CBF Before and After Extracranial-Intracranial Bypass Surgery in Patients with Ischemic Cerebrovascular Disease Studied with $^{133}$Xe-Inhalation Tomography

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SUMMARY  Cerebral blood flow (CBF) was studied by $^{133}$Xenon inhalation tomography in 22 patients with symptoms of ischemic cerebrovascular disease before and after establishment of an extracranial-intracranial bypass shunt. Selection of patients for shunting was based on angiographically demonstrated arterial occlusions and on the finding of focal low flow areas corresponding to the clinical symptoms, that consisted mainly of minor stroke with good remission and with or without subsequent TIAs. It was required that the area of low flow should clearly exceed the CT lesion present in practically all cases.

Following surgery, the permanent neurologic deficits remained unchanged, while the TIAs stopped in all but one case. Two patients showed a definite increase of CBF in the low flow area while another two showed a questionable increase. All the other cases, 18 of the 22, showed an unchanged tomographic flow map with no trend towards diminution in extension or severity of the focal hypoperfused area. A persistent low flow in areas with no corresponding CT lesion following alleviation of a possible flow impediment is interpreted to represent an incomplete infarction or diaschisis.

MEASUREMENTS OF CEREBRAL BLOOD FLOW (CBF) have become an integrated part of the preoperative evaluation program when extracranial-intracranial bypass (EC-IC) surgery is considered in patients with cerebrovascular disease. Studies using the intracarotid technique, and the intravenous $^{133}$Xenon technique have suggested that patients with a focal decrease of CBF and with a normal or only moderately reduced overall level of CBF might in particular benefit. As a focal CBF decrease in chronic cerebrovascular disease may reflect a lowered metabolic demand of infarcted tissue, some authors have pointed out that preoperative measurements in addition to rest CF measurements should include regional estimates of the cerebral vasoreactivity, cerebral metabolic rate, or cerebral blood volume. The results of these studies indicated that it may be possible to identify the subset of patients with a compromised collateral circulation.

Single photon emission computer tomography (SPECT) of inhaled $^{133}$Xenon affords an atraumatic, rapid, and easily repeatable method for analysis of regional CBF. By its 3-dimensional approach, this technique is particularly well suited for the detection of low flow areas, and allows for a direct comparison with structural changes seen on CT scan. The present report deals with the findings in a consecutive series of patients who were finally selected for shunt surgery on basis of the finding of hypoperfused areas exceeding in size a focal CT lesion of complete infarction. In most patients, several CBF measurements were performed before and after shunting.

Methods
Clinical Material
The material comprises 6 women and 16 men with an age range from 27 to 66 years (mean 50 years). Five
had mild or moderate arterial hypertension, well controlled by appropriate therapy. None had heart disease or diabetes mellitus. Most patients received antiplatelet drugs and 9 were on anticoagulant therapy.

The patients were selected according to the clinical and angiographical criteria applied in the ongoing collaborative study on EC-IC anastomosis. The clinical symptoms from the relevant hemisphere are presented in table 1. Three patients had only experienced TIAs from the relevant hemisphere. Of 15 patients who had suffered a minor stroke 7 had subsequent relevant TIAs. Of 4 patients with sequels after severe strokes, one had subsequent relevant TIAs.

Based on analysis of the clinical symptoms and symptom-provoking factors, the TIAs were classified as being either of hemodynamic or embolic origin. A hemodynamic pathogenesis was assumed, when postural changes provoked shortlasting symptoms. In all other cases distal embolism causing transient focal ischemia was considered the pathogenetic mechanism. Of the 11 cases suffering TIAs only one met the criteria of a hemodynamic pathogenesis. This patient (case LW) noted, some months after a minor stroke, almost daily attacks of difficulty of speech and weakness of her right arm in relation to postural changes, in particular during the morning hours, symptoms that promptly disappeared after shunting.

