Hemodynamically significant stenosis of the internal carotid artery treated with endarterectomy

Case report

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Repeated cerebral blood flow (CBF) measurements with xenon-133 inhalation and single photon emission tomography were performed in a patient suffering a minor stroke with subsequent orthostatic-provoked transient ischemic attacks (TIA's). Angiography revealed a thread-like internal carotid artery and an occluded external carotid artery on the side of the ischemic neurological symptoms. Computerized tomography and technetium-99m-pertechnetate brain scintigraphy 2 weeks after stroke were both normal. Before reconstructive vascular surgery, resting CBF showed a hypoperfused area corresponding to the clinical symptoms. Diamox (acetazolamide, 1 gm) increased CBF by 24% in the unaffected hemisphere, whereas even a slight decrease in flow ("steal") was seen in the maximally affected region. In contrast, theophylline (220 mg) reduced CBF in the unaffected hemisphere and caused a slight increase in the previously maximally hypoperfused area ("inverse steal"). After surgery, the flow pattern practically normalized and the TIA's disappeared.

The CBF measurements before surgery and also after the injection of the vasoactive drugs indicated that focal hemodynamic insufficiency elicited the TIA's, and pointed at a low mean arterial blood pressure of about 35 mm Hg in the affected hemisphere. The perioperative finding of a mean blood pressure in the internal carotid artery of 31 mm Hg on the symptomatic side confirmed that the brain tissue had a severely reduced perfusion pressure. On clamping the artery, a stump pressure of 22 mm Hg and electroencephalogram flattening was noted, so a temporary internal shunt was inserted. The findings demonstrate that preoperative CBF measurements, including studies of the regional vasoreactivity, may identify patients with hemodynamic TIA's. These patients are at particular risk of developing cerebral ischemia during carotid endarterectomy, as any further compromise of the inflow may precipitate frank ischemia.

KEY WORDS • ischemia • cerebrovascular disease • carotid endarterectomy • ischemic tolerance • cerebral blood flow • xenon-133 inhalation • emission tomography • transient ischemic attack

Most transient ischemic attacks (TIA's) are presumably of embolic origin. This concept is based on the absence of a hemodynamic provoking factor in the majority of cases, the absence of neurological symptoms during induced hypotension, the ophthalmoscopic visualization of embolic material in cases with amaurosis fugax, and postmortem studies. Although not very common, TIA's of hemodynamic origin do exist, as clearly indicated by clinical history and provocation of symptoms during induced hypotension.

Blood flow measurements during gradual narrowing of the internal carotid artery (ICA) have shown that a considerable constriction is required to reduce flow through the artery. Even the presence of a stenosis reducing the ICA flow to about 55% reduces the mean arterial blood pressure (MABP) of the corresponding hemisphere by an average of only 7.5%, leaving hemispheric cerebral blood flow (CBF) unaltered in the majority of cases. Due to the functional capacity of the collateral circulation, mainly through the circle of Willis and the ophthalmic artery, multiple arteriosclerotic lesions of the extracranial arteries are generally required for hemodynamic factors such as spontaneous blood pressure variations to become critical. On the other hand, the arteriographic presentation of multiple
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severe arteriosclerotic lesions does not necessarily imply a hemodynamic origin of the ischemic symptoms.

This paper presents the findings in a patient with a minor stroke and subsequent TIA's who had multiple severe arteriosclerotic lesions. Measurements of the vasoreactivity of the cerebral circulation allowed pre-operative recognition of a low-flow area with a marginal perfusion pressure. Our results indicate that measurements of CBF by emission tomography may be useful in identifying patients with TIA's of hemodynamic origin. In such patients, particular precautions should be taken during and after carotid endarterectomy.

Case Report

This 60-year-old woman had been treated with diuretics for a mild arterial hypertension over a period of 6 years since 1976, and had complained of intermittent claudication since 1979. During December, 1981, and January, 1982, she suffered 25 to 30 episodes of right-sided amaurosis fugax, mostly accompanied by paresthesia of the left arm. These symptoms lasted only a few minutes and were not related to postural changes or extreme neck movements. On awaking on the morning of February 1, 1982, the patient noted weakness, clumsiness, and paresthesia of the left arm and leg. The symptoms persisted after a week, and she sought medical advice.

