Carotid Endarterectomy Monitored With Transcranial Doppler

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Intraoperative transcranial Doppler monitoring of cerebral ischemia during carotid clamping under general anesthesia was done in 238 carotid artery operations, mostly endarterectomy. Depending on the severity of reduction of middle cerebral artery mean velocity, patients were classified as no, mild, or severe ischemia at clamping. With a carotid shunt, velocity was always in the "no ischemia" category during shunting. For patients with no ischemia, stroke was significantly lower without a shunt (2/175 no shunt *versus* 2/12 shunt). For mild ischemia, shunting did not affect the stroke rate (1/20 no shunt *versus* 0/9 shunt). For severe ischemia, strokes were less frequent with a shunt (4/9 no shunt *versus* 0/13 shunt). Intraoperative electroencephalogram predicted most, but not all severely ischemic cases. Carotid back pressure correlated with Doppler velocity, but transcranial Doppler was more helpful. Transcranial Doppler is a new and valuable technique in carotid surgery.

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C AROTID ENDARTERECTOMY HAS proven value in prevention of stroke in some groups of patients with atherosclerotic plaque of the intracervical carotid artery. Perioperative stroke has been reported to occur in 1% to 21% of cases, depending on the center and indications for surgery.[1,2] Some authors declare that some of these strokes are due to cerebral ischemia during the time of temporary carotid artery occlusion for the endarterectomy, but others ascribe perioperative stroke to embolism of plaque or thrombus during the exposure of the artery, and after reflow. The purpose of this study is to determine whether transcranial Doppler assessment of intracranial blood flow during carotid endarterectomy allows effective detection of cerebral events resulting in stroke, and whether this information can reduce the risk of stroke.

Methods

Patients undergoing carotid surgery requiring clamping of the carotid artery underwent monitoring of transcranial Doppler (TCD) velocity in the middle cerebral artery (MCA) during surgery. A total of 238 operations at University of Alabama at Birmingham Medical Center and Birmingham Veterans Administration Hospital were monitored. Two hundred thirty-one of the procedures were carotid endarterectomies, but seven had other carotid artery procedures requiring similar clamping for a similar time interval, including four carotid-subclavian bypasses and two carotid artery resections with replacement for tumor or tortuosity, and are included in this series. Of the patients considered for this study, an additional 26 operative procedures are not reported, because before operation a good MCA signal could not be obtained, usually because of temporal bone thickness.

Mean age was 66 years (± 9). Seventy-six per cent were male. Twenty-one patients had staged bilateral carotid endarterectomy, reported here as two separate operations. The indication for endarterectomy surgery was asymptomatic severe stenosis (greater than 80% area narrowing) in 27%, and symptomatic stenosis (previous transient ischemic attack or stroke) in 73%. Four patients had a fixed stroke before operation. No patient had stroke in evolution as an indication for surgery.

All operations were done with general anesthesia using nitrous oxide and isoflurane. A radial artery cannula was used for monitoring of systemic blood pressure. Many patients had preoperative oral antiplatelet agents. During the operation, heparin, 75 to 100 U/kg, was given before clamping. Sometimes, an additional dose of 1000 to 2000

units was given if clamp time exceeded 30 minutes. Average clamp time was 23 minutes (range, 5 to 87).

Most operations were monitored with 10-lead electroencephalogram (EEG), and intraoperative continuous assessment of all channels by an EEG technologist with supervision by a neurologist. In many cases, intraoperative digital subtraction angiography was done before closing the incision, to assess the technical result. Most appeared satisfactory, but in two cases, the artery was re-explored for a technical defect, one at the internal carotid endpoint, the other for an occluded external carotid artery, which was corrected by a limited endarterectomy through an external carotid arteriotomy. Patches were used at the discretion of the surgeon, with no consistent policy among the five surgeons. One surgeon routinely patched all carotid arteries with Dacron, another selectively patched some with saphenous vein if a smaller than normal internal carotid had been incised, another selectively used polytetrafluoroethylene patches, and another never used a patch.