The angiographical findings indicating lesions possibly amendable by an EC-IC bypass were in 18 cases occlusion of one internal carotid artery and in 4 cases severe stenosis or occlusion of the middle cerebral artery or its major branches. Final selection for surgery was based on the results of CT scan and CBF measurements. The criteria were the findings of an asymmetrical flow pattern with a focal hyperperfused area on the tomographic flow map in agreement with the clinical and angiographical findings. Also it was required that the size of the focal lesion seen on CT scan. As the slices of the 2 CT-scanners used (EMI 1010 and Siemens Somatom, DR) were 1.0 cm and 0.8 cm, respectively, both the slice corresponding to the OM = 5 cm or OM = 9 cm and the slices sandwiching this level were used for measurement of the full extent of the CT lesion. Then delineation was done of low flow areas where no focal CT lesions were seen, in most cases at the OM plane without CT lesions. Calculation of flow in these areas, in the following referred to as the region of interest (ROI), was then performed. The CBF values from that region and the symmetrical contralateral region were obtained in all successive CBF measurements. Calculation of the degree of side-to-side asymmetry was performed by taking the difference of flow in the ROI and the symmetrical region as a per cent of the value of the symmetrical region (the highest value), i.e. in per cent of the flow in the presumed healthy side.

For comparison with the patients in the present study mean cerebral and regional flow values were obtained from a normal material of 10 persons (hospital staff...
mean age 43 years, 52, 53) all studied three times with an interval of one week between studies. Average hemispheric CBF in this series as calculated from slice 2 was $55 \pm 100/100$ min. The standard deviation of changes in mean flow between the repeated measurements in a given subject averaged $3 ml/lOOg/min. The "ROIs" in these 10 normal cases were chosen from slice 2 and represented areas of arterial supply, i.e. territory of the anterior cerebral artery, middle cerebral artery (further subdivided in a cortical and subcortical region), and posterior cerebral artery. 14, 15 The mean value of the left to right side difference in per cent of highest side ranged from $-0.9\% \pm 2.8\%$ (1SD) (subcortical region of middle cerebral artery territory) to $2.1\% \pm 3.2\%$ (1SD) (posterior cerebral artery territory). The size of these areas ranged from 14.2 cm$^2$ to 25.7 cm$^2$.

In order to assess the variances of repeated measurements of the side-to-side asymmetry in the normal material, individual variances were calculated for each ROI again expressing the side-to-side difference in per cent of the flow of the side with highest flow. This yielded mean $S^2$ values for these regions in the 10 normal cases ranging from 4.78 (anterior cerebral artery) to 9.83 (posterior cerebral artery) with a mean value of 7.72. Calculating in the same way the $S^2$ for the ROI as defined for the patients from all the patients with at least 2 resting preoperative CBF measurements yielded a mean $S^2 = 13.49$ (n = 15). The higher variance in the patient material may reflect a truly higher day-to-day variation of regional CBF, but it should be noted that a somewhat smaller ROI was used in most patients.

The effect of EC-IC on the side-to-side asymmetry was estimated by testing for the difference between two means. 16 The average value of the side-to-side asymmetries in the ROI was calculated from all pre- and all late postoperative measurements, and the difference between these values in the individual patient, $\Delta D$, was used in the formula:

$$t = \frac{\Delta D}{\sqrt{\frac{1}{n_{pre}} S^2 + \frac{1}{n_{post}} S^2}}$$

The denominator in this formula is an estimate of the standard deviation of the mean values obtained pre- and postoperatively, where $S^2 = 13.49$ and $n_{pre}$ and $n_{post}$ are the numbers of the pre- and postoperative measurements in the individual patient. The number of degrees of freedom was 14 (15 patients used to deter-
mine \( S^2 \), yielding a \( t \)-value of 2.15 when requiring a statistical significance at \( p < 0.05 \).

The statistical analysis of postoperative flow changes was finally compared to a classification according to the visual impression obtained by repeated readings of the flow map. When a definite and constant improvement was found by visual evaluation, this was associated with focal improvement according to statistical significance at \( p < 0.05 \). Such cases are classified as improved. When repeated readings gave the visual impression of some degree of improved flow distribution, these findings coincided with a calculated \( p \)-value between 0.05 and 0.10. Such cases are classified as questionable improvement. In cases, where the calculations indicated an unchanged focal CBF visual inspection never yielded any doubt as to the unchanged flow distribution map.

Corrections for CO\(_2\) changes were not applied in the present study.

**Clinical Results**

**Neurological Changes Following Surgery**

In none of the patients with permanent neurological deficits any clear-cut improvement was noted in direct relation to the surgical procedure — neither by the patient, nor by neurological examination. At the later clinical evaluation, only one patient, case JJ, seen 4 weeks after a left EC-IC showed some improvement. As shunting in this case was performed 8 weeks following a stroke after which improvement had been in progress preoperatively, the changes following shunting were interpreted as further spontaneous recovery (CBF map unchanged postoperatively). At the 3 months follow-up 5 patients reported improvement of intellectual function, viz. concentration, memorization, and less fatigueability. The two patients, described in detail later, who showed a postoperative improvement in CBF belonged to this group.