Examination. On admission on February 11, clinical examination revealed a moderate left facial paresis and a moderate left hemiparesis with increased tendon jerk reflexes of the leg. There was no Babinski sign and normal sensation. The blood pressure was 180/90 mm Hg.

On February 15, arteriography of the right common carotid artery showed a thread-like stenosis of the ICA just distal to the bifurcation and a completely occluded external carotid artery. On February 16, a CT scan showed no lesion or enhancement foci. Brain scintigraphy with technetium-99m performed the same day showed no cerebral isotope uptake.

Following admission, during the morning hours, the patient noted some aggravation of the weakness and paresthesia of the left-sided extremities and also dizziness and an unsteady gait. Due to these clinical symptoms and the finding of an extremely narrow ICA, hypertensive therapy was instituted with a combination of sodium chloride tablets and a mineral corticosteroid, and the symptoms of orthostatic aggravation subsided completely.

On March 9, 1982, four-vessel angiography confirmed the earlier findings on the right side: a severely stenosed ICA and an occluded external carotid artery. On the left side the angiogram showed a non-stenosing lesion of the ICA and a thread-like external carotid artery, while minor non-stenosing lesions were seen to affect all the remaining vessels.

Operation. On March 15, 1982, a right-sided ICA endarterectomy was performed. The flow in the ICA was 42 ml/min at a PaCO₂ of 32 mm Hg. Blood pressure in the ICA was 31 mm Hg, while systemic MABP was 90 mm Hg. On clamping the artery, a stump pressure of 22 mm Hg was recorded. During clamping the electroencephalogram (EEG) pattern showed decrease in amplitude and low frequency. After shunt insertion, the EEG normalized. The ICA was severely stenosed, the arteriosclerotic lesion being both ulcerated and partly covered by thrombotic material.

An uncomplicated endarterectomy was performed, after which the flow in the ICA increased to 210 ml/min.

Postoperative Course. The patient was kept sedated and on artificial ventilation for about 48 hours, maintaining PaCO₂ at low levels (about 30 mm Hg) to prevent a postoperative hemorrhage in the vulnerable brain tissue. The systolic blood pressure was kept within the range of 120 to 140 mm Hg. Following this, recovery was rapid and uncomplicated, and the patient suffered no further TIA's. A slight weakness and incoordination of the left extremities persisted.

CBF Measurement

The CBF was measured by the atraumatic xenon-133 (¹³³Xe) inhalation method and single photon emission tomography. This method has been described in detail elsewhere and only a brief description will be given here. One study lasts 4 to 8 minutes, and during the first 1½ minutes ¹³³Xe is inhaled from a closed system. This yields a lung concentration curve reaching a maximum of 10 mCi/liter. A sequence of four tomographic pictures is taken with a spatial resolution of 1.7 cm in the plane. Three slices of brain tissue are studied simultaneously, each 2 cm in thickness with an unseen interslice distance of 2 cm. These slices are routinely positioned 1 cm, 5 cm, and 9 cm above the orbitomeatal plane, and are termed Slice 1, 2, and 3, respectively. A single stationary scintillation detector is placed over the right lung, and is taken to represent the arterial input curve. The sequence of the tomographic pictures together with the recorded lung curve permits calculation of the mean CBF.

In this patient, the end-expiratory FeCO₂ was measured with an infrared capnograph, and was recorded just prior to the study, during the 3rd minute, and at the end of the study.

Calculation of Regional CBF

Regional CBF was calculated from the middle slice, that is, Slice 2. These calculations were performed by encircling the region of interest by a cursor. This yields a mean flow value in the selected region as well as in a corresponding symmetrically placed region in the opposite hemisphere. In this way, regional CBF was calculated in the following regions:

1. The territory of the anterior cerebral artery (ACA), defined as the mesial one-third of the hemisphere extending two-thirds posteriorly.
2. The territory of the middle cerebral artery (MCA), defined as the remaining part of Slice 2 anterior to the occipital region provided by the posterior cerebral artery.

