Hypothesis: Intraoperative duplex scanning can identify technical defects and increase the quality of carotid artery repair.

Design: We evaluated 100 consecutive carotid operations in 96 patients (60 men and 36 women) from 1995 to 1998. Spectral-derived peak systolic flow velocities (PSV) were graded (PSV <100 cm/s, normal laminar flow; PSV 100-150 cm/s, mild or moderate flow disturbance; PSV >150 cm/s, severe flow disturbance). Prospective criteria for intraoperative revision included PSV greater than 150 cm/s, spectral broadening, and B-mode imaging of intimal flaps or intraluminal debris. Preoperative, intraoperative, and 6-week follow-up duplex scan results were analyzed.

Setting: All patients were evaluated and treated at a single academic institution.

Interventions: All procedures were performed with the patient under general endotracheal anesthesia; 86% underwent shunting and 70% underwent patching.

Main Outcome Measure: Number and type of revisions, patency of repair, residual and recurrent stenosis, and ipsilateral neurologic events.

Results: There were 33 intraoperative duplex studies with abnormal findings. Seven involved the common carotid artery and resulted in intraoperative revision of 5 intimal flaps at the site of the proximal clamp. In 11 patients, incomplete eversion endarterectomy resulted in elevated distal intimal flaps in the external carotid artery that were repaired through a separate arteriotomy. There were 15 abnormalities in the internal carotid artery prompting 5 revisions. Five studies with PSV of 100 to 150 cm/s had no defects on B-mode imaging and were observed without treatment. Five false-positive studies were attributed to increased flow velocity due to contralateral occlusive disease. At 6 weeks' follow-up, 4 of 5 repaired common carotid arteries were normal on duplex scan and 1 had a mild residual stenosis. Ten of the 11 external carotid repairs were patent and 1 was occluded. Four of the 5 internal carotid artery repairs were normal on postoperative evaluation and 1 had a mild residual stenosis. Of the 10 abnormal internal carotid arteries that were observed, 9 were normal on postoperative duplex and 1 had a mild residual stenosis. One perioperative stroke occurred in a patient with a normal, patent carotid repair.

Conclusions: Intraoperative duplex evaluation of carotid reconstruction is an efficient, sensitive tool that can detect technical lesions that will jeopardize surgical reconstruction. Interpretive judgment is required because all flow disturbances do not dictate surgical intervention. This technique enables the surgeon to maximize the quality of the arterial reconstruction during carotid artery surgery.

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Technically precise repair is the most important determinant of success of carotid endarterectomy. Several studies have demonstrated a significant correlation between technical errors in the carotid repair and the development of perioperative neurologic deficits. Intraoperative evaluation is the best way to determine the hemodynamic status of the repair because immediate operative revision is possible if a technical defect is identified. Intraoperative angiography is an accurate method of evaluation, but is time-consuming, poses the risk of causing air emboli, and exposes operating room personnel to irradiation.

In 1984, we instituted the use of intraoperative Doppler technology to evaluate our operative repair after carotid endarterectomy. Initially, we used velocity-spectral derived waveforms and demonstrated their equivalency to angiography. We have used increasingly sophisticated duplex technology for the past 12 years. The development of ultrasound probes designed specifically for intraoperative use have contributed to the efficiency of this technique. This series presents the results of a modern series demonstrating the current state of the art of intraoperative assessment and illustrates how this technology allows for more precise, durable carotid repair.

The average time of the scan was 10.6 ± 1.1 minutes. There were 33 intraoperative

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From the Medical College of Wisconsin, Milwaukee.
PATIENTS, MATERIALS, AND METHODS

PATIENTS

One hundred consecutive carotid reconstructions performed between January 1, 1995, and December 31, 1998, were evaluated in 96 patients (60 men and 36 women). All patients had preoperative, intraoperative, and 6-week postoperative duplex scans performed. The mean age at time of operation was 70 years (range, 51-86). Risk factors included smoking (63%), hypertension (62%), hypercholesterolemia (23%), and diabetes (19%). Operative indications included no symptoms (n=51), transient ischemic attack (n=26), amaurosis fugax (n=13), and stroke (n=10).