**Operative Complications and Graft Patency**

In the immediate postoperative period, one patient (case IL) suffered aggravation of her aphasia for some hours (see later for details). One additional patient (case AWP) suffered complications attributable to the shunt operation. Two months following surgery the patient noted weakness and dyscoordination of the right leg, and a CT scan showed a subdural hematoma localized around the craniotomy. Following evacuation the clinical symptoms subsided completely. CBF measurement one month later was unchanged compared to the preoperative findings. The angiogram showed a well-functioning shunt.

A total of 24 anastomoses were performed, two patients being operated bilaterally. Eleven patients un-

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**Table 1 (Continued)**

<table>
<thead>
<tr>
<th>Age/sex</th>
<th>Clinical symptoms/ side of operation</th>
<th>CT scan</th>
<th>Angiography</th>
<th>CBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 VEJ</td>
<td>Severe stroke from right hemisphere. Right side</td>
<td>Infarct in the right temporo-parietal region</td>
<td>Right ICA occluded</td>
<td>↓ in right MCA</td>
</tr>
<tr>
<td>13 SGS</td>
<td>Minor stroke and TIAs from right hemisphere. Right side</td>
<td>Small deep infarct in right frontal lobe</td>
<td>Severe stenosis of right MCA</td>
<td>↓ in right ACA &amp; MCA</td>
</tr>
<tr>
<td>14 JM</td>
<td>Minor stroke and TIAs from left hemisphere. Left side</td>
<td>Infarct in left temporal lobe</td>
<td>Left ICA occluded</td>
<td>↓ in left anterior MCA</td>
</tr>
<tr>
<td>15 RW</td>
<td>Minor stroke from left hemisphere. Left side</td>
<td>Small infarct in left temporo-parietal region</td>
<td>Left ICA occluded &amp; stenosis of left MCA</td>
<td>↓ in left posterior MCA and watershed area</td>
</tr>
<tr>
<td>16 TM</td>
<td>Minor stroke from left hemisphere. Left side</td>
<td>Small infarct in left occipital and temporal lobe. DCA</td>
<td>Left ICA occluded</td>
<td>↓ in left posterior MCA and watershed area</td>
</tr>
<tr>
<td>17 AWP</td>
<td>Minor stroke and TIAs from left hemisphere. Left side</td>
<td>Small, deep infarcts in left and right hemisphere. DCA</td>
<td>Severe stenosis of left MCA</td>
<td>↓ in left MCA &amp; ACA</td>
</tr>
<tr>
<td>18 OO</td>
<td>Minor strokes (2) from left hemisphere. Left side</td>
<td>Small infarcts in left frontal and temporal lobes</td>
<td>Stenosis of the left fronto-parietal branches</td>
<td>↓ in left MCA</td>
</tr>
<tr>
<td>19 PN</td>
<td>Minor strokes (2) and TIAs from left hemisphere. Left side</td>
<td>Small infarct in left parietal lobe</td>
<td>Left ICA occluded</td>
<td>↓ in left MCA</td>
</tr>
<tr>
<td>20 KKH</td>
<td>Minor strokes and TIAs from left hemisphere. Left side</td>
<td>Infarct in left temporal lobe. DCA</td>
<td>Left ICA occluded</td>
<td>↓ in left MCA &amp; ACA</td>
</tr>
<tr>
<td>21 KBT</td>
<td>Severe stroke from left hemisphere. Left side</td>
<td>Large infarct in left temporal region. DCA</td>
<td>Left ICA occluded</td>
<td>↓ in left MCA</td>
</tr>
<tr>
<td>22 JJ</td>
<td>Severe stroke from left hemisphere. Left side</td>
<td>Infarct in left temporal lobe</td>
<td>Left MCA occluded</td>
<td>↓ in left ACA &amp; MCA</td>
</tr>
</tbody>
</table>
derwent postoperative angiography at the 3 months follow-up, confirming patency in all cases, but in two patients a narrow shunt lumen and poor contribution to the filling of the brain arteries was noted. In the remaining patients patency was assessed and confirmed by the palpation of a pulsating vessel at the border of the craniotomy. The neurosurgeon operating all patients in the present series has previously reported a patent rate of 95%. Antiplatelet and anticoagulant therapy was left unchanged postoperatively.

