Role of EEG monitoring and cross-clamping duration in carotid endarterectomy

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The usefulness of electroencephalographic (EEG) monitoring as well as the significance of the period of cross clamping in carotid endarterectomy have not been completely defined. In particular, the clinical importance of major EEG changes has not been fully investigated and some recent studies seem to indicate that the method has little value. As to the duration of cross clamping, there is strong evidence that occlusion times of about 15 minutes are tolerated under general anesthesia, but no information is available regarding longer periods of occlusion.

The authors describe a consecutive series of 141 carotid endarterectomies in which the patients with EEG changes were shunted only when occlusion was anticipated to last longer than 30 minutes. Early major EEG changes (during the first 4 minutes) occurred in 14% of the cases. In the absence of EEG changes, long occlusion periods of 40 to 50 minutes were well tolerated. In contrast, the 20 patients with major persistent EEG changes did not tolerate protracted occlusion and three of them had immediate postoperative neurological complications. It seems that, in these circumstances, the incidence of neurological deficit is a function of the duration of cross clamping; these three patients had undergone occlusion for 15 to 30 minutes. Their deficits partially resolved.

On the basis of these results it is concluded that: 1) EEG recording is a reliable monitoring system in carotid artery cross clamping. No major strokes due to temporary carotid artery occlusion occurred in the series. 2) The clinical significance of major persistent EEG changes is not negligible. Cross clamping for longer than 15 minutes in the presence of significant EEG alterations is potentially dangerous.

KEY WORDS • carotid endarterectomy • electroencephalography • carotid occlusion

TEMPORARY shunting and the use of different monitoring systems during carotid artery clamping are the most controversial technical aspects of carotid endarterectomy. Some authors do not use a shunt at all, some use it routinely, and some use it selectively on the basis of different monitoring criteria. The monitoring systems most commonly relied on to select the patients at major risk of ischemia arising from cross clamping include monitoring of neurological functions by using regional anesthesia, measurement of stump pressure, measurement of regional cerebral blood flow (CBF), and continuous electroencephalographic (EEG) monitoring.

A number of aspects concerning the monitoring systems and cross clamping in general remain to be defined. The value of EEG findings as an index of cerebral ischemia arising from cross clamping has been suggested by several studies. A close correlation between EEG findings and CBF measurement has been reported, and clinical experience has demonstrated that patients who do not show EEG changes tolerate temporary carotid occlusion.

The clinical significance of major EEG changes observed during cross clamping has not been fully investigated and the value of this diagnostic method has been the subject of criticism by some authors. A recent study has evaluated EEG monitoring in relation to extracranial carotid artery surgery, and seems to indicate that the method has little value in identifying cerebral ischemia of clinical significance.

Similarly, there is a lack of information as to the effect of the duration of arterial cross clamping in these patients. Experimental studies have shown that tolerance to ischemia is a function of the extent and time of flow reduction but, with only a few exceptions, no clinical studies have identified a critical time of occlu-
sion for unselected patients undergoing carotid endarterectomy. There is strong evidence that an occlusion time of about 15 minutes, under general anesthesia and usually hypertension, is tolerated by virtually all patients, and some studies show that an occlusion period of 30 minutes may be borne. No data are available as to the safety of longer periods of occlusion which may be necessary for the procedure.

In an attempt to learn more about these two aspects of carotid endarterectomy, we initiated a prospective study in the summer of 1982. We decided to modify our previous approach and to treat a consecutive series of patients by shunting those with EEG changes only when occlusion was anticipated to last longer than 30 minutes. During the 3-year period from August, 1982, to July, 1985, we performed 141 consecutive procedures according to this method, and we report the results of the series in this paper.

Clinical Material and Methods

The series consisted of 141 consecutive carotid endarterectomies performed on 177 patients (96 men and 31 women). The mean age of the patients was 58 ± 7.7 years. The indications for surgery included asymptomatic carotid stenosis in 27 procedures (19.1%), usually in patients with previously treated symptomatic contralateral internal carotid artery (ICA) lesions; hemispheric or retinal transient ischemic attacks (TIA's) in 39 (27.7%); reversible ischemic neurological deficit in 36 (25.5%); and hemispheric stroke (usually without severe residual deficit) with and without superimposed TIA’s in 39 (27.7%).

Contralateral ICA occlusion was present in 22 cases (17.3%), and in 14 an extracranial-intracranial bypass procedure had been performed previously. In 18 cases, the endarterectomy was carried out before an aortocoronary bypass procedure, under the same anesthesia. Bilateral procedures were performed in two stages in 12 cases, and in one operation in two cases (in combination with cardiac surgery).

