Cerebral protection during carotid endarterectomy: to shunt or not to shunt

Bruce L. Gewertz, M.D., and Christopher K. Zarins, M.D.

Department of Surgery, Section of Vascular Surgery, University of Chicago, Chicago, IL 60637.

INTRODUCTION

There is a wide variation in the neurologic complication rate from carotid endarterectomy ranging from near zero to 20% or higher. In an effort to reduce perioperative strokes, some surgeons utilize intraluminal shunts in all patients to maintain cerebral perfusion during carotid occlusion. Other surgeons have achieved equally satisfactory results without the use of shunts. The resolution of this controversy has been impeded by the multiple causes of perioperative stroke which include embolization and reperfusion injury as well as ischemia. In fact, most neurologic complications may not be directly related to the duration of carotid occlusion.

It is well accepted that the selection of patients strongly influences both the incidence of deficits and the mechanism involved. Perioperative stroke rates are uniformly lower in patients operated upon for transient ischemic attacks or asymptomatic carotid lesions and higher in patients with previous cerebral infarctions. Intraoperative embolism is the more likely cause of neurologic complication in a patient with a patent contralateral carotid artery; ischemic injury is a greater concern if the contralateral carotid is occluded or if severe intracranial disease limits collateral blood flow.

Unfortunately these clinical and angiographic indicators are based on the characteristics of large populations and are not sufficiently specific to allow reliable preoperative identification of the individual patient at risk. This shortcoming is most distressing in an operation such as carotid endarterectomy whose utility is totally dependent on a reproducibly low neurologic complication rate.

Many vascular surgeons feel that routine intraluminal shunting has some theoretic and practical disadvantages. Most specifically, shunts have been associated with air bubble or plaque embolization as well as intimal injuries. In those lesions extending along the internal carotid artery, an indwelling shunt may contribute to poor visualization of the distal endpoint of the endarterectomy. The infrequent but vexing occurrences of such complications have stimulated many surgeons to approach shunting in a selective manner; that is, utilizing preoperative and intraoperative assessment of cerebral perfusion to identify those patients in whom intraluminal shunting offers an advantage. In most series this has resulted in the shunting of approximately 20-25% of patients while the majority of patients are not subjected to any of the potential complications of shunt placement. This essay will focus on the means of identifying patients at risk for intraoperative cerebral ischemia and conclude with a more detailed description of our use of the intraoperative electroencephalogram (EEG) as an indicator for shunt placement.

RATIONALE FOR SHUNT USE

The neurologic sequelae of temporary carotid occlusion are dependent upon both the severity of cerebral ischemia (reflecting the adequacy of collateral blood flow) and the duration of ischemia. In experimental models, profound reductions of cerebral blood flow to less than 2 ml/min/100 gm (about 5% of "normal" cerebral blood flow) can be tolerated for up to 13 minutes with complete return of cortical electrical responses. However, with more prolonged flow reductions, even if less severe, recovery is less likely. This relationship explains the fact that expeditious operations with short carotid occlusion times may achieve excellent results irrespective of whether shunts are employed.

Intraluminal shunts serve one purpose — maintenance of carotid blood flow during carotid occlusion. As such, the use of shunts should not change the incidence of the other principal causes of perioperative neurologic deficits such as embolization or thrombosis of the endarterectomy site.

INTRAOPERATIVE MONITORING TECHNIQUES

Surgeons employing selective shunting rely on three principal methods of assessing cerebral perfusion during carotid occlusion: direct observation of the conscious patients, measurement of internal carotid artery back pressure ("stump pressure") and observation of the EEG. Other less frequently used methodologies include direct measurement of cerebral blood flow by radioactive gas "washout" and transcranial doppler measurements of blood flow velocity in middle cerebral artery. The latter methods are currently utilized primarily for research.

While many experienced surgeons have reported excel-
Eugent results with carotid endarterectomy in awake patients, disadvantages include: a) interference with the airway in elderly patients, b) poor patient compliance limiting exposure of the distal internal carotid artery, and c) heightened anxiety complicating pre-existent coronary disease. Theoretic objections to "stump pressure" measurements relate to the inability of extracranial pressures to accurately assess perfusion pressures distal to intracranial lesions. There is still no resolution as regards the lowest "acceptable" stump pressure; this ranges from 40 to 60 mmHg depending on the surgeon. Even when a standard pressure is selected, there is quite a variable incidence of "inadequate" stump pressure in different clinical series. Low pressures (<50 mmHg) are reported in as few as 25% or as many as 66% of endarterectomy patients. The reliability of stump pressure measurements was most severely questioned by Kwaan et al., who noted that 33% of their awake patients who lost consciousness within one minute of carotid occlusion maintained stump pressures greater than 50 mmHg.

