Carotid endarterectomy with routine electroencephalography and selective shunting: Influence of contralateral internal carotid artery occlusion and utility in prevention of perioperative strokes

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Objective: Carotid endarterectomy (CEA) is associated with a risk of cerebral ischemia during carotid clamping, particularly in the face of contralateral internal carotid artery (ICA) occlusion. We examined the results of CEA with continuous electroencephalography in patients without and with contralateral ICA occlusion.

Design and Setting: We reviewed 564 primary CEAs with routine electroencephalography and general anesthesia performed between April 1, 1989, and March 31, 1999, in a community teaching medical center. Main outcome measures were perioperative stroke, temporary lateralizing neurologic deficit, and death. Shunts were placed primarily for significant electroencephalographic changes after carotid clamping but also selectively for contralateral ICA occlusion, prior stroke, or surgeon choice. CEA was performed for asymptomatic disease in 35% of cases.

Results: Significant electroencephalographic changes occurred in 16% versus 39% (P < .001) and shunts were placed in 13% versus 55% (P < .001) of patients with patent (n = 507) versus occluded contralateral ICA (n = 57), respectively. The fraction of CEAs with significant electroencephalographic changes during clamping was stable, but shunt use declined slightly over time as our confidence in electroencephalography increased. Patches were placed more often (86% versus 65%; P = .002), but other operative details were similar when the contralateral ICA was occluded. Five early (30 days) strokes (0.9%) and eight early temporary postoperative neurologic events (1.4%) occurred, all ipsilateral to CEA and all after the patient left the operating room with none in patients with contralateral ICA occlusion. Two perioperative deaths occurred, one in a patient without and one in a patient with contralateral ICA occlusion. Neither of these deaths was related to ipsilateral stroke. No increase in stroke rate with decreased shunt use over time was seen.

Conclusion: Routine use of electroencephalography was associated with apparent complete elimination of intraoperative strokes and less than 1% risk of perioperative strokes. These observations appear to be true even in the face of contralateral ICA occlusion. Electroencephalography is a sensitive detector of cerebral ischemia and a valuable tool for determination of need for shunting during CEA. Surgeons should consider routine use of electroencephalography and selective shunting for significant electroencephalographic changes with clamping. (J Vasc Surg 2002;35:1114-22.)
Preoperative arteriograms were standard during the early part of this experience. However, duplex scanning was the only preoperative carotid imaging study in most patients beginning in mid 1997.\textsuperscript{5,6} The radiologist’s estimate of carotid bulb/ICA stenosis from the final report of the arteriogram was recorded. If an arteriogram was not performed, the estimated stenosis was recorded from the report of the preoperative carotid duplex scan performed in our vascular laboratory.\textsuperscript{7,8}

Twenty patients were excluded from analysis because they had undergone secondary (“redo”) CEA, external CEA in the presence of an occluded ICA, repair of carotid artery aneurysm, emergent CEA for acute ICA occlusion, or combined CEA and coronary artery bypass. Sixteen patients, who did not undergo electroencephalographic monitoring because operations were performed when electroencephalography was not available for various logistic reasons, also were excluded. These 16 unmonitored patients were indistinguishable from the 536 patients who underwent the remaining 564 CEAs with respect to age and other comorbidities.

Conventional CEA technique was used\textsuperscript{9} in most patients, but eversion endarterectomy was used in selected cases with redundant internal carotid arteries toward the end of the study period.\textsuperscript{10,12} All operations were performed with general endotracheal anesthesia.

Conventional electroencephalograms were monitored with standard gold cup electrodes affixed to the scalp with collodion. Electrode impedance was maintained at less than 10 kOhms with a conductive gel. Double-distance recordings were supplemented with a parasagittal central electrode montage covering the “watershed areas.” For the initial recordings, pen and ink tracings were made with a 17-channel polygraph (Nihon Kohden, Irvine, Calif). The recordings in the most recent years were obtained with a digital electroencephalographic system (Telefactor, Conshohocken, Pa). Processed electroencephalography was not used in the operating room, initially because it was not available with the Nihon-Kohden polygraph and subsequently to maintain continuity in the decision-making process. Evoked potential monitoring was not used because of the prolonged response time associated with that technology. Surgeons depended on the evaluation by an experienced technologist, but a neurologist or neurophysiologist was always immediately available for consultation, if not physically present in the operating room at the time of the operation.