Recurrence of Ischemic Symptoms

In the observation period of 3 to 27 months (mean 12 months), only one patient suffered recurrence of symptoms of cerebral ischemia: Case BSP suffered two, presumably embolic, TIAs from the hemisphere of interest. In this patient the CBF measurement at the 3-months follow-up showed a focal improvement in CBF, and angiography showed a patent and well-functioning shunt.

CBF Results Early After Shunting

Fourteen patients were studied in the early postoperative period, 4 to 12 days (average 8 days) after surgery. Of the two patients who showed an increased CBF after 3 months only one showed a diminished side-to-side asymmetry at the early postoperative measurement after 8 days, and further improvement was seen at the 3 months follow-up. In the remaining 12 patients, the early postoperative CBF maps were essentially as the 3 months follow-up studies. No evident hyperemias or new ischemias were observed on the early pictures.

CBF Results Later After Shunting

In table 2, the time course of side-to-side asymmetry in the ROI is presented, and table 3 shows the averaged CBF value in the ROI for all pre- and postoperative studies. Based on the statistical analysis of changes in side-to-side asymmetry in the ROI, i.e. on the ΔD values, and on visual inspection, the patients were grouped in 3 categories according to the changes following surgery: Improved,questionably improved, and not improved.

Patients with improved regional CBF (2)

Two patients (cases 1 and 2) showed a significantly diminished side-to-side asymmetry, as evaluated from both statistical analysis and visual inspection.

Case BSP

This 35-year-old woman had suffered a severe stroke with left-sided hemiparesis. Two years later, the patient had several TIAs with pins and needles of the right side of her face and right arm, and two episodes of minutes lasting right-sided hemiparesis. Angiography showed normal neck vessels but bilateral occlusions of the anterior and middle cerebral arteries. CT scan showed a large infarct in the right parieto-occipital region but no lesion in the left hemisphere (fig. 1c). The CBF map (fig. 1a) showed low flow in the territories of both the anterior and the left middle cerebral arteries. In addition, low flow was seen corresponding to the infarcted area on the CT scan. Two months after a left-sided EC-IC bypass, she suffered two short lasting presumably embolic TIAs with rightsided paresthesias. However, a marked improvement in CBF was noted in the focal low-flow area in the left hemisphere one month later. A flow increase was also seen in the frontal region of the contralateral hemisphere (fig. 1b). This was the only patient, who postoperatively showed a normal flow map in the hemisphere shunted.

Case LW

This 55-year-old woman had suffered a minor stroke with a right-sided slight hemiparesis combined with slight aphasia, from which she practically recovered. Six months later she noted almost daily attacks of weakness of her right arm and of aphasia lasting for a few minutes. The symptoms occurred in particular during the morning in relation to postural changes. Angiography showed an occluded left internal carotid artery and a moderate stenosis of the right internal carotid artery (3 mm in diameter at the narrowest point). CT scan showed a small deepseated infarct in the left hemisphere (fig. 2c). The CBF map showed low flow in the regions of both anterior cerebral arteries, and in the territory of the left middle cerebral artery shunted.
Table 3  For Each Patient, the Average Value of CBF in the ROI for all Pre- and Postoperative CBF Measurements are Shown, both in Absolute Values (ml/100 g/min) and as Degree of Side-to-side Asymmetry.

