Local Haemodynamic Changes During Carotid Endarterectomy—The Influence on Cerebral Oxygenation

B. Kragsterman,* H. Pärsson and D. Bergqvist

Department of Surgical Sciences, Uppsala University, Uppsala, Sweden

Objectives. To characterize carotid bifurcation haemodynamics and cerebral oxygenation during clamping and at reperfusion after carotid endarterectomy (CEA).

Materials and methods. Sixty-two patients with a symptomatic high-grade stenosis of the internal carotid artery (ICA), who underwent CEA under general anaesthesia, were studied prospectively. Measurements of stump pressure, volume flow (transit time flowmetry) and changes in cerebral oxygenation (near-infrared spectroscopy (NIRS)) were performed. Selective shunting was based on stump pressure only.

Results. Stump pressure correlated with both ICA flow before clamping (r = 0.45; p = 0.03) and changes in cerebral oxygenation (rSO2) during clamping (r = 0.61; p = 0.002), the latter was reversed by shunt placement. ICA flow before clamping also correlated with changes in rSO2 during clamping (r = 0.41; p = 0.01).

Conclusion. Measurements with transit time flowmetry and cerebral oximetry are technically easy and help to determine the need for selective shunting during CEA. High ICA flow before clamping in combination with a low stump pressure usually indicates the need for a shunt. Volume flow measurements may also be useful in the quality assessment of the CEA.

Key Words: Carotid endarterectomy; Cerebral oxygenation; Oximetry; Volume flow.

Introduction

CEA for symptomatic high-grade stenosis of the ICA is an established procedure to reduce the risk for a new neurological event.1–5 The overall benefit of this prophylactic procedure is dependent on the periproductive results regarding the combined risk for stroke and death. Insufficient cerebral collateral flow during cross-clamping of the ICA may result in inadequate perfusion and intraoperative stroke. In these patients, restoration of cerebral perfusion is necessary to achieve a good neurological outcome. The insertion of a shunt can restore adequate cerebral perfusion but may make the procedure technically more demanding and also cause embolisation or endothelial damage. To select patients in need of a shunt, reliable neuromonitoring is desirable, especially if the surgery is performed under general anaesthesia. The cerebral haemodynamics differ significantly between patients undergoing CEA, partly due to coexisting extra- and intracranial artherosclerotic lesions and the capacity of the collateral vessels.6,7 With the aim of characterising carotid bifurcation haemodynamics and cerebral oxygenation during CEA, data from stump pressure measurement, transit time flowmetry and cerebral oximetry were analyzed.

Patients and Methods

Sixty-two consecutive patients (48 men, 14 women) between 48 and 84 years of age were prospectively included in the study. All patients had given informed consent to participate and the medical ethics committee for Uppsala University had approved the study (Uppsala 99080). All patients had stenotic ICA lesions of >70% as measured by duplex ultrasonography, with focal neurological symptoms attributed to the stenosed carotid artery. Six patients had amaurosis fugax, 37 TIA and 19 a minor stroke as indication for CEA.

All procedures were performed under general anaesthesia using intravenous vasodilators (nitroglycerin) or vasoconstrictors (phenylephrine) to maintain systolic blood pressure within 20% of baseline readings. All patients received aspirin 75 mg or clopidogrel 75 mg preoperatively and 5000 IU heparin i.v. before clamping. Dextran 70 (50 ml/h, 10 h) was started after arrival in recovery unit. The CEA was performed with...
Cerebral Oxygenation during Carotid Endarterectomy

standard surgical technique through a vertical skin incision, exposure of the common (CCA), external (ECA) and internal (ICA) carotid artery arteries followed by a longitudinal arteriotomy. A polyester patch (Fluoropassiv®, Sulzer Medica, UK) was used selectively.

Measurements

Arterial blood pressure was measured in the CCA using a 22G cannula connected to a calibrated pressure transducer before and after clamping of CCA and ECA (stump pressure). A Javid shunt was inserted if the (mean) stump pressure was less than 40 mmHg.

Volume blood flow was measured using a calibrated transit time ultrasonographic perivascular probe, positioned on the proximal part of the prepared CCA (minimising manipulation to the bulb). Probe size chosen accordingly to vessel diameter, most often a 8 mm device (CardioMed flowmeter CM1005, Medistim A/S, Oslo, Norway). Measurements were recorded, when signals readings were optimised as indicated by the flowmeter, separate on CCA, ICA and ECA. Flow was re-established up the ECA before the ICA. Following reperfusion, the probe was positioned at the same site and flow was separately measured in CCA, ECA and ICA, 5 and 10 min after declamping.