Electroencephalographic recordings were begun before anesthesia to establish a baseline and were continued through induction and intubation. Typical anesthesia included induction with thiopental sodium and a paralyzing agent in boluses expected to last less than 30 minutes followed by maintenance anesthesia with inhaled isoflurane or sevoflurane. Nitrous oxide was avoided because of decreased electroencephalographic amplitude, and narcotics were avoided because of electroencephalographic slowing known to be associated with these agents. The effect on the electroencephalography of the short acting barbiturates used for induction in this regimen has generally abated by the time carotid clamping is anticipated.\textsuperscript{13} Close communication between the electroencephalographic technologist and anesthesiologist ensured a balance between adequate anesthesia and adequate electroencephalographic recording. Changes in dosage were documented on the record-}

An experienced technologist interpreted the recording on the basis of visual analysis of the tracings. Any noticeable decrease in electroencephalographic amplitude or frequency (>10%) was brought to the attention of the surgeon. The most frequent change observed with carotid clamping was a dramatic decrease of electroencephalographic amplitude, and electroencephalographic slowing or mild electroencephalographic amplitude changes were much less common. Electroencephalographic changes were most often bilateral, but occasionally asymmetric changes were seen, indicating probable inadequate collateral communication between right and left hemispheric circulations.

Patch closure of the carotid arteriotomy was used selectively. Selective shunting was performed at the beginning of the study period with classic criteria, primarily CEA ipsilateral to a recent (within 6 weeks) stroke, the presence of a contralateral ICA occlusion,\textsuperscript{14} or the development of significant electroencephalographic changes during initial carotid clamping. However, shunt placement was at the discretion of the operating surgeon. Because of the concern that injured brain might be “electrically silent” on electroencephalography despite its sensitivity to reduced blood flow during clamping,\textsuperscript{14} we were more likely to place shunts in patients who had had recent ipsilateral strokes, even if the electroencephalography remained stable during clamping.

Characteristics of patients who underwent primary CEA with routine electroencephalography are listed in Table I. ICA occlusion contralateral to the side of CEA was present in 57 of the operations (10%). Angina pectoris was more common, and any clinically overt coronary artery disease tended to be more common in the patients with contralateral ICA occlusion. Other patient characteristics were similar in patients with and without contralateral ICA occlusion. Contralateral CEAs were performed in 28 patients at intervals ranging from 7 days to 5.8 years after the first CEA, so that a total of 507 CEAs were performed in 479 patients without contralateral ICA occlusion.

Classification, data analysis, and reporting were performed in accordance with criteria established by the Society for Vascular Surgery/American Association for Vascular Surgery.\textsuperscript{16} Univariate comparisons of patient characteristics and outcomes were performed with Student \textit{t} test (two-tailed), \textit{χ}\textsuperscript{2} test (with Yates continuity correction for 2 × 2 tables), or Fisher exact test (two-tailed). Main outcome measures were stroke or retinal infarct, temporary (less than 24 hours duration) lateralizing neurologic or ocular event, or death. Significance was assumed for all statistical tests at a \textit{P} value of less than .05.
RESULTS

Noticeable electroencephalographic changes were significantly more likely to occur during carotid clamping with contralateral ICA occlusion (Table II). Shunts were placed much more often with contralateral ICA occlusion as well. Among patients without contralateral ICA occlusion, trends toward increased likelihood of electroencephalographic change (14% versus 19%) and shunt placement (12% versus 18%) in patients with 50% to 79% stenosis versus those with 80% to 99% stenosis of the contralateral carotid were not significant (P > .1, with χ² test). Patches were more likely to be placed with contralateral ICA occlusion. Operative details were otherwise similar without and with contralateral ICA occlusion. No patient awoke from anesthesia with an apparent hemispheric stroke or retinal infarct. Five of the patients (1%) with patent contralateral ICA had perioperative (within 30 days) strokes, all of which were ipsilateral to the side of CEA, and all strokes occurred 3 or more hours after emergence from anesthesia. One of these five perioperative strokes occurred 3 days after surgery and was shown to be caused by ipsilateral intracerebral hemorrhage. All five of these strokes occurred in patients who underwent conventional CEA, all five had undergone patching with Dacron, four of the five needed distal tacking

Table I. Comparison of patients with contralateral ICA occlusion with patients without contralateral occlusion