<table>
<thead>
<tr>
<th>Patient</th>
<th>CBF Pre</th>
<th>CBF Post</th>
<th>% asymmetry Pre</th>
<th>% asymmetry Post</th>
<th>Δ</th>
<th>FeCO₂ Pre</th>
<th>FeCO₂ Post</th>
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<tbody>
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<td>BSP</td>
<td>40</td>
<td>53</td>
<td>30</td>
<td>17</td>
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<tr>
<td>LW</td>
<td>43</td>
<td>55</td>
<td>31</td>
<td>17</td>
<td>14</td>
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<td>31</td>
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<tr>
<td>CR</td>
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<td>52</td>
<td>15</td>
<td>8</td>
<td>7</td>
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<td>23</td>
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<tr>
<td>NS</td>
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<td>45</td>
<td>16</td>
<td>8</td>
<td>8</td>
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<tr>
<td>IL</td>
<td>56</td>
<td>60</td>
<td>14</td>
<td>18</td>
<td>-4</td>
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<td>35</td>
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<tr>
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<td>14</td>
<td>19</td>
<td>5</td>
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<td>32</td>
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<tr>
<td>BM</td>
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<td>21</td>
<td>16</td>
<td>5</td>
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<td>16</td>
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<tr>
<td>SGS</td>
<td>51</td>
<td>51</td>
<td>11</td>
<td>9</td>
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<td>34</td>
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<td>36</td>
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<tr>
<td>TM</td>
<td>45</td>
<td>38</td>
<td>20</td>
<td>22</td>
<td>-2</td>
<td>37</td>
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</tr>
<tr>
<td>AWP</td>
<td>44</td>
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<td>13</td>
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<td>-1</td>
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<td>13</td>
<td>15</td>
<td>-2</td>
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<td>34</td>
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<tr>
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<td>24</td>
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</tr>
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<td>JJ</td>
<td>34</td>
<td>35</td>
<td>28</td>
<td>26</td>
<td>2</td>
<td>39</td>
<td>37</td>
</tr>
</tbody>
</table>

ΔD denotes the improvement in asymmetry. End-expiratory CO₂ (FeCO₂) is also indicated. In patients with 2 preoperative and 2 postoperative CBF measurements, a change in ΔD of 7.9 or 6.5 is needed to reach statistical significant values of $p < 0.05$ and $p < 0.10$, respectively. The corresponding values for patients with 2 preoperative and 1 postoperative CBF measurement are 9.7 and 7.9, respectively.

artery (fig. 2a). On the assumption that the stenosing lesion of the contralateral internal carotid artery might have a hemodynamic significance, a right-sided carotid endarterectomy was first performed. However, the clinical symptoms (TIA) did not subside, and CBF measurement 2½ months later was unchanged. A left EC-IC bypass was then performed after which the patient was free of TIA.

CBF measurements 3 and 6 months after the bypass showed an improvement of CBF in the territories of the left anterior and middle cerebral arteries. This patient also showed an improvement in the frontal lobe of the right hemisphere, viz. on the side contralateral to the shunt (fig. 2b).

**Patients with questionable improvement in regional CBF (2 cases)**

Two patients (cases CR and NS) were included in this group. Both the statistical analysis and repeated visual inspections of the flow map indicated a minor increase of CBF in the ROI following the surgical procedure.

Patients with no improvement in regional CBF at rest (18 cases)

After surgery 18 patients showed a completely unchanged flow map at rest, as judged both from calculations of changes in side-to-side asymmetry and from visual inspection.

**Case IS**

This 55-year-old man suffered a moderate stroke with almost complete remission over 3 days. Angiography showed occlusion of the right internal carotid artery as well as of the right vertebral artery. CT scan showed a deepseated subcortical infarct in the right hemisphere (fig. 3c). CBF measurement showed a low flow in the region of the right middle cerebral artery in both slice 2 and 3 (fig. 3a), clearly exceeding in size the hypodense area on the CT scan. Three months following a right-sided EC-IC bypass, angiography showed a well-functioning anastomosis. However, the CBF study showed no changes in the flow distribution, i.e. the degree of side-to-side asymmetry persisted unchanged (fig. 3b), and the focal low flow areas persisted in the CT negative regions.

**Discussion**

In the present study, patients with ischemic cerebrovascular diseases were primarily considered for EC-IC bypass surgery on the clinical and angiographical criteria now generally agreed on for this surgical procedure, i.e. minor stroke and/or TIAs combined with severely obstructive lesions of the cerebral arteries inaccessible to neck vessel surgery. In such patients, measurements of CBF and CT scans were undertaken, and the finding of focal low-flow, CT negative areas were used as final criterion for selection of candidates. To our surprise, 18 of the 22 patients showed a completely unchanged tomographic picture with persistent low flow in the shunted area. Shunt patency was verified by angiography in about half of these cases and could be surmised in the remainder.