OPERATIVE TECHNIQUE

All procedures were performed with general endotracheal anesthesia. After dissection of the carotid bifurcation, all patients were given heparin. During the endarterectomy, an intravascular shunt was used for 86 patients and 70% underwent patch closure of the arteriotomy. For 70 patients, the arteriotomy was closed with a patch angioplasty, using internal jugular vein in 62% (n=43), Dacron in 33% (n=23), saphenous vein in 4% (n=3), and polytetrafluoroethylene in 1% (n=1). Customarily, systemic heparinization was not reversed at the conclusion of the procedure and low molecular weight dextran was administered intravenously (25 mL/h) for 24 hours.

INTROOPERATIVE ASSESSMENT

The adequacy of arterial repair was assessed by duplex ultrasonography (ATL 3000 with a CL10-5 26-mm probe; Advanced Technical Labs, Bothell, Wash). The probe was placed in a gel-filled sterile sleeve and the operative field was immersed with saline for acoustic coupling. We recorded the peak systolic velocity (PSV) and end diastolic velocity in the common carotid artery (CCA), internal carotid artery (ICA), and external carotid artery. Using B-mode gray scale imaging, the luminal surface of the vessel wall is interrogated. Cross-sectional diameters of the bifurcation are obtained to allow postoperative assessment of subsequent dilations of the repair. In patients with polytetrafluoroethylene patches, only the artery proximal and distal to the patch can be imaged because polytetrafluoroethylene does not transmit the ultrasound signal. The studies are videotaped, allowing the time of the scan to be measured.

INTERPRETATION OF INTRAOPERATIVE DOPPLER FLOW PATTERN

Velocity spectra were classified by the degree of spectral broadening and the magnitude of PSV. Intraoperative velocity spectra of the ICA were classified into 3 categories: (1) normal laminar flow (<100 cm/s), (2) mild or moderate flow disturbance (100-150 cm/s), and (3) severe flow disturbance (>150 cm/s). The term “spectral broadening” denotes the increased range of velocity within a flow pattern and signifies turbulent flow. Carotid artery spasm or increased compensatory collateral flow resulting from contralateral carotid occlusion can result in elevated PSV, but produces minimal spectral broadening. Arterial reconstructions demonstrating severe (>150 cm/s) flow disturbance with spectral broadening were immediately explored and revised or were investigated further by intraoperative angiography if an obvious source of the flow abnormality was not present.

B-mode imaging provided complementary information including detection of intimal flaps, platelet debris, or clamp injuries. Distal ICA flaps were immediately revised. Defects less than 2 mm in the CCA or bulb were not revised if there was not a significant flow disturbance, which is defined as a PSV exceeding 125 cm/s, the development of a color mosaic on a duplex image that indicates turbulent or disordered flow, and a loss of the spectral window on the waveform analysis.

tive duplex studies with abnormal findings. Seven involved the CCA and resulted in intraoperative revision in 5 (Table 1). These presented as intimal fractures occurring at the site of the proximal clamp placement. Two patients with scans that showed abnormalities secondary to step-off in the size of the vessel at the endarterectomy breakpoint did not undergo revision.

Eleven patients had external carotid artery flow disturbances, all of which were caused by elevated distal intimal flaps secondary to an incomplete eversion endarterectomy (Table 2). These were repaired through arteriotomy in the external carotid artery, which did not require reclamping of the CCA or ICA.

There were 15 abnormalities in the ICA (Table 3). Five of these required revision of a patch or patching of a previously unpatched artery. Five studies had PSV in the 100 to 150 cm/s category, but had no defects on B-mode imaging and were observed without treatment. The arterial reconstruction was clearly visualized in its entirety and no stenosis, wall abnormalities, or technical defects were detected. The remaining 5 were felt to be false-positive studies owing to an increase in velocity flow due to occlusion or high-grade stenosis of the contralateral ICA, a small ICA, or arterial spasm. In these false-positive studies, a distinguishing characteristic was the absence of turbulent flow.

At the 6-week postoperative duplex, 4 of the 5 repaired CCAs demonstrated normal flow and 1 had a mild residual stenosis. Ten of the 11 external carotid artery repairs were patent and 1 was occluded. Four of the 5 ICA repairs were normal and 1 had a mild residual stenosis. Of the 10 abnormal ICAs that were observed, 9 were normal on postoperative duplex and 1 had a mild residual stenosis.