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>With contralateral occlusion (57 operations in 57 patients)</th>
<th>Without contralateral occlusion (507 operations in 479 patients)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>70.8 ± 10.0</td>
<td>71.8 ± 7.9</td>
<td>.46*</td>
</tr>
<tr>
<td>Gender, male/female</td>
<td>41 (72%)/16 (28%)</td>
<td>305 (60%)/202 (40%)</td>
<td>.11†</td>
</tr>
<tr>
<td>Hypertension</td>
<td>39 (68%)</td>
<td>360 (71%)</td>
<td>.79†</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>12 (21%)</td>
<td>96 (19%)</td>
<td>.84†</td>
</tr>
<tr>
<td>History of cigarette smoking</td>
<td>25 (61%)</td>
<td>302 (60%)</td>
<td>.90†</td>
</tr>
<tr>
<td>History of angina</td>
<td>19 (33%)</td>
<td>89 (18%)</td>
<td>.007†</td>
</tr>
<tr>
<td>Previous myocardial infarction</td>
<td>10 (18%)</td>
<td>100 (20%)</td>
<td>.84†</td>
</tr>
<tr>
<td>Previous coronary bypass</td>
<td>13 (23%)</td>
<td>121 (24%)</td>
<td>.99†</td>
</tr>
<tr>
<td>Any history of coronary artery disease</td>
<td>30 (53%)</td>
<td>195 (38%)</td>
<td>.054†</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>4 (7%)</td>
<td>32 (7%)</td>
<td>.78†</td>
</tr>
<tr>
<td>Chronic obstructive lung disease</td>
<td>4 (7%)</td>
<td>46 (9%)</td>
<td>.81†</td>
</tr>
<tr>
<td>Ipsilateral carotid stenosis &gt;80%</td>
<td>46 (81%)</td>
<td>414 (82%)</td>
<td>1.00†</td>
</tr>
<tr>
<td>Asymptomatic stenosis</td>
<td>18 (32%)</td>
<td>182 (36%)</td>
<td>.62†</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation or n (%).
P value calculated with:
* Student t test (two-tailed).
† χ² test.
‡ Fisher exact test (two-tailed).

Table II. Details of operation and outcomes, comparison of patients with contralateral ICA occlusion with patients without contralateral occlusion

<table>
<thead>
<tr>
<th></th>
<th>With contralateral occlusion (57 operations in 57 patients)</th>
<th>Without contralateral occlusion (507 operations in 479 patients)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEG changes associated with carotid clamping</td>
<td>22 (39%)</td>
<td>80 (16%)</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Use of shunt</td>
<td>31 (55%)</td>
<td>66 (13%)</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Placement of patch</td>
<td>49 (86%)</td>
<td>331 (65%)</td>
<td>.002*</td>
</tr>
<tr>
<td>Distal tacking sutures</td>
<td>33 (57%)</td>
<td>273 (54%)</td>
<td>.62*</td>
</tr>
<tr>
<td>Early ipsilateral stroke (within 30 days)</td>
<td>0</td>
<td>5 (1%)</td>
<td>1.00†</td>
</tr>
<tr>
<td>Early ipsilateral temporary neurologic event (within 30 days)</td>
<td>0</td>
<td>8 (1.6%)</td>
<td>1.00†</td>
</tr>
<tr>
<td>Perioperative death (30 days)</td>
<td>1 (2%)</td>
<td>1 (.2%)</td>
<td>.19†</td>
</tr>
<tr>
<td>Postoperative length of stay (days)</td>
<td>2.4 ± 2.6</td>
<td>2.0 ± 1.5</td>
<td>.19†</td>
</tr>
<tr>
<td>Direct costs</td>
<td>$3367 ± 1679 (n = 27)</td>
<td>$2930 ± 1806 (n = 320)</td>
<td>.21‡</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation or n (%).
P value calculated with:
* χ² test.
† Fisher exact test (two-tailed).
‡ Student t test (two-tailed).
EEG, Electroencephalography.
sutures, all five underwent CEA for stenosis of 80% or more, and four of the five were symptomatic before CEA. None of these five strokes occurred in a patient with electroencephalographic changes during clamping, and none of the five occurred in a case in which a shunt was used. No patient with an occluded contralateral ICA had perioperative stroke. Transient perioperative hemispheric or ocular events, all of which were ipsilateral to the CEA, occurred in eight patients (1.6%) with patent contralateral ICA. No transient neurologic events occurred in patients with occluded contralateral ICA.