This finding of a persisting hypoperfusion in areas without a CT lesion may either indicate a state of neuronal inactivity "diaschisis" or an ischemic tissue lesion "incomplete infarction", also called "diffuse selective neuronal cell loss". The neuropathology underlying the phenomenon of diaschisis has not yet been clarified, but it has been suggested, that diaschisis may result from deactivation due to interruption of activating afferent pathways. Diaschisis has been described in patients with ischemic cerebral infarction, where a reduction in CBF was observed in the contralateral cerebral or cerebellar hemisphere. In our present series of EC-IC bypass cases, one patient (KH) who only suffered TIAs had a persistent low flow following shunting and a normal CT scan. Although the CT scan might not have detected a lacunar infarct, undercutting of afferent fibers is not likely to be the reason for the low flow in this patient. Furthermore, in our previous study of TIA patients involving reconstructive surgery of the carotid artery, similar CT-normal/CBF-positive cases were seen that were un-
changed by effective revascularization. Moreover, in most of the patients with a CT lesion, the anatomical localization of the infarcts could hardly alone explain the tomographically seen remote low flow area as undercutting of neuronal pathways.

Neuropathologic studies in man have demonstrated, that a selective neuronal cell loss, evident by a reduction in the neuronal density accompanied by microglia proliferation and slight reactive astrocytosis may occur in patients following a diffuse hypoxic insult. Also, these changes have been observed in regions surrounding areas of complete infarction. Experimental studies have documented an association between a low flow and a selective neuronal tissue damage. In a study on Macaque monkeys, temporary occlusion of the middle cerebral artery (MCA) was performed for a time interval ranging from 15 minutes to 3 hours. CBF was measured by implanted electrodes using the hydrogen clearance method prior to, during, and after the MCA occlusion. The findings were correlated to the neuropathological findings obtained 2 to 4 weeks after MCA occlusion. Incomplete selective tissue necrosis in the grey matter was observed in 13 of 19 animals. The study of Mies et al using a stroke model with MCA occlusion in the cat showed similarly regions of complete infarction surrounded by areas of low flow 8 weeks after infarction. Although the macroscopic inspection showed sharply demarcated infarcts, the microscopic examination revealed gradually decreasing

![Figure 1](image)

**Figure 1.** Preoperative tomogram of case BSP (slice 2) showed a low flow in the anterior part of both the left and the right hemisphere (la). In addition, a low flow was seen in the posterior part of the right hemisphere, where CT scan showed a hypodense lesion (lc). Postoperatively, improvement of CBF was seen anteriorly in both hemispheres, and the flow distribution was normal in the left hemisphere (lb). The low flow area corresponding to the CT lesion in the posterior part of the right hemisphere persisted. The reference region of interest was chosen in the occipito-temporal region in the left hemisphere. The pictures are scaled according to the mean flow value obtained in this region and displayed from 4–164.
neuronal density on approaching the peri-infarct zone. A significant linear correlation was found between the decrease in neuronal density and the changes in CBF, measured by I4C-iodo-antipyrine autoradiography. In this study, low flow areas were also seen in some regions without structural changes, findings that were interpreted as functional inactivation.

In the light of our own observations and the studies mentioned, we propose that the lack of increase in a regional low CBF after revascularization is due to diachisis and/or selective ischemic neuronal loss, lesions that are invisible on CT scan. Both lesions decrease regional metabolic demand and consequently cause a reduction of regional CBF which is unaltered by a successful shunt operation.

How to Identify Hemodynamic Cases?

It is implicit from the above discussion, that most of our patients had no evidence of a persisting hemodynamic impediment that could explain the low-flow CT-negative areas. Apparently collateral flow sufficed to supply a flow matching local metabolism. Thus, despite shunting no change in tissue flow occurred. In essence, all these cases had suffered a prior acute cerebrovascular disease, a stroke, plus in some cases TIAs caused by embolic events.

But our series, as that of most other surgically treated cerebrovascular-disease series, included a few hemodynamic cases, viz. patients in whom a chronic
hemodynamic impediment and poor collaterals coexist. Although it must be admitted, that the clinical efficacy of EC-IC shunting is still undocumented, and awaiting the results from the ongoing multicentre study, most investigators agree that hemodynamic cases represent a very important subset in whom a clinical benefit could be expected. In the following various approaches to identify such cases will be discussed.

In some patients a significant hemodynamic impediment may be diagnosed on clinical grounds alone, i.e. by TIAs occurring in relation to positional changes. In our study only one patient (case LW) suffered such symptoms. There are good reasons to suspect, however, that more cases should be classified as hemodynamic. First of all the anamnestic information is imprecise. Second, one may readily conceive of a marginally perfused brain area in which ischemia does not elicit overt symptoms that can be identified as a TIA. And, thirdly, even if a very significant hemodynamic impediment exists it could well be that no systemic hypotension has yet supervened to elicit an attack of frank ischemia with acute symptoms and with cell death permanently harming the patient. Antihypertensive treatment may here in particular be invoked as a provoking factor.

