Changes in Internal Carotid Blood Flow after CEA Evaluated by Transit-time Flowmeter

M. Aleksic,* V. Matoussevitch, J. Heckenkamp and J. Brunkwall

Division of Vascular Surgery, Department of Visceral- and Vascular Surgery, University of Cologne, Cologne, Germany

Aim. The aim of this study was to investigate whether there was an association between the degree of the stenosis of the internal carotid artery (ICA) and post-operative increase of blood flow.

Methods and materials. In 200 out of 660 patients undergoing carotid endarterectomy (CEA) for a high-degree ICA stenosis, pre-operatively a bilateral selective carotid and intracerebral angiography was performed. The degree of the ipsilateral and contralateral stenosis was digitally assessed by using computer software according to the CC-Index. Intraoperatively, the pressure ratio over the stenosis (ICA/CCA) was measured by direct arterial puncture. Blood flow in the ICA was measured before and after CEA with an ultrasound flowmeter using the transit-time principle. These findings were correlated to the degree of stenosis revealed by angiographic analysis and the pressure ratio.

Results. Before CEA the median blood flow in the ICA was 171 ml/min (range 620 ml/min) with a significant (p < 0.001) post-operative increase to 250 ml/min (range 875 ml/min). The median relative increase of flow (post-flow–pre-flow/pre-flow) was 42%. The pre-CEA flow volumes were dependent on the degree of stenosis and also the pressure ratio. The increase of flow following CEA correlated better with pressure ratio (r = −0.435, p < 0.001), than the stenosis severity (r = 0.319, p < 0.001). Analysis of variance identified only the pressure gradient as an independent determinant of flow changes following CEA.

Conclusions. The blood flow increase following CEA is mainly determined by the pressure gradient across the stenosis.

Keywords: Carotid surgery; Flow changes; Transit-time flowmeter.

Introduction

The primary goal of carotid endarterectomy (CEA) is the removal of the atheromatous plaque to eliminate the source of future cerebral emboli. Additionally, cerebral perfusion will increase which could adversely lead to neurological complications like severe headache, seizures or even intracerebral hemorrhage.1 Cerebral hyperperfusion syndrome (CHS) accounts for up to 35% of all perioperative neurological events,2 and is believed to be due to impairment of the cerebral vessel autoregulation with maximal vasodilatation in the chronically underperfused brain tissue.3–5 The aim of the present study was to correlate the increase of ICA flow measured by a transit-time flowmeter to the degree of the ICA stenosis which was assessed by digital angiography.

Materials and Methods

From January 2000 to December 2004, a total number of 660 patients underwent CEA. In 200 patients (145 males, 55 females, median age 70 years ranging from 45 to 88 years), which represent the study group, pre-operatively a bilateral selective carotid and intracerebral angiography was performed with biplanar projections (oblique and a.p.). The indication for intraarterial angiography was multivessel disease or if an ICA occlusion or tandem stenosis were suspected. The grade of the ipsilateral and contralateral ICA stenosis was assessed according to the CC-index (Fig. 1) in the plane showing the tightest stenosis. For digital processing and magnification a commercial graphical software (Adobe Photoshop®) was used. Depending on the degree of the ICA stenosis the patients were divided into groups with less than 70% (n = 31), 70–79% (n = 44), 80–89% (n = 84) and more than 90% stenosis (n = 41). In 25 patients, angiography showed a contralateral ICA occlusion.

*Corresponding author. Marko Aleksic, MD, Division of Vascular Surgery, Department of Visceral- and Vascular Surgery, University of Cologne, Kerpener Str. 62, 50937 Cologne, Germany. E-mail address: marko.aleksic@uk-koeln.de
Some 152 of the patients were asymptomatic whereas 32 had experienced transient ischemic attacks. Sixteen patients had a history of stroke. The majority of patients (195/200) underwent CEA under local anaesthesia, where an intraluminal shunt was inserted only if hemispheric deficits or unconsciousness occurred on test clamping ($n \geq 40$). The remaining five patients had surgery under general anaesthesia and routine shunt placement because clinical neuro-monitoring was not possible after a major stroke with either hemiplegia or aphasia.