Temporary shunts were placed in a significantly greater fraction of patients (55%) with electroencephalographic changes (39%) in the group with contralateral ICA occlusion (Table II). Because this might have reflected the surgeon’s incomplete confidence in electroencephalography, especially early in the experience, we further examined the likelihood of shunting during the study interval (Table III). Of nine patients with contralateral ICA occlusions who underwent shunting despite absence of electroencephalographic change with clamping, three had had strokes before CEA, three had had at least one transient ischemic attack or episode of amaurosis fugax before CEA, and three were asymptomatic. Thus, only three of these nine patients can be considered to have undergone shunting because of concerns about “electrically silent” injured brain after a stroke, and six underwent CEA with a shunt probably primarily on the basis of the surgeon’s lack of complete confidence in electroencephalography in the setting of contralateral carotid occlusion. No detectable change was seen between the early and late eras in the frequency of electroencephalographic changes associated with clamping. This was also true when comparison was confined only to patients with contralateral ICA occlusions. However, the likelihood of shunting fell slightly during the study period as we became more confident in electroencephalography, but this trend was not significant. Indeed, this trend appeared to be completely the result of a decline in the use of shunts with contralateral ICA occlusions. The trend toward less frequent use of shunts with contralateral occlusion in the latter portion of the experience was large (62% versus 43% early versus later era) but did not reach statistical significance. The likelihood of stroke also trended lower from the early to late eras, but this trend also did not reach significance.

Two perioperative deaths occurred. One was caused by myocardial infarction on the first postoperative day. The second patient, a man who was hypertensive and hemodialysis dependent, underwent an uneventful CEA after a hemispheric stroke ipsilateral to an 80% to 99% internal carotid stenosis. This patient also had total occlusion of the contralateral internal carotid and a 4-mm aneurysm of the anterior communicating artery and died suddenly of subarachnoid hemorrhage on the 10th post-CEA day. Resource utilization as measured by length of stay and direct costs was similar with and without contralateral ICA occlusion (Table III).

### DISCUSSION

Some surgeons have proposed that the ease and safety of carotid shunting warrant its use in all CEAs.\textsuperscript{16,17} Others have pointed out that the risks of some types of stroke may actually be increased with the use of shunts and have argued that shunts should not be used at all.\textsuperscript{18-21} Clearly, shunts may be associated with a unique set of potential complications,\textsuperscript{22} and CEA can be performed more easily with more confidence about the distal terminus of the endarterectomy and probably quicker in the absence of a shunt. The potential to maximize benefit and minimize risk associated with the use of shunts would seem to depend on selective use of shunts. The risks of stroke related to embolism during dissection, embolism from or thrombosis of the endarterectomy site after removal of clamps, and postrerufusion hemorrhage would not be expected to be decreased with shunting. The potential value of shunting during CEA would seem completely restricted to patients with inadequate blood flow to maintain brain viability during the period of clamping during CEA. Previous studies suggested that inadequate cerebral perfusion during clamping was responsible for at least a third of perioperative strokes,\textsuperscript{23} but as the contribution of embolism during carotid dissection has come to be appreciated and surgeons have accordingly altered their technique to reduce this risk, inadequate blood flow during clamping may be responsible for an even greater fraction of perioperative strokes.\textsuperscript{24} Thus, any method to detect inadequate cerebral flow would seem a

### Table III. Trend in use of shunts, number of CEA with electroencephalograph changes during carotid clamping, and early ipsilateral strokes in early versus later era

<table>
<thead>
<tr>
<th>Era of operation</th>
<th>1989 to 1994 (n = 248)</th>
<th>1995 to 1999 (n = 316)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEG changes during clamping</td>
<td>50 (20.2%)</td>
<td>54 (17.1%)</td>
<td>.48*</td>
</tr>
<tr>
<td>Use of shunt</td>
<td>48 (19.4%)</td>
<td>49 (15.5%)</td>
<td>.29*</td>
</tr>
<tr>
<td>Use of shunt in patients with contralateral ICA occlusion</td>
<td>21 of 34 (62%)</td>
<td>10 of 23 (43%)</td>
<td>.28*</td>
</tr>
<tr>
<td>Early ipsilateral stroke</td>
<td>4 (1.6%)</td>
<td>1 (0.3%)</td>
<td>.17†</td>
</tr>
</tbody>
</table>

P value calculated with:
* \( \chi^2 \) test.
† Fisher exact test (two-tailed).
EEG, Electroencephalogram.
potential criterion for selective shunting and reduction of hypoperfusion-type perioperative strokes.13

Various methods have been used to monitor cerebral function and provide cerebral protection during CEA,13,25 including electroencephalography,13,22,26-35 CEA in conscious patients,25,36-40 other anesthetic manipulations,41,42 measurement of ICA “stump pressure,”43-45 monitoring of middle cerebral artery blood flow velocity with transcranial Doppler,46-49 cerebral infrared oximetry,50,51 and some combinations of the aforementioned.52-60 These techniques also have been used to select such patients for shunting, and significant success has been achieved with many of these approaches.