Decision on use of a shunt depended on the choice of the surgeon, and generally reflected the controversies in this field in the larger community of all carotid surgeons. Some of the surgeons never shunted, but another used a shunt for EEG changes. One surgeon routinely used a shunt in nearly all carotid operations. In the first years of the study, the relevance of low TCD velocity was unproven, so TCD data were not used in determining whether to insert a shunt, but in more recent times, with assessment of the data, more patients with TCD ischemia have had shunting. For this study, shunting is defined as insertion of a temporary internal carotid artery shunt with <4 minutes' total ischemic time during the operation.

Transcranial Doppler was monitored with an EME TC 2-64 (Eden Medical Electroniks, Uberlingen, Germany) or Medasonics (Medasonics Corp., Fremont, CA) instrument, as we have previously described.[3] This is a range gated pulsed wave Doppler with 2-MHz transducer at power of 1000 mW/cm^2. The transducer is secured to the scalp with adhesive dressings, and protected from motion with a plastic housing. The pulsed system allows selection of the depth of measurement, with the MCA in this series located at a mean depth of 48 mm (range, 35 to 55).

At the discretion of the surgeon, some patients also had measurement of carotid stump pressure. After heparinization, this was done with an 18-gauge, 1-inch needle in the common carotid artery. If the bifurcation stenosis was nearly totally occlusive, then the stump pressure catheter was inserted directly into the internal carotid artery.

All patients had complete neurologic examination on awakening, then periodically during the hospitalization. For this study, patients who had a neurologic deficit persisting for over 24 hours after the surgery are classified as having sustained a stroke.

Results

Three patients died within 30 days after surgery, for a mortality incidence of 1.3%. Two deaths were consequent to stroke; one was due to myocardial infarction. Nine strokes occurred, two in the shunted group of 34 patients (5.8%), and seven in the 204 patients without a shunt (3.4%, p = nonsignificant).

In Figures 1 and 2 are representative TCD tracings during operative procedures. In those cases with severe depression of the MCA velocity after clamping, a large increase in velocity was noted if a shunt was inserted. For unshunted patients in the group of patients classified as severe ischemia after clamping, average mean velocity at clamping was 2% of baseline (±4%). In shunted cases with severe ischemia at clamping, mean velocity averaged 3% (±5%) at clamping, and 76% (±22%) after insertion of a shunt. In all cases where a carotid shunt was inserted, the mean velocity during shunting was in the "no ischemia" category (>41% of baseline), no matter whether the pre-shunt velocity indicated no ischemia, mild ischemia, or severe ischemia.

One hundred eighty-seven cases (Table 1) were classified as having no ischemia during clamping (mean velocity > 41% of baseline). Of these, 12 were shunted, one of whom suffered a stroke, evident on awakening, and another developed severe disability 2 hours after awakening from anesthesia that on re-exploration was found to be due to platelet thrombosis of the carotid artery. A mild EEG change had occurred in this case at clamping. The stroke rate for shunted cases with no Doppler ischemia was 17%. One hundred seventy-five had no shunt, of whom 1.1% sustained perioperative stroke, both due to cerebral hemorrhage. One of these had hyperemia by in-
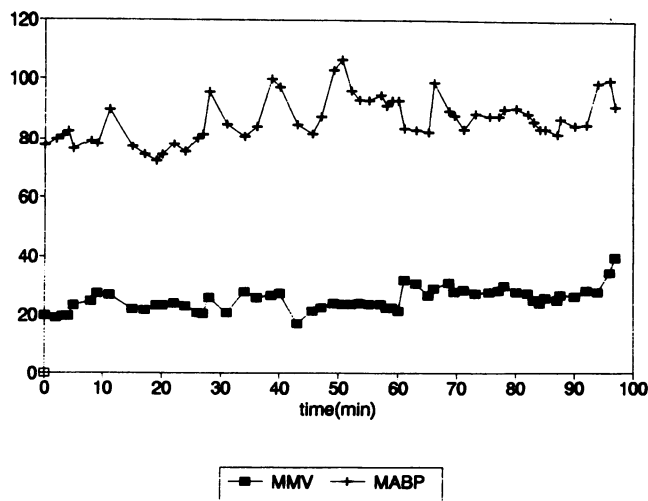