After exposition of the common (CCA), internal (ICA) and external carotid artery (ECA) an 8 mm ultrasound perivascular flowmeter probe (Medi-Stim AS, Oslo, Norway) was attached to the CCA. The flow in the ICA was recorded by clamping the ECA. The pressure ratio over the stenosis (ICA/CCA) was determined by direct puncture of the CCA proximal and ICA distal to the stenosis using a 22 G cannula, which was connected to a calibrated pressure transducer system. After systemic administration of 5000 IU of heparin and a standard endarterectomy followed by repair with a Dacron patch (190/200) or eversion endarterectomy (10/200) were performed depending on the anatomical situation. Following reperfusion, flow measurement was repeated. The relative increase in flow was calculated as the difference between post- and pre-operative flow divided by pre-operative flow.

The data was analyzed using SPSS statistical package. Continuous data (age, CC-index, flow values, pressure ratio) are presented as median and range. Wilcoxon-test for non-parametric, paired variables was used to compare pre- and post-operative blood flow. Kruskal–Wallis test and Mann–Whitney-U test for non-parametric unpaired variables were applied comparing flow changes within subgroups. Spearman’s correlation test and analysis of variance (ANOVA) were employed to determine the relation between the different variables. Differences were considered significant at a level of $p < 0.05$.

**Results**

In total, five patients suffered from a perioperative stroke of which three were due to an intracerebral hemorrhage accounting for a CHS rate of 1.5%. One patient developed a new neurological deficit during ICA clamping despite shunt insertion. In one patient with a factor-V mutation (Leiden) a post-operative ICA thrombosis and cerebral infarction occurred. Median ICA stenosis was 83% (with a range of 82%). The median pressure ratio was 0.89 varying from 0.16 to 1.0. In 102 patients, the pressure ratio was less than 0.9 whereas only 36 had a pressure ratio less than 0.7. Flow volume in the ICA before and after endarterectomy is shown in Table 1. Initial flow differed significantly according to the degree of stenosis as classified by the angiographic measurement ($p < 0.001$) with post-hoc identification of $\geq 90\%$ as a decisive category. A pressure ratio $< 0.7$ or 0.9 ($p < 0.001$ and $p = 0.011$) and a contralateral ICA occlusion ($p = 0.002$) were associated with a significantly reduced flow. There was a significant ($p < 0.001$) increase in blood flow in the ICA after endarterectomy (Table 1). The increase in flow differed in the various subgroups with highest changes demonstrated for subtotal stenosis ($p < 0.001$) and pressure ratio $< 0.7$ or 0.9 (both $p < 0.001$). Increase in flow was not different in patients with occluded or patent contralateral ICA ($p = 0.475$). The correlation between flow increase after CEA and the pressure ratio ($r = -0.435, p < 0.001$) was stronger than for the angiographic degree of stenosis ($r = 0.319, p < 0.001$) (Figs. 2 and 3).

The three investigated parameters (degree of stenosis, pressure ratio, contralateral ICA patency) were entered into an analysis of variance (ANOVA),

---

**Fig. 1.** Angiographic example and definition of stenosis measurement.
which revealed that increase in flow was independently related only to the pressure ratio \( p < 0.001 \) (Table 2).

### Discussion

Carotid endarterectomy is accompanied by changes of cerebral perfusion which might have catastrophic consequences when CHS occurs. This study demonstrates that the ICA blood flow depends on the degree of stenosis if angiographic categories \(( \geq 90\% )\) or the pressure ratio are used as discriminating factors. With a pressure ratio less than 0.9 the ICA flow is reduced from 193 to 150 ml/min and it drops even more from 180 to 95 ml/min with a cut-off at 0.7. ICA blood flow increases significantly in the presence of a contralateral carotid occlusion.