Two cerebral oximeters (model Invos 4100A, Somnatecs, MI, USA) were used for simultaneous bilateral rSO2 monitoring. Sensors from the dual-channel system were applied on the forehead bilaterally. The system monitored changes in cerebral saturation referred to as an rSO2 index, the absolute values being considered too relative within a given patient. The numerical rSO2 readings recorded at 1-min intervals were stored on computer discs. Percent change was calculated according to the formula:

\[
\text{%Change} = \frac{\text{mean } \text{rSO2 preclamp} - \text{min } \text{rSO2}}{\text{mean } \text{rSO2 preclamp}} \times 100
\]

Continuous measurements started at induction of anaesthesia and were performed until 12 h postoperatively. No surgical decisions were made based on results from oximetry readings.

All patients were submitted to a postoperative duplex investigation and examination by a neurologist at 30 days.

Statistics

The median and ranges are presented. Non-parametric rank tests were used to compare rSO2 and flow values before, during clamping and after reperfusion. All p-values were 2-sided and significance assessed at the 0.05-level. For correlation the Spearman Rank Correlation Coefficient was used. Statistical analyses were performed using commercial available statistical package (SPSS v 10.0 SPSS Inc, USA).

Results

The median duration of carotid clamping was 42 (32–57) minutes. Eight patients were operated upon using a Javid shunt (based on stump pressure < 40 mmHg). A patch was used for closure in 51 (82%) patients. Three revisions were performed based on intraoperative flow measurements, one in the ICA and two in the ECA. The ICA was stenosed at the distal endpoint, which was corrected by revising the patch. Separate clamping of the ECA and a transverse arteriotomy/endarterectomy corrected the lesions in the ECA.

Sixty-one patients left the hospital without any further neurological events. One patient (operated upon with a shunt) developed an intraoperative stroke; immediate reexploration did not reveal any technical defects. A postoperative CT scan demonstrated an ipsilateral ischemic lesion in the territory of the middle cerebral artery. Duplex follow up within 30 days revealed no major pathology of the ICA. Apart from the patient with the intraoperative stroke, no other patient (61/62) had any deterioration in neurological status at one month.

Table 1. Results of median flow (ml/min) before and after the CEA.

<table>
<thead>
<tr>
<th></th>
<th>CCA</th>
<th>ECA</th>
<th>ICA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before clamp</td>
<td>164 (102–412)</td>
<td>102 (38–190)</td>
<td>78 (39–222)</td>
</tr>
<tr>
<td>5 min after declamp</td>
<td>238 (141–460)</td>
<td>79 (55–116)</td>
<td>122 (90–194)</td>
</tr>
<tr>
<td>10 min after declamp</td>
<td>297 (174–430)*</td>
<td>81 (40–148)</td>
<td>162 (80–436)*</td>
</tr>
</tbody>
</table>

* p < 0.001–0.05.
observed repeatedly but not invariably. The method was technically feasible in all patients.

The results of changes in cerebral oxygenation during the CEA are summarized in Table 2. A significant decrease of rSO2 was seen at clamping in patients requiring shunt, i.e. those with stump pressure < 40 mmHg. After shunt placement the decrease of rSO2 was reversed. No significant changes in rSO2 were observed in the contralateral hemisphere in any group, regardless of contralateral occlusion or not. There were no technical problems or difficulties in registration of signals in any patient.

A significant finding in this study was higher ICA volume flow before clamping in patients with low stump pressure \( (r = -0.45, p = 0.03) \) and also in those developing decreased rSO2 during clamping \( (r = 0.41, p = 0.01) \) (Figs. 1 and 2). Patients with contralateral ICA occlusion had higher ipsilateral ICA flow before clamping \( (128 (82–222) \text{ ml/min}) \) versus those with an open contralateral ICA \( (74 (39–173) \text{ ml/min}) \) \( (p = 0.04) \). The correlation between low stump-pressure and decrease in SO2 during clamping was also significant \( (r = -0.61, p = 0.002) \) (Fig. 3), and was reversed by insertion of a shunt.