CEA in conscious patients has become the norm in many centers. However, middle-year general surgery residents participate in nearly all of the CEAs we perform. The prospect of teaching a relatively junior resident with a patient at least somewhat aware of the intraoperative discussion and the undeniable increase in time necessary to complete the operation made CEA in awake patients seem impractical in our situation. Stump pressure measurement is a simple and inexpensive way to test adequacy of collateral blood flow during carotid clamping but provides only a “snapshot” measurement before opening the carotid artery. Even small alterations in blood pressure may make significant differences in adequacy of collateral flow,61 and not all have found stump pressure to be reliable.44,53,62-64

Extensive literature existed in the use of conventional (unprocessed) electroencephalography before initiation of electroencephalography in our program.26,28,29,31,65,66 Electroencephalography correlates well with cerebral blood flow changes.67 Although that literature suggested that specificity of electroencephalography was significantly less than perfect (ie, many patients with electroencephalographic changes during clamping would not have apparent strokes),27,52,55,68 electroencephalography appeared to be associated with excellent sensitivity for cerebral ischemia during CEA with general anesthesia (ie, patients without intraoperative electroencephalographic changes were unlikely to have intraoperative strokes). Therefore, electroencephalography appeared to be an excellent candidate to provide a basis for selective shunting,35 albeit at the expense of shunting some patients who would have tolerated CEA without a shunt, and for this reason, we chose to use this technique beginning in 1989.

Steed et al37 performed 345 CEAs in conscious patients without shunts and concluded that emboli during dissection or at the time of clamp release were the cause of most intraoperative strokes. However, Imperato et al23 and Riles et al69 in a follow-up article concluded that the risk of stroke as the result of embolization during carotid dissection was quite low, possibly reflecting some difference in technique of CEA. McKinsey et al70 also noted that emboli during carotid dissection and at the time of unclamping were apparently a less common cause of perioperative strokes than had been observed by Steed and others in the past. No doubt exists that the risk of embolization during dissection and at the time of release of clamps can be significantly influenced by operative technique.24 This has undoubtedly influenced surgeons to take more care at these two critical points during CEA. None of our patients awoke with an apparent cerebral hemispheric deficit, and all perioperative strokes became apparent at least 3 hours after emergence from anesthesia. Thus, at least in this moderate-sized series of consecutive operations, the risk of intraoperative stroke appears to have been entirely eliminated with the combination of these technical principles, electroencephalography and selective shunting. Ballotta et al52 made a similar observation in a series of 369 CEAs.

Despite an acceptable stroke risk for CEA without any shunts in some series,20 CEA without at least selective shunting appears associated with a substantially higher risk of perioperative stroke.71 The fact that a substantial fraction of patients with contralateral ICA occlusion would tolerate temporary clamping without significant electroencephalographic changes and that they tolerated CEA without use of a shunt suggests that the excellent sensitivity of electroencephalography for detection of inadequate cerebral blood flow extends to patients with contralateral ICA occlusions.67 Some prior studies have noted an increased risk of stroke at the time of CEA in the presence of contralateral ICA occlusion, but others and we have observed no increase18,65,72-78 or at most an insignificant increase29 in stroke risk under these circumstances. The operative approach in all of these cited studies, except Ott et al18 and Redekop and Ferguson,74 included routine or selective shunting. The complete absence of strokes in the group with contralateral ICA occlusion cannot be expected to be maintained as sample size increases, but it appears that this risk is quite low and indistinguishable from that in patients without contralateral ICA occlusion. Stump pressure appears to have adequate sensitivity, particularly in the presence of contralateral carotid occlusion.45 Perioperative morbidity and mortality in this series compare quite favorably with those in other contemporary studies of CEA.1,14 Our 16% rate of shunt placement is remarkably similar to that of other studies with electroencephalography as the primary criterion for shunt placement.22,23,26,30 Furthermore, the relative likelihood of shunting in this series (1.3% for patients with patent contralateral ICA, 5.5% for patients with occluded contralateral ICA, with the rate in the latter group declining over time) is also quite similar to that in previously published studies.