General anesthesia with normocarbia and mild hypoxia was used. Continuous EEG monitoring was conducted in all patients with an eight-channel machine, using needle electrodes placed according to the International System. In general, in the absence of cardiological contraindication, mild arterial hypertension was induced with dopamine or phenylephrine before the artery was clamped. Whenever possible, a further increase in blood pressure was obtained in patients with EEG changes at cross clamping; however, in patients undergoing surgery for severe stenosis (70% occlusion or more), major efforts were made to obtain normotension or mild hypotension at the moment of releasing the clamps. Before clamping, the patients were given 5000 U of sodium heparin intravenously, and an additional dose of 2500 U was administered when an occlusion time longer than 45 minutes was necessary.

In all cases but three, a standard endarterectomy was performed with emphasis on complete exposure of the lesion in the ICA. This was obtained in virtually all patients, even in those with very high lesions. In two patients, the involved segment was resected and replaced with a prosthesis. In one patient, because of the very poor condition of the arterial walls, the main trunk of the external carotid artery was exchanged with that of the ICA after a standard ICA endarterectomy.

An intraluminal shunt was used when major persistent EEG changes were observed during the first 4 minutes of cross clamping (early changes), but only when an occlusion time longer than 30 minutes was anticipated on the basis of: 1) the angiographic picture; 2) direct examination of the lesion at surgery; or 3) difficulty with the initial removal of the distal part of the plaque. The following patterns have been considered as major EEG changes: 1) slow (delta) waves, either hemispheric or diffuse; or 2) focal or diffuse wave suppression (50% or greater reduction of background activity voltage; that is, low voltage). Similar changes that were clearly related to anesthetic or ventilatory variations as well as changes that were reversed spontaneously or by hypertension within minutes were not taken into consideration.

The arteriotomy was closed without a patch in the first 52 consecutive cases. Since then we have placed a venous or synthetic patch with a few exceptions (patients with EEG changes who were not shunted). The introduction of the patch technique was the only modification added to the original protocol in this series.

Postoperative angiography and/or Doppler sonography were used in all cases and showed the patency of the operated vessel in all instances but three. In six procedures, angiography was performed immediately on the appearance of neurological deficits.

Results

For analysis, the procedures were divided into four groups according to the EEG findings and the use of an internal shunt (Table I). All the patients were examined regularly during the 1st month postoperatively and thereafter at 6-month intervals. The follow-up period ranged from 1 to 34 months (mean 18 months), and during this time no stroke occurred in the entire series. One patient died from a myocardial infarction. Two patients had asymptomatic recurrence of stenosis at a late Doppler sonography control study.

Group 1

Eight patients had Group 1 procedures (with early major EEG changes and insertion of a shunt within 3 to 15 minutes). None of these patients had immediate or delayed new neurological deficit after surgery. One patient presented a transitory recurrent nerve palsy. The EEG changes were reversed with insertion of the shunt in all instances.
TABLE 1

Summary of findings in 20 endarterectomy patients with EEG changes*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Contralateral ICA Lesions</th>
<th>EEG Changes</th>
<th>ICA Occlusion Time (min)†</th>
<th>Shunt Insertion</th>
<th>Induced Hypertension</th>
<th>Postoperative Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59</td>
<td>thrombosis bypass</td>
<td>LV</td>
<td>4</td>
<td>yes</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>2</td>
<td>58</td>
<td>thrombosis bypass</td>
<td>LV</td>
<td>5</td>
<td>yes</td>
<td>no</td>
<td>uneventful</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
<td>thrombosis</td>
<td>LV</td>
<td>11</td>
<td>yes</td>
<td>yes</td>
<td>transitory recurrent nerve palsy</td>
</tr>
<tr>
<td>4</td>
<td>59</td>
<td>thrombosis</td>
<td>DW</td>
<td>4</td>
<td>yes</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>5</td>
<td>59</td>
<td>none</td>
<td>LV</td>
<td>12</td>
<td>yes</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>6</td>
<td>59</td>
<td>none</td>
<td>LV</td>
<td>12</td>
<td>yes</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>7</td>
<td>59</td>
<td>thrombosis bypass</td>
<td>DW</td>
<td>8</td>
<td>yes</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>8</td>
<td>66</td>
<td>thrombosis</td>
<td>DW</td>
<td>6</td>
<td>yes</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>9</td>
<td>63</td>
<td>none</td>
<td>LV</td>
<td>30</td>
<td>yes</td>
<td>no</td>
<td>hand paresis, improved in 30 days</td>
</tr>
<tr>
<td>10</td>
<td>65</td>
<td>none</td>
<td>LV</td>
<td>25</td>
<td>yes</td>
<td>yes</td>
<td>arm paresis, markedly improved in 4 days</td>
</tr>
<tr>
<td>11</td>
<td>61</td>
<td>stenosis &gt; 80%</td>
<td>DW</td>
<td>16</td>
<td>yes</td>
<td>no</td>
<td>uneventful</td>
</tr>
<tr>
<td>12</td>
<td>48</td>
<td>none</td>
<td>LV</td>
<td>30</td>
<td>no</td>
<td>no</td>
<td>uneventful</td>
</tr>
<tr>
<td>13</td>
<td>52</td>
<td>thrombosis bypass</td>
<td>DW</td>
<td>30</td>
<td>no</td>
<td>no</td>
<td>uneventful</td>
</tr>
<tr>
<td>14</td>
<td>57</td>
<td>thrombosis bypass</td>
<td>DW</td>
<td>20</td>
<td>no</td>
<td>no</td>
<td>uneventful</td>
</tr>
<tr>
<td>15</td>
<td>55</td>
<td>stenosis 50%</td>
<td>DW</td>
<td>20</td>
<td>no</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>16</td>
<td>61</td>
<td>thrombosis bypass</td>
<td>LV</td>
<td>30</td>
<td>no</td>
<td>no</td>
<td>uneventful</td>
</tr>
<tr>
<td>17</td>
<td>53</td>
<td>stenosis 50%</td>
<td>LV</td>
<td>27</td>
<td>no</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>18</td>
<td>64</td>
<td>thrombosis</td>
<td>LV</td>
<td>11</td>
<td>no</td>
<td>yes</td>
<td>uneventful</td>
</tr>
<tr>
<td>19</td>
<td>73</td>
<td>stenosis &gt; 80%</td>
<td>LV</td>
<td>16</td>
<td>no</td>
<td>no</td>
<td>hand paresis, markedly improved in 4 days; residual slight arm paresis</td>
</tr>
<tr>
<td>20</td>
<td>49</td>
<td>none</td>
<td>LV</td>
<td>100</td>
<td>no</td>
<td>yes</td>
<td>uneventful</td>
</tr>
</tbody>
</table>