At 6 weeks, recurrent stenosis in the 16% to 49% category (PSV >100 cm/s and <125 cm/s) was noted in 10 ICAs that had an intraoperative scan with no abnormal findings, demonstrating the development of fibrointimal hyperplasia early in the postoperative period.

There was 1 perioperative death from myocardial infarction, 1 nonfatal myocardial infarction, and 2 neck hematomas requiring evacuation. There was 1 stroke attributed to an allergic reaction to dextran and severe intraoperative hypotension. In this patient, the carotid re-
pair was widely patent on duplex scan after the stroke. One patient, who had a small internal carotid flap identified with PSV of 160 cm/s, did not undergo revision and suffered an ipsilateral transient ischemic attack 21 days after surgery. An angiogram demonstrated a 50% diameter reducing “shelf.” The patient was given warfarin sodium (Coumadin; DuPont Pharmaceuticals Co, Wilmington, Del) and during 20 months’ follow-up had no further neurologic symptoms.

**COMMENT**

Carotid endarterectomy has been shown to be a durable and effective treatment for the prevention of ipsilateral neurologic events.6,7 The ability to achieve a very low stroke rate depends on technical perfection. We previously reported a significant long-term reduction in late ipsilateral stroke in patients without residual or recurrent stenosis as determined by duplex Doppler scanning in the early postoperative period.1 Intraoperative duplex scanning provides a sensitive tool for achieving a technically optimal carotid reconstruction. However, the intraoperative interpretation requires judgment. Not every abnormality requires revision. False-positive studies result from arterial spasm, contralateral ICA occlusion, high-grade stenosis, or an incorrect Doppler angle. Doppler angles less than 60° result in an increased PSV. Duplex imaging provides both an anatomical and physiological evaluation. When spectral broadening and turbulence are associated with an arterial luminal defect on B-mode imaging, the significance of this lesion must be considered seriously. Performing intraoperative duplex provides a baseline study from which all other postoperative studies can be compared.

Although arteriography has been widely used to evaluate carotid repair, it is not an innocuous procedure. Care is required to minimize the additional risks that may be incurred by arterial puncture and the subintimal injection of contrast material. Furthermore, angiography in the operating room is usually performed in only 1 projection. The ability to achieve multiplanar views is more sensitive for identifying small defects such as platelet debris.

Continuous waveform Doppler signals using waveform analysis or audible interpretation can be used to determine patency of a reconstructed carotid artery. Although continuous waveform Doppler technology is inexpensive and abnormal signal recognition requires minimal training, the assessment is subjective and audible interpretation is not quantitative.

Reluctance to use duplex scanning during operations has been attributed to the need to prolong the procedure, the complexity in performing the test, the difficulty in interpreting the examination, the expense of the instrumentation, and the erroneous assumption that arteriography is superior. The scans in this study were routinely performed in 10 minutes. If an abnormality was detected, the surgeon had the opportunity to carefully evaluate the area of concern.

The importance of achieving a technically perfect repair cannot be overstated. Our institutional experience spans more than 10 years with this technique, and we have learned that there are 3 distinct anatomical sites to carefully scrutinize when performing intraoperative duplex studies. Most significant is the distal ICA endarterectomy end point. Because of its orientation in the flow stream, a...
defect can result in flap dissection and acute occlusion or accumulation of platelet debris. The proximal clamp may fracture the intima of the CCA and cause a flow disturbance, which may be the source of emboli or the site of stricture and/or occlusion from intimal hyperplasia. We noted 5 intimal flaps occurring in the proximal CCA from application of a vascular clamp even when the jaws of the clamp were modified with protective material. After detecting this the first time, we started using clamps with soft jaws. We have continued to see this pattern of injury. Another possible cause could be the application of a Rummel tourniquet to secure the intraluminal shunt. Not all of these lesions would cause problems, but certainly an intimal flap has the potential to elevate with arterial flow and obstruct the CCA. Clamp injury to the CCA has not been noted in other reports on intraoperative duplex imaging.8-11 The external carotid artery should not be neglected, as it can be a source of transient ischemic attack or may preserve ICA flow in the event of CCA occlusion.