Some investigators have combined methods of cerebral monitoring with the premise that no single method offers adequate accuracy for prediction of post-CEA neurologic deficits.54,57-59 Electroencephalography is likely to be available in virtually any hospital with associated services adequate to support a program of CEA. Hospitals that do not have electroencephalography are unlikely to have transcranial Doppler testing available as an alternative. Conventional “unprocessed” electroencephalography as practiced in the electroencephalography laboratory is relatively easy to transport to the operating room. Given the excellent sensitivity of electroencephalography, it would seem that the only possible benefit of combining electroencephalog-
raphy with other methods of cerebral monitoring, principally transcranial Doppler, would be to improve specificity and, therefore, to reduce the requirement for shunting. We acknowledge that shunts add risk, otherwise routine shunting would seem the most appropriate approach to this problem, and minimizing shunt use is our goal. However, a certain familiarity and comfort with shunts seems desirable, especially in a teaching program, so that shunts can be placed safely and expeditiously when they are necessitated. Our current shunt rate seems to address both of these goals adequately.

We asked our hospital several years ago to estimate costs for several items associated with CEA, including electroencephalography. Direct costs for electroencephalographic monitoring, primarily salary and benefits along with disposables, were estimated to be much less than $100 per case. This does not include the neurologist fee for interpretation, and it would be difficult to accurately account for indirect costs, such as equipment depreciation. However, monitoring during CEA is only a small part of the effort of our Sleep Disorders and Electroencephalography Center and probably has little impact on capital and personnel costs. A reasonable estimate of total costs of electroencephalographic monitoring is probably approximately $200 to $300 per case. Although this sum is not inconsequential, as discussed previously, we suspect that the operation can be performed in less time and perhaps more precisely without a shunt. Total costs in our operating room approach $2000 per hour. Thus, reduction of operating time by as little as 10 minutes may negate much or all of the cost associated with electroencephalographic monitoring during CEA. A complication of shunt placement is also likely to be expensive. Thus, when compared with routine shunting, the added total cost of routine electroencephalographic monitoring may be offset by decreased costs associated with a shorter operation and fewer shunt-related complications.

A continuing interest can be seen in performance of CEA without shunting under any circumstances, generally with high-dose barbiturate “cerebral protection.” Frawley et al.42 have written that “Thiopental cerebral protection has rendered intraluminal shunting obsolete.” We would agree with these authors that “... shunting does not necessarily guarantee a deficit-free outcome,”73,80 but we would counter that the theoretic efficacy of pharmacologic cerebral protection needs further clinical confirmation before it should be adopted generally. The use of high doses of barbiturates would prevent the immediate assessment of neurologic function when the operation is completed because the patient would be expected to remain unresponsive for several hours after termination of surgery.42 Furthermore, we have had occasion to observe the electroencephalogram become isoelectric (“flat line”) within seconds of placing carotid clamps in patients with contralateral ICA occlusion. We would be reluctant in such a case to depend on the cerebral protective effect of barbiturates and would feel compelled to place a shunt. The return of electroencephalographic activity and the demonstration of flow in the shunt with a simple 10-MHz handheld Doppler probe applied directly to the shunt is comforting in such a case.

CONCLUSION

CEA in a program including routine electroencephalography and selective shunting is associated with a low risk of perioperative stroke. This benefit extends to patients with contralateral ICA occlusion as well, and placement of a shunt in patients with contralateral ICA occlusion would appear unnecessary unless they had electroencephalographic changes during clamping or had had a stroke before CEA. Electroencephalography is likely to be available in any hospital that has the other resources to consider CEA. Surgeons should consider using routine electroencephalography for cerebral monitoring and for a criterion for selective shunting during CEA.

REFERENCES

DISCUSSION

Dr Frank LoGerfo (Boston, Mass). I have two questions. The first is, these changes on electroencephalography (EEG) are not subtle. Do you really need all of that horsepower in the operating room to make that decision that there is a change on the EEG?

And secondly, this entire effort revolves around concerns about placing a shunt, because if there were no downside to placing a shunt, we could just all place a shunt in everyone, which is my policy. When you do that, the operation from the beginning is designed to place a shunt, so your dissection is done in a way to make placement of the shunt very easy because you know you are going to do it. If you are not sure you are going to place that shunt, I have always had the concern that you are not going to have things laid out to facilitate placement of that shunt quite as well as you would if you do it as a routine, but in any case, I think that debate will go on and on.