* Group 1 patients had electroencephalographic (EEG) changes and shunts inserted within 15 minutes of the start of surgery; Group 2 patients had EEG changes and shunts placed after 15 minutes of surgery; Group 3 patients had EEG changes but no shunts were placed. ICA = internal carotid artery; LV = low voltage; DW = delta waves.

† Indicates occlusion time before shunt insertion.

Group 2

Three patients underwent Group 2 procedures (with early major EEG changes and insertion of a shunt after 16 to 30 minutes). The late insertion of the shunt was determined by the necessity to extend the original arteriotomy in one case and to replace the involved ICA segment with a prosthesis in the other two cases.

One patient who was shunted 30 minutes after cross clamping (Case 9) awoke from anesthesia with a new deficit consisting of a severe contralateral hand paresis. Emergency angiography showed patency of the prosthesis placed between the common carotid artery and the ICA and no abnormalities of the intracranial circulation. This patient's EEG changes did not reverse on insertion of the shunt or on release of the clamps. The deficit cleared almost completely in the 30-day period of observation.

Another patient, shunted after 25 minutes, had no apparent new neurological deficits on awakening from anesthesia. However, a very severe arm paresis was appreciated 2 hours later. Emergency angiography was performed and the findings were within normal limits. The deficit cleared almost completely in 3 to 4 days. The EEG changes of this patient had reversed with the shunt.

Group 3

Nine patients had Group 3 procedures (with early major EEG changes but no shunt insertion). In this group the cross-clamping time averaged 22.2 ± 7 minutes in eight cases. In the ninth patient the occlusion lasted 100 minutes, but the EEG tracing was peculiar: a 50% reduction of voltage was recorded during the first 25 minutes; a significant improvement was then observed. Subsequently, the tracing was characterized by fluctuations of voltage.

In this group, one patient (Case 19) awoke from anesthesia with a new deficit consisting of a contralateral hemiparesis. The deficit markedly improved in a few days. Emergency angiography did not show any abnormality of the operated carotid segment or of the intracranial circulation. Early and late computerized tomography examinations were normal. The occlusion time in this patient lasted 16 minutes, and EEG changes did not reverse at the release of the clamps.

Group 4

The 121 remaining cases underwent Group 4 procedures (without early major EEG changes and without shunt placement). In this group, the artery was occluded for an average of 36.7 minutes (range 12 to 80 minutes).
In 13 cases, arterial cross clamping lasted 50 minutes or more. In four cases, major EEG changes were observed late during the occlusion (after the 4th minute). In all instances, these late changes resolved either spontaneously or on release of the clamps; at maximum they lasted 20 minutes. In four procedures, major EEG changes consisting of diffuse delta waves occurred after release of the clamps. They were unrelated to variations of blood pressure or anesthetic parameters and reversed spontaneously within 5 to 20 minutes. Their pathogenesis remains to be identified.