Intraoperative assessment of carotid repair results in more careful scrutiny of the technical reconstruction by the surgeon. Small defects are obvious because of the sensitivity of the technique. As a result, the incidence of patching carotid arteries has increased from less than 10% to the 70%. While all detected lesions will not result in vessel occlusion and/or neurologic deficits, the surgical axiom “the better the operation, the better the operative results” remains valid. For the best carotid artery reconstruction, early and late postoperative results begin with a technically perfect repair. Intraoperative duplex gives the surgeon a timely and unique opportunity to achieve this technical goal.

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Corresponding author: Jonathan B. Towne, MD, Medical College of Wisconsin, 9200 W Wisconsin Ave, Milwaukee, WI 53226 (e-mail: jtowne@mcw.edu).

REFERENCES


DISCUSSION

Bruce L. Gewertz, MD, Chicago, Ill: The results reported today are excellent: a single death and a single stroke in 100 patients. This again demonstrates that carotid endarterectomy can be done well in many different ways: With local or general anesthesia, with shunts and without shunts, with monitoring and without it, and, finally, with intraoperative surveillance and without it. The 2 principal intraoperative assessments are duplex scanning and arteriography. Duplex scans offer a 3-dimensional view with dynamic measures of blood flow. Unfortunately, as the authors emphasize in their article and in the presentation, interpretation requires experience and considerable judgment. Angiograms are unidimensional without information about turbulence of blood flow. One could argue that experience is less critical, at least in acquiring the data.

These strengths and weaknesses are evident in the current report. Of the 33 scans with abnormal findings, 22 involved the CCAs or ICAs. The authors chose to fix about half of these, 5 of the 7 CCA lesions and only 5 of the 15 ICA lesions. The excellent results speak for their good judgment in deciding which lesions need fixing. However, in our litigious society, one might be concerned about the legal jeopardy of not treating a documented abnormality, even if deemed insignificant in the time, in a patient who later experiences a neurologic complication or even a recurrence.

This leads to a general feeling that real benefit needs to be demonstrated for any routine intraoperative assessment in distinction to my personal preference for selective use of scans or angiograms for patients in whom visualization of either end point is suspect. We obtain intraoperative angiograms in less than 10% of our patients and have experienced a similar 1.1% stroke rate for more than 600 consecutive procedures.

I have 3 questions for Drs Mays and Towne. First, have they made any changes in their surgical technique to address the 11% incidence of external carotid artery lesions or the 7% incidence of proximal or clamp injuries? Second, do they feel the primary benefit of the routine use of scans is preventing immediate complications or avoiding long-term problems such as recurrent or residual lesions? Finally, do they think that the use of shunts in 86% of the patients hindered visualization or contributed in some other way to proximal or distal abnormalities?

Mellick T. Sykes, MD, San Antonio, Tex: We recently reviewed our last 5 years of carotid endarterectomy done by general surgery residents with vascular surgery faculty. We had a 0.8% stroke or mortality rate using a very similar technique but using only continuous wave Doppler technology for intraoperative evaluation. Do you have any explanation for the similarity of results?

Second, one of the problems that we have had really almost more than perioperative transient ischemic attacks is the syndrome of postendarterectomy reperfusion hyperemia with seizures and intracranial bleeding. Have your intraoperative velocities correlated with this or have you seen this in your last 100 cases?

Last, one of the interesting findings of this study is the high incidence of intimal cracks using clamps on the CCA. Have you modified your proximal clamp technique on the basis of these findings?

Sachindar S. Hans, MD, Warren, Mich: I enjoyed the presentation and I am impressed by Dr Towne’s group’s continued interest in duplex imaging, initially in lower extremity arterial constructions and now in carotid endarterectomy. I rise to share with you a personal experience with 1400 consecutive completion carotid arteriograms. The first 100 were performed by direct puncture of the CCA, and the last 1300 were
performed by 20-gauge catheter insertion through the superior carotid artery, which was ligated after the arteriogram was completed.