I point out to you that when the EEG changes, the brain cell is almost dead. Of course, there is no oxidative reserve in the nerve cell, so that when you see that change on the EEG, you are perilously close to cell death. So, there is not much margin for error, and I am not sure you want to take every patient down that road and skirt with that for the purpose of avoiding something that is pretty simple.

Dr Joseph Schneider. Thank you very much. First of all, with respect to your comment about horsepower and having all this equipment in the operating room, our anesthesiologists would probably not be comfortable interpreting a compressed spectrum device display, so I doubt we could do this without an EEG technologist, even with less than a standard EEG setup. We had the experience a few years ago when looking at the results of our critical pathway in carotid surgery to examine the direct costs associated with EEG. The hospital told us the direct costs were only about $55 per case. The indirects are likely to be a substantially larger number, but the hospital did not have any interest in us abandoning EEG because it seemed to be associated with good outcomes.

With respect to the horsepower, the neurologist is not complaining and the hospital is not complaining. The activity does seem to be pretty low cost because it is only a small part of the overall effort in the sleep center and EEG center.

With respect to concerns about placing a shunt and a prospective plan to place a shunt, one thing we do address briefly in the manuscript is that some familiarity with shunting is important and it is useful to place shunts occasionally so that you do not feel that it is new to you when you are in a crisis and have to do it. We shunted about 17% of the patients in this series and 14% of our patients overall in our entire database of 1000 patients, and I feel that is a reasonable rate of shunting. Shunts are not innocuous, and the operation will take longer with a shunt. I think that most people who shunt selectively would agree that the operation is easier and faster and that they feel better about the endpoint with a shunt, and they are willing to approach this with selective shunting precisely because of the fact that, just as you said, the occasional patient has a problem related to placement of the shunt itself.

With respect to your comment about the timing and the fact that the brain cell is nearly dead when EEG changes, I agree completely that time is critical. I also agree that these EEG changes are not subtle and it does not take very long for them to develop. I do not know that there would be any way to measure the additional time that it takes to wait for the EEG to change and then decide to place the shunt, but my sense is it is not more than 10 or 15 seconds as I wait for the technologist to tell me the EEG is okay.
or not okay. I do not think that it adds a whole lot of time and probably does not really change things from the standpoint of having another neuron die because of an extra 10 or 15 seconds.

Dr Robert Zwolak (Lebanon, NH). Joe, several years ago the administrators of our hospital discouraged me from what had been my prior practice of using EEG for all cases. They discouraged me based on apparent significant expense. It is hard for me to think this could cost only $55: preparation of the scalp, application of the electrodes, some number of hours if the tech stays for the entire operation, and then removal of electrodes. How have you trimmed this so that it would only cost $55 to accomplish?

Dr Schneider. I suppose it is possible our hospital may have had another agenda because they also charge $1700 to do this and probably occasionally collect this amount! Seriously, when we first started doing the critical pathway, our administrators were not interested. The hospital was profitable for carotids at the time, and I would like to think that the estimated direct cost they gave us for EEG is a real number. This clearly does not reflect the indirects associated with just having an EEG and sleep center, but I think if you look at the number of EEGs that are done in the hospital, the other activities of these technologists, the amortization or depreciation of the machines and that sort of thing, total costs are certainly not $1000 a case. The additional cost may be a few hundred dollars per case, and since they are billing, and at least in some cases collecting, the hospital is not very unhappy about us using this technology.

Dr William C. Mackey (Boston, Mass). I think this is a terrific manuscript. I enjoyed it. I am impressed by the cost data though. We actually looked at our cost because recently we had our most experienced EEG technician who had been with us for over 20 years leave. EEG is very subjective and technician dependent. We were accustomed to doing the EEG monitoring with only our technician in the room because he was so experienced and we had very great faith in his ability to interpret subtle changes. When the EEG technician left, it prompted me to really look at why we were using EEG and should we continue to use it since I was going to have to train someone new and go through a learning curve that I was not very comfortable with. We actually looked at the cost of this in great detail. In our hospital, it is about $355 in added cost—this includes what we think are both direct and indirects. Based on this, we had a hard time justifying continuing with EEG, especially since we were going to have to train someone. There would initially be a lot of uncertainty and probably our incidence of shunting would go up because of our lack of comfort with a new technician.