Following CEA the increase in ICA blood flow is related to the degree of the removed stenosis. Although group comparison showed that patients with a subtotal \(( \geq 90\% )\) stenosis had the highest increase in flow in this study, those differences were not pronounced enough to confirm the categories of stenosis as an independent factor for flow increase. This finding is contrary to those of other studies which for example state that there is a disproportional increase even in stenosis \( \geq 60\% \). This disparity may relate to differences in stenosis measurement in these studies. A number of different methods of quantifying

### Table 1. ICA flow given as median and range = max. – min. value (in brackets) depending on degree of stenosis (CC-index), pressure ratio and contralateral ICA patency

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Flow before CEA in ml/min</th>
<th>Flow after CEA in ml/min</th>
<th>Flow change in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>200</td>
<td>171 (620)</td>
<td>250 (875)</td>
<td>42 (10700)</td>
</tr>
<tr>
<td>CC-index</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;70%</td>
<td>31</td>
<td>220 (447)</td>
<td>240 (860)</td>
<td>30 (173)</td>
</tr>
<tr>
<td>70–79%</td>
<td>44</td>
<td>213 (380)</td>
<td>255 (391)</td>
<td>29 (219)</td>
</tr>
<tr>
<td>80–89%</td>
<td>41</td>
<td>168 (620)</td>
<td>248 (825)</td>
<td>40 (6650)</td>
</tr>
<tr>
<td>( \geq 90% )</td>
<td>84</td>
<td>109 (429)</td>
<td>237 (300)</td>
<td>100 (10698)</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.7</td>
<td>36</td>
<td>95 (379)</td>
<td>277 (425)</td>
<td>122 (6650)</td>
</tr>
<tr>
<td>( \geq 0.7 )</td>
<td>164</td>
<td>180 (619)</td>
<td>240 (860)</td>
<td>31 (10700)</td>
</tr>
<tr>
<td>&lt;0.9</td>
<td>102</td>
<td>150 (476)</td>
<td>269 (875)</td>
<td>60 (6650)</td>
</tr>
<tr>
<td>( \geq 0.9 )</td>
<td>98</td>
<td>193 (619)</td>
<td>240 (810)</td>
<td>28 (10700)</td>
</tr>
<tr>
<td>Contralat. ICA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occluded</td>
<td>25</td>
<td>230 (530)</td>
<td>316 (837)</td>
<td>42 (10700)</td>
</tr>
<tr>
<td>Patent</td>
<td>175</td>
<td>168 (460)</td>
<td>240 (525)</td>
<td>30 (332)</td>
</tr>
</tbody>
</table>

![Fig. 2](image1.png) ![Fig. 3](image2.png)

**Fig. 2.** Correlation of flow increase and degree of stenosis (CC) by scattered plot.

**Fig. 3.** Correlation of flow increase and pressure ratio by scattered plot.
carotid stenosis on angiography are available. We employed the CC method since previous studies suggest this is the most reproducible technique.\(^7\)

In contrast to the degree of stenosis, the pressure ratio showed a statistically stronger association to flow changes and was demonstrated to be an independent determinant of flow increase after CEA. In this study, a pressure gradient <0.7 predicted marked post-operative cerebral hyperperfusion. ICA flow after CEA increased more than twice in patients with a pressure ratio less than 0.7. The principle advantage of pressure gradient compared to the degree of stenosis is that it provides a complete assessment of the cerebral perfusion including the impact of the circle of Willis and the contralateral ICA.

When evaluating flow changes in the ICA following CEA, the contribution of ECA flow which increases with severe carotid stenosis\(^8\) is important. The different resistance of the distal vascular bed of the carotid branches has to be considered. After removal of an ICA stenosis flow will follow least resistance, which might result in the observed redistribution of blood flow into the ICA.\(^9\) The standard CEA and patch repair do not allow a controlled desobliteration of the ECA. Such effects can be assessed only by simultaneous flow measurement of the carotid vessels before and after CEA, which has not been performed consistently in previous studies.\(^10\) We attached the flowmeter probes to the CCA before carotid clamping in order to prevent manipulation of the plaque and the ICA. In summary, ICA flow before CEA is influenced by the degree of stenosis and by the patency of the contralateral ICA. Blood flow increase after CEA is significantly associated with the underlying pressure ratio across the stenosis. It is beyond the scope of this study to define factors which might predict the development of CHS.

### Table 2. ANOVA for flow increase as the dependent variable

<table>
<thead>
<tr>
<th>Factor</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC-index</td>
<td>1.0</td>
<td>0.319</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td>25.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Contralateral ICA patency</td>
<td>1.7</td>
<td>0.195</td>
</tr>
</tbody>
</table>

---

**References**


Accepted 31 August 2005
Available online 20 October 2005

---

**Carotid Blood Flow Changes After CEA**

---

**Eur J Vasc Endovasc Surg Vol 31, 1 2006**