful at finding intraoperative defects that could have led to a postoperative stroke or an internal carotid artery thrombosis. However, none of these methods provided the combination of physiologic and anatomic information that could be provided by duplex ultrasound.

This series is a review of our initial experience with intraoperative use of color duplex ultrasound during carotid endarterectomy. In this series, we divided intraoperative duplex ultrasound findings among normal, minor, and major defects. Our incidence of major defects was 11%, which is quite comparable to other previous studies.[16,17,19] Although an 11% incidence of major defects as detected in our experience with intraoperative duplex ultrasound may seem high, it may be partially explained by a selection bias in our review, for only 155 of 333 carotid endarterectomies during the study period underwent intraoperative ultrasound. It is possible that the higher incidence of major or minor defects were found because surgeons were more likely to ask for an intraoperative ultrasound if they were suspecting an anomaly after completion of the endarterectomy. Currently in our practice, intraoperative duplex ultrasound assessment is now done routinely for all carotid endarterectomies. The positive impact of intraoperative duplex ultrasound on postoperative outcome is quite difficult to prove. In this initial experience with 155 carotid endarterectomies, however, our permanent postoperative stroke rate was 1.9% (3/155) (Table II). Of these three patients with major postoperative strokes, two had a major defect that was not corrected. These significant defects were proximal stenoses from residual plaque in the common carotid artery. Although these numbers are small, they do suggest that a patient found to have major residual defects that are not revised immediately is at a definite increased risk for poor neurologic outcome postoperatively. Furthermore, all 14 patients identified as having a major defect who underwent immediate surgical revision were indeed confirmed to have a significant lesion, and this did not adversely affect their postoperative outcome, for no stroke occurred in this group (Table II). This opinion that a significant defect should be corrected immediately and that carotid reopening did not adversely affect postoperative outcome in their experience is also shared by other authors.[16-19]

The optimal intraoperative management of minor defects remains uncertain. In our series, 30% of carotid endarterectomies were found to have minor defects. Again, this high incidence may be due in part to a selection bias of having this intraoperative ultrasound done in a nonconsecutive series instead of routinely. However, the postoperative outcome of these 45 patients with 47 minor defects was excellent with no postoperative stroke and only one restenosis at short-term follow-up. What remains unknown will be the impact of these unrevised minor technical defects on the occurrence of late restenosis or a late ipsilateral neurologic event. Bandyk and colleagues[23] have shown that the presence of residual turbulence after carotid endarterectomy as assessed by pulsed Doppler spectral analysis is a significant risk factor for increased occurrence of late occlusion or restenosis. They also showed

that unrepaired defects identified by intraoperative duplex ultrasound also led to an increased risk of late restenosis.[17] Reilly et al[19] also confirmed that unrepaired defects identified intraoperatively by DUS during carotid endarterectomy were an independent risk factor for late recurrent stenosis. Finally, Kinney et al[18] confirmed that a residual defect identified by intraoperative duplex ultrasound during carotid endarterectomy was a positive risk factor for long-term carotid restenosis as well as for an increased late ipsilateral stroke rate.

Our short mean follow-up, unfortunately, does not allow us to make any significant conclusion on the impact of intraoperative ultrasound on late restenosis and late ipsilateral neurologic event. Further studies are needed to better assess the long-term impact of intraoperative duplex ultrasound on the incidence of late carotid restenosis and on late ipsilateral stroke rate. However, our initial experience with intraoperative ultrasound did draw our attention to the importance of trying to reach technical perfection during carotid endarterectomy and had the benefit of improving our surgical technique regarding, more specifically, the management of the proximal end point at the level of the common carotid artery and the need to ensure there is no residual proximal plaque and to ensure better management of the external carotid artery in which 64% of the major revised defects were found (9/14). These nine patients had large intimal flaps or raised plaque at the distal end point of the site of the eversion endarterectomy of the ECA, which caused marked dampening or reduction in blood flow velocities. These lesions were considered significant and were corrected to prevent the theoretical possibility of an ECA thrombosis with retrograde extension into the bulb, which could lead to possible embolization into the ICA. Revision of these ECA defects was relatively simple with completion endarterectomy with or without patch angioplasty and all patients had a favorable outcome.

Conclusion

Intraoperative duplex ultrasound is a quick, safe, and accurate method of assessing the technical adequacy of carotid endarterectomy. Intraoperative duplex ultrasound offers superior anatomic information with B-mode imaging in multiple planes combined with hemodynamic information by Doppler spectral analysis. Patients found by intraoperative DUS to have minor defects or major defects that were immediately revised had a normal postoperative outcome. Patients found to have significant defects should undergo immediate revision to avoid poor neurologic outcome postoperatively. Longer follow-up is needed to better assess the potential impact of minor defects on the risk of late restenosis and ipsilateral stroke rate.

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