FIG. 1. Carotid endarterectomy. Shunt not used. Artery clamped at 40 min, resulting in no ischemia (MMV > 41% of preclamp level).
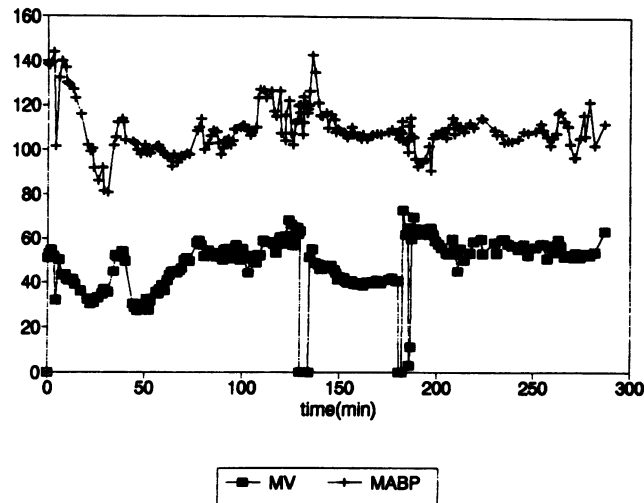
FIG. 2. MCA Doppler velocity (MV). Severe ischemia at clamping time (130 min on X-axis), relieved by shunt. Ischemia again at 180 min when shunt is removed. Patient had severe EEG changes coincident with the times when MV = 0. MABP, arterial systemic mean pressure.

tracranial Doppler in the operating room, the other had hemorrhage on the fifth postoperative day. In procedures with no ischemia by intracranial Doppler, the lower stroke rate when a shunt was not used is statistically significant to p < 0.022.

Twenty-nine cases were classified as mild ischemia. Nine were shunted with no strokes, and 20 were not shunted, with stroke in one case (5%), due probably to spontaneous occlusion of the stenotic carotid artery before clamping, early in the anesthetic course, with unrecognized EEG changes.

Twenty-two cases were classified as having severe ischemia at clamping (mean velocity < 15%). Thirteen were shunted, with no strokes. Nine were not shunted (including one case where a shunt was actually inserted, but a very high ischemic time of 6.5 minutes with MCA flow of zero still occurred because of technical difficulties of the operation). In the unshunted category, there were four strokes, for an incidence of 44% (p < 0.0173 for shunt compared with no shunt).

TABLE 1. Rate of Perioperative Stroke

Ischemia	V	Shunt Status No.	Stroke No. (%)	
None	>41%	Shunt 12	2/12	(17)
p < 0.03		No shunt 175	2/175	(1.1)
Mild	16–40%	Shunt 9	0/9	(0)
p = NS		No shunt 20	1/20	(5)
Severe	0–15%	Shunt 13	0/13	(0)
p < 0.02		No shunt 9	4/9	(44)

Fisher's exact test.

Electroencephalogram was not recorded in 13 cases, and in two additional cases the EEG was suppressed by deep anesthesia with supplemental barbiturate at the time of clamping to the level of suppression burst anesthesia. In 181 procedures, there was no change in EEG at the time of clamping. For these, the mean velocity averaged 70%. of the immediate preclamp level ±24%. For the 28 cases with mild EEG changes, mean velocity (MV) was 51% ± 30%, and for 22 with severe EEG change, 10% ± 13%. Five cases had severe ischemia by intracranial Doppler, but no abnormality of the EEG. Two of these had strokes. Neither was shunted.