EEG MONITORING

In our practice, we have utilized the scalp recorded electroencephalogram (EEG) as an indirect measure of cerebral blood flow. The EEG reflects summed postsynaptic potentials arising from cortical neurons in the vicinity of the recording electrodes. The amplitude (measured in microvolts) and power (measured in microvolts squared) are indices of the "amount" of EEG activity present while the frequency content describes the "character" of the EEG (i.e. whether it is composed mostly of slower frequencies (delta or theta) or faster frequencies (alpha or beta)). In general, cortical ischemia results in diminished amplitudes and slower frequencies.

Numerous studies which have correlated cerebral blood flow with EEG changes indicate that reducing cerebral blood flow below 15 ml/min/100 gm during carotid endarterectomy produces EEG changes, Sundt et al used Xe-133 to measure cerebral blood flow during more than 1,000 carotid endarterectomies and found that the critical flow required to maintain a normal EEG was 15 ml/min/100 gm. This "electrical threshold" corresponded to about 30% of normal cerebral blood flow. In another study by Morawetz et al, only 5% of patients with regional cerebral blood flow greater than 15 ml/min/100 gm showed EEG changes whereas 50% of patients with regional blood flows less than this value experienced changes in their EEG consistent with ischemia.

Astrup and others have suggested that the threshold for brain infarction is about 10 ml/min/100 gm, lower than the "electrical threshold" of approximately 15 ml/min/100 gm. Brain areas perfused between 10 and 15 ml/min/100 gm may be electrically silent but viable within the so-called "ischemic penumbra." An appropriate criticism of EEG monitoring is its insensitivity to such silent regions which may slip beneath the 10 ml/min/100 gm level without changing the EEG.

The initial intraoperative experience with EEG utilized the unprocessed signal displaying voltage from multiple leads as a function of time. Interpretation was somewhat subjective and required the undivided attention of an experienced encephalograph. In the last 10 years, automated processors of the EEG signal have become commercially available. This equipment allows more objective assessment and demonstrates trends much more clearly. At the University of Chicago, we utilize power spectral analysis (PSA) of the EEG. The PSA technique employs a mathematical model (Fourier analysis) to examine the relative contributions of sign waves of different frequencies, thus giving a picture of whether the EEG wave form is best described by low frequency waves or if there is a significant contribution from higher frequency activity. The analyzer provides this data in successive compressed spectral arrays (averaged over 30 second epochs) traced on a strip chart. Simultaneously, a histogram of the power spectrum of six pre-selected frequency bands is displayed on a separate monitor, updated every three seconds, and printed every three minutes. The power for each of the three broad frequency bands is easily observed: low (delta and theta, 0.25 to 6.0 Hz); middle (alpha, 6.0 to 10.5 Hz); and high (sigma to beta, 10.5 to 16.0 Hz).

In a recent series of 105 consecutive procedures, we noted three distinct EEG responses to carotid occlusion:

1. *Mild or no power reduction* in which the EEG power change did not exceed 50% for any frequency band. This was observed in 82 patients (78%).

2. *Marked power reduction* (see Figure 1) characterized by reduction of EEG power by more than 50% in one or two frequency bands (12 patients, 11%).

3. *Global power reduction* (see Figure 2) reflecting a 50% reduction of EEG power in all three frequency bands (11 patients, 11%).

A total of 34 patients were shunted (32%). Nineteen (18%) demonstrated no power reduction but were shunted on the basis of preoperative criteria alone. Historical and angiographic indications for shunting included stroke within 6 weeks, contralateral carotid occlusion, or severe or multiple intracranial stenoses. These criteria are derived from an earlier study by our group which used EEG to determine the relative risk of intraoperative cerebral ischemia for a large number of clinical and angiographic indicators. Previous cerebrovascular accident, intracerebral disease and contralateral carotid stenosis>75% of diameter, all markedly increased the risk of cerebral ischemia following carotid occlusion. Seventy-four percent of patients with recent strokes (4 - 6 weeks prior to surgery) demonstrated EEG changes during endarterectomy as compared to only 33% of patients with distant strokes (>6 weeks prior to surgery) and only 40% of patients with transient ischemic attacks.

Five of the 12 patients with marked power reduction were shunted based on these preoperative criteria. Shunting caused a gradual reversal of the power reduction in all five of the cases which was complete within five minutes after opening of the shunt. The seven unsunted patients showed initial and then intermittent reductions of power, especially in the high frequencies. There were no postoperative deficits in this group.
Figure 1 - Compressed spectral arrays (CSA) display of EEG activity during carotid endarterectomy. Loss of high frequency activity was seen on the right following clamping of the right internal carotid artery. No shunt was employed and no postoperative neurological deficit was observed. (From Gewertz & McCafferty, Current Problems In Surgery, in press, 1987.)