To identify the subset of patients with an impaired collateral capacity, Norrving and colleagues studied CBF and CO₂-vasoreactivity with ¹³¹Xenon-inhalation and stationary equipment in patients with unilateral occlusion of the internal carotid artery. They observed a reduced CO₂ response only in the patients with an
impaired collateral capacity as judged from the angiographic findings. In a similar way Halsey et al studied CBF in a series of 19 patients before and after EC-IC bypass. They concluded, that this operation did not affect the resting flow level but did augment the collateral reserve in patients where it has been most severely impaired by the arterial lesions preoperatively. The significance of a compromised collateral circulation was further evaluated by Spetzler et al. In 71 patients treated with an EC-IC bypass for symptomatic cerebrovascular occlusive disease, a definite correlation was established between the severity of the angiographically demonstrated vascular lesions and lower middle cerebral artery perfusion pressures.

Cerebral vasoreactivity may also be tested using acetazolamide (Diamox®), which increase CBF by an effect similar to breathing air with an increased CO₂-content. Intravenous administration of the drug causes no discomfort, and furthermore, neither hypopnoe nor blood pressure changes are induced. We have previously reported on a case, where the hemodynamic significance of the arteriosclerotic lesions were disclosed by testing with Diamox. In this patient, with a thread-like internal carotid artery, CBF did not increase in the low flow area already present in the resting state in CT negative regions. Further validation of the Diamox test is ongoing, as studies on the cerebral vasoreactivity have been included in the pre- and postoperative CBF studies in our EC-IC cases.

Studies of CBF and CMRO₂, by positron emission tomography will allow for identification of patients with "misery perfusion", i.e. an increased local oxygen extraction fraction. Such findings have been observed in the acute phase following an ischemic stroke, but have also been reported in a case of chronic cerebrovascular disease. In this case an EC-IC bypass was able to abolish the clinical symptoms and improve CBF and cerebral oxygen extraction. However, such measurements have no potential for revealing the cases having an adequate resting state blood supply but a restricted collateral capacity, unless the blood pressure is reduced or flow increased by a functional test discussed above.

Recent reports on combined measurements of CBF and cerebral blood volume (CBV) studied with positron emission tomography have suggested that the CBF/CBV ratio may be a useful indicator of the circulatory reserve. It is assumed, that in cases with a reduced cerebral perfusion pressure, CBV will increase due to vasodilation, whereas CBF may remain unchanged due to a pressure within the autoregulatory range, or decrease when the perfusion pressure is below the lower limit of autoregulation. Similar studies using the single photon tomography and ⁹⁹Tc-labelled red blood cells are currently undertaken in our laboratory.

References
SYNCOPE has been described as a relatively common, potentially dangerous problem that often remains unexplained despite extensive clinical evaluation. The possibility that syncope might at times represent an isolated manifestation of cerebrovascular disease has been raised. A recent one year prospective study of patients with syncope revealed a high overall mortality. An excess of sudden death was found among subjects with syncope with mortality rates ranging from 3 to 24% in one year depending on patient subgroup. The excess mortality was found in patients with evidence of underlying cardiovascular or life-threatening non-cardiovascular illnesses. There was no evidence of excess mortality (including cardiovascular and cerebrovascular mortality) in patients with syncope of unknown etiology and no other major illnesses.

Other retrospective and cross-sectional studies of syncope in patients and highly selected study groups have been reported. More generalizable epidemiologic information regarding syncope from a large well-defined free-living population with selective bias minimized would help to clarify the significance and prognostic meaning of this apparently common symptom. Twenty-six year follow-up of 5209 subjects evaluated biennially in the Framingham Study provides such information on syncope.

The objective of this report is to examine the prevalence, morbidity and mortality associated with isolated syncope (i.e., transient loss of consciousness in the absence of prior or concurrent neurologic, coronary, or other cardiovascular disease stigmata).
CBF before and after extracranial-intracranial bypass surgery in patients with ischemic cerebrovascular disease studied with 133Xe-inhalation tomography.
S Vorstrup, N A Lassen, L Henriksen, J Haase, H Lindewald, G Boysen and O B Paulson

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