Transcranial Doppler velocity during the period of carotid clamping generally increased mildly during the first 5 minutes of occlusion (Fig. 3), but after this did not vary by much. For the unshunted cases, there was no correlation of clamp time with severity of Doppler ischemia, or with occurrence of stroke.

Of the 22 cases of severe ischemia at clamping of the carotid, the EEG did not change in five. Two of these had persisting neurologic complications. One was mild; one was severe and ultimately fatal. In neither of these was a shunt used. In patients sustaining perioperative stroke, TCD still returned essentially to baseline levels at the end of the clamp time. This suggests that the strokes were ischemic in origin, rather than embolic, where a persistent low velocity would be expected.

There was a positive correlation of TCD velocity after clamping and absolute carotid back pressure (Fig. 4). All cases with severe ischemia by TCD had stump pressure below 40 mmHg. Many unshunted cases with low stump pressure, however, had resolution of the severe TCD ischemia within 5 minutes after clamping (Fig. 3).

On preoperative arteriogram, 33 cases had contralateral carotid occlusion. Of these, 14 had no ischemia by TCD
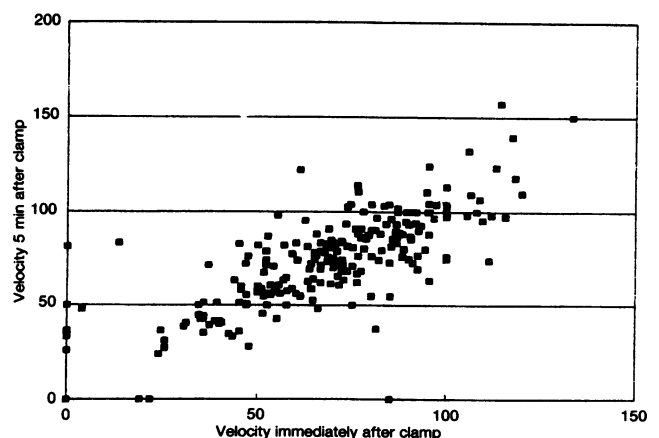

FIG. 3. Velocity immediately after clamping correlates with velocity 5 min later, but some cases with zero flow spontaneously increased to no ischemia without a shunt.
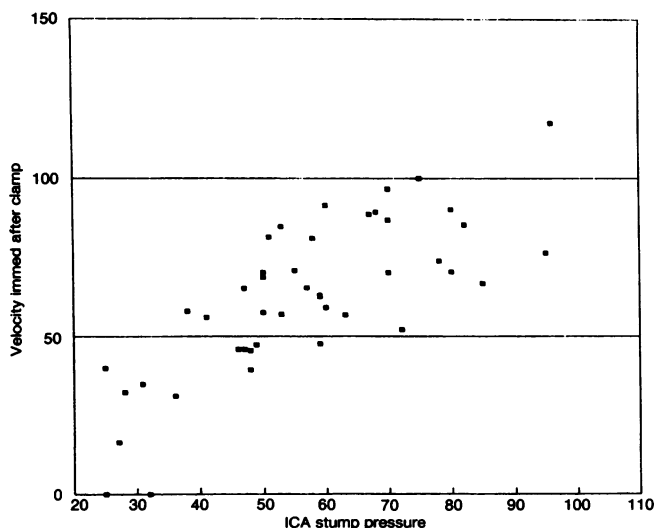
FIG. 4. MCA mean velocity as percentage of preclamp level. Lower stump pressure correlates with lower mean velocity after clamping.

on clamping. Eight had mild ischemia, and there were 11 with severe ischemia. Severe ischemia was therefore more likely if the contralateral carotid artery was occluded. There was no correlation of nonocclusive contralateral stenosis with TCD results.

Transcranial Doppler had value in management of other complications. Sometimes hyperperfusion was noted, occasionally followed by cerebral hemorrhage. Five per cent of procedures had mean velocity after declamping greater than twice the preclamp level. One of these sustained cerebral hemorrhage. Also, a case of intraoperative, postendarterectomy intimal flap, obstructing flow and requiring revision of the endarterectomy, was noticed by TCD, but was not seen on digital subtraction angiography.