External carotid artery stenosis was detected in 3.7% and occlusion of the external carotid artery was detected in 1%. We did not correct external carotid artery stenosis, but we did correct external carotid artery occlusion, as you are well aware that external carotid artery contributes about 30% to the collateral blood flow to the brain. However, the abnormalities in the ICA and the CCA are of major concern to the surgeon. The incidence of abnormalities was 3.1% in the ICA in the first 226 cases, and about 2% in the entire series. The most important cause was distal intimal flap, a residual plaque, or a kink. I am somewhat surprised by the high incidence of proximal clamp defects in your series and as noted by the previous discussant, we do not apply clamps to the CCA. Even soft Fogarty clamps applied to the CCA can cause intimal trauma. We apply double-loop Silastic tape to the CCA.

I have 3 questions for the authors. First, given a much higher incidence of anomalies in the ICA and the CCA in your series, compared with the 2% to 3% incidence reported by completion carotid arteriography, do you think that duplex scanning may be too sensitive for routine use?

Second, have you been able to reduce the incidence of recurrent carotid stenosis, as many recurrent carotid stenoses are due to residual disease rather than to true recurrence? Third, although your incidence of perioperative neurological deficits is low, have you been able to reduce the incidence of perioperative neurological deficits by the routine use of carotid duplex imaging?

Daniel J. Reddy, MD, Detroit, Mich: I am interested in the two thirds of patients who had an intraoperative duplex scan with no abnormalities at the completion of the operation. If findings are normal, do you need the surveillance study at 6 weeks? Eliminating retained stenosis should reduce the number of stenoses at 6 weeks. Does it?

James J. Peck, MD, Portland, Ore: Is this a consecutive series of 96 patients treated with carotid endarterectomy? ie, do all carotid endarterectomy patients obtain an intraoperative duplex scan? Are there patients who had endarterectomy alone without duplex? What percentage of all carotid endarterectomy patients benefited from intraoperative duplex scan?

Dr Towne: I am happy that we have generated this discussion. In response to Dr Gewertz, since we have started using intraoperative duplex, our rate of patching has increased to 65% to 70% in a surgical group that rarely patched the carotid operative repair. I can’t say that they all need to be patched, but what duplex scan has done is to magnify the technical aspect of this repair such that if your goal is to do a technically and hemodynamically precise repair, you need to patch more.

The findings with the proximal clamp I think are a bit mind boggling. I had it happen once, and I really carefully look for it now. It’s like so many things in surgery and vascular surgery in particular: the more you look for things, the more you find. Will all of these defects cause trouble? No. But the ones that do are spectacular. And at this time when you are trying to get your stroke rates as close to 1% or even less if you can, techniques to detect any technical defect are important.

Regarding the role of the shunt, I have grown up as a shunt surgeon. I think there is no question that the shunt may inhibit your repair somewhat, but with experience this does not affect the ultimate technical result.

Dr Sykes, I applaud your results. My concern about the continuous wave Doppler technology is that I think it needs even more operator technique for interpretation than the duplex does and it doesn’t give you the precision of identifying defects visually. If you are getting good results, obviously you don’t do anything to improve it. Perhaps, though, if you did use duplex technology, your results might even be better. One of the problems that leads into one of the other questions is something that haunts me—those patients who develop postoperative hyperemic syndrome. We tend to see it in patients with bilaterally tight lesions. There is no correlation with anything that we determined intraoperatively, the anesthetic, the conduction of this procedure, etc. At this point in our experience, it is something that we can’t prevent.

Dr Hans, I thank you for your long-term outstanding results. For Dr Reddy’s question: indeed, if you do have an intraoperative study with no abnormalities as we have demonstrated in half the early recurrent stenoses “are really residual stenoses.” For Dr Dry’s question: indeed, if you do have an intraoperative study with no abnormalities as we have demonstrated in some of these patients, 10 of the patients will have some changes in the postoperative study. The healing of the endarterectomy site is a very dynamic process. There is remodeling occurring.

I would like to close by saying that it is a surgical axiom that the more precise the technical reconstruction, the better the operative results. I think intraoperative duplex scanning helps the surgeon perform a technically precise reconstruction and certainly I would recommend it for your consideration.

The conditions necessary for the surgeon are 4: first, he should be learned; second, he should be expert; third, he must be ingenious; and fourth, he should be able to adapt himself.

Guy de Chauliac
1300-1370

Reference: Ars Chirurgica. Introduction.