Ten of eleven patients with global power reduction were shunted. Much of the low frequency EEG reduction was reversed within five minutes, although 7 patients demonstrated sustained high frequency reductions, EEG power then remained at near pre-clamp levels throughout the remainder of the surgery, except during removal of the shunt (Figure 3). The postoperative neurologic examination was unremarkable in these patients.

The only postoperative deficit observed in the series was exhibited by a patient with a severe but nonulcerative stenosis who could not be shunted for technical reasons. His EEG remained suppressed for the 45 minutes of carotid occlusion (see Figure 2). Upon awakening from anesthesia, this patient demonstrated a left hemiparesis and a dense homonymous hemianopsia, both of which gradually cleared within 24 hours. The patency of the operated carotid was confirmed by real-time imaging.

When reviewing the entire group, it was clear that the three frequency bands were differentially affected by carotid occlusion. High frequency activity was the most susceptible to reduced blood flow, showing a greater incidence and degree of reduction. If high frequencies remained stable after clamping, major reductions in low or middle frequencies were not observed. The amount of EEG power reduction for each of the three frequency bands is shown in Figure 4. None of the patients with marked power reduction showed less than a 40% reduction of high frequency activity. In contrast, only 13 patients showed a greater than 40% reduction in low frequencies. This latter group was comprised of the 11 patients with global reduction plus two borderline patients (classified as marked power reduction) who had greater than 40% reductions of all frequencies.

Faught also noted that the loss of high frequencies was a very sensitive measure of cerebral ischemia although this change alone was not associated with residual neurologic deficits. Our data are consistent with this observation. Seven patients with marked power who were not shunted had reduced high frequencies throughout the time of carotid artery occlusion, yet demonstrated no postoperative deficits. In addition, seven of the shunted patients with global power reduction had selective reduction of high frequency activity even after shunting and also had no postoperative deficits. Conversely, we observed that decreases in the power of the most robust...
low frequency band were always associated with reduction of middle and high frequencies, supporting the contention that reduction of low frequencies is a more specific sign of clinically relevant ischemia.

Because global reduction of EEG spectral power was associated with the single transient postoperative neurological deficit (presumably due to intraoperative ischemia), we believe that shunts should be placed when this pattern is seen following clamping of the internal carotid artery. Our observation of these severe changes in 11% of our patients is consistent with other studies that concluded that 9 to 16% unsolicited carotid procedures will require shunting based on EEG criteria alone.

Still at issue is whether patients with partial EEG reduction are experiencing clinically significant cerebral ischemia. We observed no morbidity among the six patients with marked power reduction who were not shunted. However, five patients showing this EEG pattern were shunted based on preoperative criteria which may have prevented postoperative deficits. A larger series of patients is needed to refine the decision making process for this group.

Finally, arbitrary shunting should be strongly considered in patients with recent strokes or reversible ischemic neurologic deficits (RIND) in whom viable brain tissue may be electrically silent and hence not evaluable by EEG. This recommendation is supported by our earlier data demonstrating a high incidence of intraoperative ischemia in patients with these clinical characteristics.

CONCLUSION

Based on our clinical experience we believe that the majority of carotid endarterectomies (approximately 70%) can be performed safely and most precisely without the use of an intraluminal shunt. Any shunt-related complications are totally avoided in these patients, Even if cerebral blood flow is substantially reduced to less than 15 ml/min/100 gm during endarterectomy, short periods of ischemia (less than 20 minutes) will be tolerated by nearly all patients except those with recent stroke or reversible ischemic neurologic deficits (RIND) who harbor marginally viable tissue prior to surgery. However, it must be acknowledged that a precise operation achieving technical perfection may occasionally require more
Figure 4 — Percentage of EEG power reduction in the 23 patients demonstrating EEG changes following carotid occlusion. High frequency attenuation was more common than reduction in low frequency. The single patient suffering a temporary neurologic deficit demonstrated greater than 80% reductions in all frequencies. (From Ivanovic et al., Ann. Vasc. Surg., 1: 112-117, 1986.)

than 20 minutes; shunting may be crucial in this subgroup of patients.

If one is to shunt selectively, EEG facilitates the best assessment of cerebral function. The frequencies and amplitude of postsynaptic electrical potentials detected by the EEG correlate well with regional cerebral blood flow. While EEG can be influenced by changes in systemic hemodynamics and anesthetic levels, such interactions are reasonably well defined and can be taken into consideration. Finally, the commercially available processing equipment which allow continuous spectral analysis and histogram displays have greatly improved intraoperative interpretation by decreasing subjectivity and offering rapid identification of trends.

CONSULTED BIBLIOGRAPHY


Acknowledgements: The authors gratefully acknowledge the secretarial skills of Mrs. Terry Kirkpatrick in preparation of this manuscript.