Mean preclamp systemic blood pressure in the nonischemic category was 97 ± 17. For mild ischemia, pressure was 98 ± 15, and for severe ischemia, 101 ± 16.

Discussion

Transcranial Doppler velocity assessment of flow in the MCA can potentially predict cerebral ischemia during carotid surgery. Recent technical refinements have allowed accurate insonation of the MCA in most subjects.

Insertion of a plastic shunt tube into the common and internal carotid arteries during the time of carotid bifurcation occlusion may allow temporary perfusion of the ipsilateral carotid territory. In an individual case, this might help prevent perioperative strokes related to ischemia, but could increase the incidence of strokes due to embolization, or can damage the intima of the more distal internal carotid artery.[4,5]

Some surgeons routinely use a shunt in all carotid endarterectomies. Others seldom use a shunt, but some rely on selective shunting. Selective shunting requires some assessment of which patients are at potential risk for brain ischemia during clamping. Preoperative status of the contralateral carotid, preoperative neurologic status of the patient, intraoperative back pressure measurements, local anesthesia with monitoring of neurologic examination, intraoperative measurement of regional cerebral blood flow with xenon, and intraoperative EEG have all been used to make this decision, but there has been inconsistent value to these modalities in preventing operative stroke. For example, Sundt[6] reported a 24% incidence of major focal EEG changes during carotid clamping, which is then an indication for use of a shunt. But in other series that do not use EEG or shunts, the incidence of operative stroke is much lower than 24%. In cases monitored under local anesthesia, 3% have serious cerebral dysfunction despite a normal EEG, and 5.1% have an abnormal EEG despite a normal neurologic examination. A persistent regional cerebral flow below 10 mL/minute with xenon is associated with irreversible neuronal damage, but our own work did not show low xenon flow to be a good predictor in carotid endarterectomy.[7]

In this series, TCD assessment of severely reduced MCA velocity during carotid clamping accurately predicted the need for a carotid shunt. Severe ischemia, such that use of a shunt would be considered, occurred in 9.2% of cases. Thus, by TCD, more than 90% of carotid operations do not have criteria for use of a shunt. These findings help explain why those series in which shunts are always used do not have a substantially different stroke rate from centers using selective shunting, or centers never using shunts. In more than 90% of carotid operations, by these TCD data, a shunt has no value, and the data also suggest that the shunt may increase the risk of stroke in patients with adequate TCD velocity during clamping.

Patients sustaining severe ischemia by TCD were not distinguishable by any established preoperative criteria from those with mild or no ischemia. None of the severely ischemic patients had a history of fixed stroke before the surgery. Although contralateral occlusion was more common in the group with severe ischemia (50%), most patients with contralateral occlusion (2/3) did not have severe ischemia.

It could be argued that severe ischemia was present in some patients because their blood pressure was not adequately increased before or during clamping. The blood pressure data, however, argue against this hypothesis. During the period of clamping, the anesthesiologist usually maintained blood pressure about 10% above baseline levels, to facilitate cerebral perfusion. In some cases, a transient low blood pressure reduced the TCD velocity at test

clamping, so clamping was delayed until the blood pressure was in an acceptable range. All TCD velocity data described above are associated with an effort at optimal management of systemic pressure. In all cases of severe ischemia at clamping, it was the general perception of the surgeon that a reasonable effort had been made to optimize the systemic arterial pressure, and that severe ischemia was truly due to inadequate collateral circulation to the ipsilateral MCA, unresponsive to reasonable efforts to increase the blood pressure, carried out with the anesthesiologist's knowledge of the response of MCA velocity to his efforts with blood pressure. This view is supported by the blood pressure data. At clamping, there was no significant difference in the mean systemic blood pressure for the severely ischemic, mildly ischemic, or nonischemic categories, and in fact there was a nonsignificant trend toward higher blood pressures in the group with severe ischemia by TCD.