No patient in Group 4 awoke from anesthesia with a new neurological deficit. Two patients had an ischemic stroke on the 2nd postoperative day, and emergency angiography showed thrombosis of the operated vessel. A third patient presented a reversible ischemic neurological deficit referable to the carotid artery on the 2nd postoperative day. In this case also, angiography showed an occlusion of the operated ICA. Two cases of wound hematoma were recorded in this group. There were two cases of dysphonia: the recurrent nerve palsy was permanent in one case and markedly improved in the other.

**Discussion**

The overall postoperative results in this series of 127 patients submitted to carotid endarterectomy have been satisfactory, especially considering that one-third of the cases were at high surgical risk (22 had contralateral ICA occlusion and 18 were submitted to an aortoconoronal bypass procedure under the same anesthesia). No deaths were related to the operation; severe permanent morbidity occurred in two patients (1.6%) and slight permanent morbidity, inclusive of peripheral nerve palsy, occurred in seven (5.5%). This discussion will focus not on the method and its results but on the pertinent aspects of the study: the value of EEG monitoring and the significance of cross-clamping duration.

This study confirms that most patients who undergo carotid endarterectomy do not show major EEG changes during cross clamping of the artery. Our 14% incidence of early changes (during the first 4 minutes of surgery) is close to that reported by many authors, but higher incidences have also been observed. A different patient population, technical recording problems, and variations in interpreting the tracings could well explain the discrepancies.

There was a higher incidence of EEG changes in patients with contralateral ICA occlusion (eight of 22 cases or 36%) than in patients with a patent contralateral artery (12 of 119 cases or 10%). However, the difference does not reach a high level of statistical significance (p < 0.025) and therefore this point remains to be further clarified.

In the absence of EEG changes, relatively long periods of occlusion (40 to 50 minutes) are well tolerated, at least under general anesthesia and full heparinization. In other words, EEG monitoring did not give false-negative findings as previously reported in relation to this surgery. The present study gives more precise delineation of the duration of cross clamping that can be considered safe in patients without EEG changes. Interestingly, the only false-negative findings of EEG monitoring when used as a test of tolerance to ICA occlusion have been reported in patients with pathological conditions different from atherosclerosis. In the presence of major persistent EEG changes, cross clamping of the ICA does not seem to be equally tolerated. Three of 20 procedures associated with electrical abnormalities were followed by an immediate neurological deficit. The deficits in one of these were observed 2 hours after surgery; however, the impairment might have been present when the patient awoke from anesthesia, when a precise clinical evaluation is not always possible. In all three cases, emergency angiography ruled out intracranial occlusions or other signs of embolization, like irregularities of the operated segment; therefore, a hemodynamic cause for these deficits cannot be excluded. The 15% incidence of postoperative neurological complications in the 20 patients with early EEG changes is significantly higher than the zero incidence of immediate neurological deficits following the 121 procedures without early and persistent EEG changes (p < 0.005). All the deficits that were apparently related to cross clamping partially resolved. Whether recovery from this kind of neurological impairment is the rule remains a very important point to be clarified. These data contrast with those reported by Ferguson’s series in a series of 102 monitored unshunted cases. He reported one stroke among 35 patients with EEG changes, and that was of uncertain origin. The high incidence (34%) of EEG changes in Ferguson’s series is noteworthy: likely it was because all the abnormalities observed during the entire period of cross clamping were considered.

In an attempt to identify patients at major risk among those with EEG changes we have analyzed many parameters. Neither the severity of electrical abnormalities, the presence of contralateral ICA occlusion, nor the clinical presentation (TIA’s or stroke) seem to have a role. It is possible that the complications in two of our three patients were caused by difficulties in the procedures; however, many other operations had the same degree of difficulty.

Our results suggest a critical period of cross clamping in cases with major EEG changes in the order of 15 minutes. In fact, no deficits occurred in the nine patients with EEG changes and a period of occlusion within these time limits (eight Group 1 patients and one Group 3 patient). On the contrary, three of 11 patients with EEG changes in whom the ICA was occluded for periods between 15 and 30 minutes had an immediate neurological deficit (two Group 2 patients and one Group 3 patient). The small number of cases in the two subgroups (occlusion for less than 15 minutes and occlusion between 15 and 30 minutes) does not allow a definitive conclusion in this regard. However,
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indirect but strong support for this hypothesis comes from the very low incidence of immediate neurological deficits in some large series of patients without shunts in whom the average cross-clamping duration was 15 minutes.3,5,26 We continue to monitor the patients because in our hands most procedures take longer than 15 minutes, especially if the arteriotomy is closed by a patch, the usefulness of which has been supported by recent studies.7,12 Thrombosis and embolization are the most common causes of stroke associated with this procedure. In our series, thrombosis of the operated vessel was the only cause of serious permanent morbidity. We think that the incidence of both of these complications could be lowered by a more meticulous technique. This is easily obtained in the absence of any uncertainty as to the patient’s tolerance of relatively long periods of occlusion, a factor that does not seem to be completely free of risk in some patients.

References


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