Table 2. Results of cerebral oximetry (rSO2) during CEA. Correlation between decreases in rSO2 and need for shunt (stump pressure < 40 mmHg). Reversed by shunt placement

<table>
<thead>
<tr>
<th></th>
<th>Preclamp</th>
<th>Clamp</th>
<th>5 min after declamp</th>
<th>10 min after declamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>No shunt</td>
<td>63 (59–65)</td>
<td>62 (57–67)</td>
<td>66 (63–73)</td>
<td>65 (63–71)</td>
</tr>
<tr>
<td>Shunt</td>
<td>65 (62–71)</td>
<td>49 (42–54)*</td>
<td>61 (57–70)</td>
<td>62 (61–70)</td>
</tr>
<tr>
<td>After shunt</td>
<td>58 (57–61)*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\* \( p < 0.01 \).

Discussion

The combination of intraoperative measurements of stump pressure, volume flow and cerebral oximetry during CEA seem useful methods to decide on shunt use and to help in the quality assessment after CEA. Intraoperative stroke has been reported to account for 15–20% of the perioperative strokes, due to hypoperfusion during cross-clamping or thromboembolism.\(^8,^9\) The risk of cerebral ischemia when occluding the ICA is dependent on the cerebral collateral flow and several methods having been described to evaluate and monitor this risk both before and during the surgery.\(^10–12\) It is important to detect not only the effects of cross-clamping but also the quality of the surgery, as technical imperfection can cause flow disturbances and/or thromboembolism.\(^8,^9,^{13}\)

The practice of intraoperative cerebral monitoring varies between surgeons and institutions depending on local tradition, surgeons’ preferences, technical resources, economy and the fact that no single method is superior in all aspects.\(^14\) Neurormonitoring techniques differ in their possibility to detect cerebral ischemia, need for expert interpretation and availability. Transcranial Doppler (TCD), somatosensory

Fig. 1. Correlation between stump pressure and ICA flow before clamping. Spearmans’ corr \( r = -0.45, p = 0.03 \).

Fig. 2. Correlation between ICA flow before clamping and changes in cerebral oxygenation at clamping. Spearmans’ corr \( r = 0.41, p = 0.01 \).

Eur J Vasc Endovasc Surg Vol 27, April 2004
evoked potentials (SEP) and electroencephalography (EEG) are well established forms of monitoring but they all have some disadvantages regarding accessibility and/or interpretation. Measurement of carotid artery stump pressure has been used for a long time. It is technically simple but the threshold values that predict the risk of cerebral hypoperfusion are ill defined and the specificity is low.

Intraoperative flow measurements using transit time flowmetry are documented for lower extremity vascular surgery. Experimental data on accuracy is also reported. However, its application during CEA has not been fully investigated, Gordon et al. reported a series characterising flow differences before and after the endarterectomy. The method gives both quantitative volume flow measurements and morphological differences in the flow waveform of the CCA, ECA and ICA.

Cerebral oximetry with near-infrared spectroscopy (NIRS) allows for continuous monitoring of changes in cerebral oxygenation (rSO2) through adhesive sensors on the patients’ forehead. Extracranial contamination may influence the readings but with focus on changes in oxygenation and by using dual detector system and sequential clamping this risk may be reduced.

By combining these techniques, we found interesting correlations supporting the indication for a shunt. A high ICA flow before clamping, in combination with a low stump pressure, strongly suggested the need for intraoperative shunt placement. These methods could also be useful in the intraoperative quality assessment of the CEA. If the ICA flow is lower after than before the CEA or is markedly decreasing during reperfusion, especially in combination with a high resistance waveform (e.g. low diastolic component), this could indicate technical errors. This was also supported by the duplex follow up where no major pathology of the ICA was found. The external carotid artery (ECA) sometimes occludes following CEA due to an inadequate endarterectomy of the ECA origin. Some feel that the ECA is an important collateral and should be preserved if possible. Poor flow up the ECA is easily detected with flowmetry, and can often be resolved by a thrombectomy/revision through a localised transverse arteriotomy in the ECA.

In conclusion; intraoperative transit time flow measurement (in combination with stump pressure) and cerebral oximetry are technically easy and may be useful methods in determining the need for selective shunting. Volume flow measurements may also be useful in the quality assessment of the CEA.

Acknowledgements

This study was supported by: Swedish Stroke Association, Gorhon Foundation, Torsspirans Foundation, Swedish Research Council.

References

1 European Carotid Surgery Trialists’ Group, MRC European Carotid Surgery Trial: interim results for symptomatic patients with severe (70–99%) or with mild (0–29%) carotid stenosis. Lancet 1991; 337:1235–1243.

Accepted 20 January 2004