Neurologic morbidity was usually, but not always, preceded by evidence of ischemia by both EEG and Doppler. Presumably, the reason that in some cases one of these monitoring techniques shows severe ischemia when the other does not is that EEG is a good test of cerebral cortical activity, but TCD is a better test of deeper portions of the hemisphere, including the basal ganglia and internal capsule.[8]

All of the patients with severe Doppler ischemia had low stump pressure, but many with adequate Doppler flow also had an initially low stump pressure. The stump pressure is an isolated measurement at one time, whereas the TCD has the advantage of continuously assessing intracerebral arterial flow, which may increase during the first few minutes after clamping.

In conclusion, TCD is our primary cerebral monitoring technique in the clinical practice of carotid surgery. We believe it is of more practical value than EEG, but we also use EEG. Transcranial Doppler can be obtained in over 90% of patients, and is not inconvenient to the surgical procedure. Severe TCD ischemia for which we recommend a shunt does not occur in most patients. Use of a shunt is associated with lower stroke incidence in severe TCD ischemia. Shunting is not associated with a lower incidence of stroke in mild TCD ischemia, so we do not recommend shunting for most carotid surgery. Measurement of back pressure does have value in assessing the tolerance of the brain to temporary carotid occlusion during carotid endarterectomy.

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DISCUSSION

Dr. Robert B. Smith III (Atlanta, Georgia): Dr. Ochsner, Dr. Jones, Members and Guests, Now that some of the long-awaited results of both the symptomatic and asymptomatic randomized clinical trials of carotid endarterectomy are being reported, new standards of acceptable perioperative morbidity and mortality rates are being formulated. The combined serious morbidity rates, stroke plus death, for the NASCET study and for the two VA cooperative studies recently reported range from 2.1% to 5.5%. The same value for the experience described by Dr. McDowell was 5.0%, placing them just within acceptable limits of current practice. This outcome was achieved with a mixed approach to shunting and patching, according to the preference of the individual surgeons. The only uniform element was the use of transcranial Doppler to monitor middle cerebral artery flow intraoperatively. It is interesting that transcranial Doppler flow correlated rather well with the 10-lead electroencephalogram (EEG), but less well with carotid stump pressures. At Emory, we have no experience with transcranial Doppler monitoring intraoperatively, preferring either local anesthesia, allowing constant communication with the patient, or compressed spectral array EEG if general anesthesia is used. Regardless of the method of monitoring, however, it is our preference to shunt all patients. Although we agree that probably fewer than 10% of carotid endarterectomy patients actually require shunting, an all-shunt policy avoids the search for that 10% and the

possibility of an erroneous selection process. It is our view that the risks of shunt insertion are exceedingly small and are outweighed by the benefits achieved.

I have several questions for the authors. How would you advise managing a patient whose transcranial Doppler flow is already quite low before clamping but does not change appreciably with flow interruption? Should that patient be shunted or not? How much does this monitoring method add to the expense of the operative procedure, and is it more or less costly than 10-lead EEG? Do you really need both simultaneously for safe performance of the operation? Finally, you were able to detect postendarterectomy hyperperfusion in a few patients, sometimes followed by intracranial hemorrhage. Once hyperperfusion is known, are there any practical measures to minimize the likelihood of catastrophic intracranial bleeding? I enjoyed the paper. Thank you.

Dr. William Edwards (Nashville, Tennessee): Dr. Ochsner, Dr. Jones, Members and Guests, I enjoyed Dr. McDowell's presentation and appreciate him bringing this information to us. I must say, however, that his stroke rate struck me, as I read the abstract, and I thought that that indicated some problems in his study.

I think that we need to look at the new cooperative study showing the parameters of stroke that had occurred in that group; we need to remember that from operative intervention we are going to have a stroke