I wonder if you look at cost when you routinely shunt in the small number of patients that were shunted because of recent stroke or contralateral occlusion or earlier in your experience you actually looked at incremental cost, because I do not believe for a minute that EEG monitoring costs only $55 in your hospital. A shunt is pretty inexpensive, and regional anesthesia may be even less expensive because the incidence of shunting is so low. We have now gone to routine shunting, which, since my hospital, New England Medical Center, was one of the first centers to use EEG monitoring, is a fairly radical move. We now shunt everyone simply because we cannot justify the cost and the training time it will take to get a new technician up to speed.

Dr Schneider. First of all, the direct cost does not reflect the total cost. The hospital told us that the direct cost was $55 per case. This was 5 years ago, but the consumer price index probably has not changed very much since then. I suspect that the indirects are three, four, or five times that, so we are probably in the same range as you, and the total costs are probably in that $300 range. However, what you cannot do is look at the incremental costs associated with routine shunting. Unless you have a large data set from a prospective randomized trial, you cannot look at the increase in the operating time or the increase in the likelihood of a shunt-related complication, both of which tend to increase total cost, and all those things are likely to be important only on the margin. The thing about carotid surgery is when your roof does not leak you do not want to fix it. Dr Mackey, my biggest surprise is that you are willing to change when your results have been so good at the New England Medical Center. We are blessed with two or three excellent technologists whom I trust completely, and quite honestly, the only time the neurophysiologist is in the room is when he is actually doing the monitoring because the experienced technologist is not available.

Dr Ronald Nath (Medford, Mass). A few years ago, we presented our paper to the society here regarding EEG monitoring in the awake patient in which we compared EEG monitoring of the neurologic status in the awake patient under regional cervical block anesthesia. Our results were similar to yours. We interestingly found that the rate of shunt utilization in the awake patient was about half the rate of shunt utilization in the asleep patient and the EEG-monitored patient. We also found that the costs of using EEG are significant, and based upon that and the fact that the physiologic response of the patient under awake cervical block anesthesia is significantly better, their blood pressures do not vary, and really we almost use no invasive monitoring anymore, thereby saving additional costs. We employ awake anesthesia in almost all of our patients. We do have a teaching service. We do take residents through these cases in the awake patient, and with appropriate sedation, for the patient that is, and appropriate mumbling on the part of the physician, we actually do manage to take them through it in a very successful way. I think it is important for the residents to have to learn how to do these operations in the awake patient. It saves time, it saves money, physiologically the patients do better, shunt utilization is decreased, and we feel it is superior methodology.

Dr Schneider. We have third-year residents on our service, and at Northwestern, our service is probably their first real operative service. We actually do these cases without residents at Glenbrook, a smaller hospital, and these cases take about an hour there. Our time at Evanston with the residents is closer to 2 hours. I do not think that I want to do this operation in an awake patient, especially since a few of our senior anesthesiologists might not be interested in regional anesthesia and would likely be off in another room during portions of the case. Again, when your roof does not leak, you do not want to fix it. We are pretty happy with our results, and I do not think we would want to change that one item unless we had a more senior resident on the service. I must respectfully ask what evidence there is that doing this operation with cervical block takes less time? I would suspect it takes more time unless it happens to be one of the cases where a shunt is avoided in the awake patient but would have been placed in the patient under general anesthesia. We have cited your excellent article in our manuscript. I find it intriguing that you would have placed shunts based on EEG changes in 28% of your patients with general anesthesia, whereas your 14% rate of shunt placement in awake patients is remarkably similar to our rate of 13% in patients without contralateral ICA occlusion and 17% overall, all with general anesthesia and EEG. One of your three strokes in general anesthesia patients occurred in a patient who underwent CEA without EEG and could not be shunted, the second was due to intracerebral hemorrhage several days after surgery, and the third was thought to be a complication of shunt placement. I would respectfully suggest that the first case provides no information regarding the value of EEG, the late intracerebral hemorrhage in the second would seem unlikely to have been related to the use of general anesthesia and EEG, and the third, if anything, provides weight to the argument that shunts may be detrimental and should be used selectively. Furthermore, your study was not randomized, and case selection bias could explain some of your results. I would also respectfully suggest that the promise of a physiologically less stressful operation appears unfilled with cervical block, at least that is my conclusion based on the literature cited in the manuscript.