3. The cortical part of the MCA, defined as the outermost border of this region.

4. The “region of interest” (ROI), which was visually depicted and chosen regardless of vascular territories and anatomical structures.

5. The mean hemispheric flow.

In the patient reported here, the ROI was a low-flow region located anteriorly in the right hemisphere corresponding to the watershed area between the ACA and the MCA.

Results of CBF Measurements

The first CBF measurement was performed 14 days after the acute stroke. The resting flow showed a clear side-to-side asymmetry, with a reduced flow in the right frontotemporal region (Fig. 1A), in the area referred to as the ROI. The CBF was repeated 5 minutes after an intravenous injection of 220 mg of theophylline (Fig. 1B). In the unaffected hemisphere, mean CBF was reduced by 17%, whereas a slight increase of flow in the ROI could be noted (“inverse steal”), and the asymmetrical flow pattern was abolished. A moderate improvement in the clinical symptoms was observed.

Three weeks later, just prior to surgery, the resting CBF measurement was repeated. This study showed that the asymmetrical flow pattern persisted unchanged in extent and severity (Fig. 1C). Twenty minutes after the intravenous injection of 1 gm of acetazolamide (Diamox) the CBF measurement was repeated (Fig. 1D). Except in the ROI, an overall increase in CBF was seen, amounting to 24% in the unaffected hemisphere. In the ROI, a reduction in CBF was noted in the watershed area between the ACA and the MCA.

Postoperatively, the CBF measurement showed a focal increase in the ROI, and the tomographic flow map of Slice 2 appeared normal without asymmetry (Fig. 1E and F), while a slight degree of asymmetry still persisted in the upper slice (Slice 3). Table 1 presents the actual flow values calculated from the middle slice (Slice 2) as well as the FeCO₂ and the blood pressures recorded.

Discussion

Clinical Evidence Pointing to a Hemodynamic Pathogenesis

In this patient with a minor stroke and subsequent TIA’s, a hemodynamic pathogenesis of the TIA’s is suggested by the close relationship of postural changes to attacks, which tended to occur in the morning after bed rest and later to be alleviated by a medically induced increase in blood pressure. The clinical impression is supported by the angiographic finding of a severely stenosed ICA and an occluded external carotid artery ipsilateral to the symptomatic hemisphere. The fact that no gross brain damage had occurred is indicated by the absence of focal lesions on the computerized tomographic (CT) scan and a normal technetium scintigram without evidence of isotope uptake. As no infarction could be demonstrated, the low-flow areas seen on the tomographic flow map were assumed to indicate a perfusion pressure too low to allow autoregulation even in the resting recumbent position.

On these grounds it was to be expected that reconstruction of the ICA would normalize pressure and flow in the low-flow areas and free the patients from further TIA’s.

Hemodynamics of Low-Flow Areas

In patients with ischemic cerebrovascular disease, the finding of a low-flow area with a normal CT scan represents one or both of the following two conditions: irreversible ischemic tissue damage and potentially reversible hemodynamic insufficiency.

Irreversible ischemic tissue damage may result in a

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<tr>
<th>Flow Study</th>
<th>Mean Hemispheric Flow</th>
<th>Mean Flow in ROI (on rt) &amp; Corresponding Area (on lt)</th>
<th>Cortical Flow in MCA Territory</th>
<th>Mean Flow in ACA Territory</th>
<th>Mean Flow in MCA Territory</th>
<th>FeCO₂</th>
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<td>2: theophylline (2/15/82)</td>
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<td>3: rest (3/3/82)</td>
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<td>4: Diamox (3/3/82)</td>
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<td>* Flows are given in ml/100 gm/min, pressures in mm Hg. ROI = region of interest; MCA = middle cerebral artery; ACA = anterior cerebral artery.</td>
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FIG. 1. Emission tomograms showing cerebral blood flow (CBF).  A: Tomogram performed 14 days after the acute stroke. A low flow is seen in the right middle cerebral artery (MCA) territory. B: Measurement of CBF was repeated 5 minutes after the intravenous injection of 220 mg of theophylline. Mean CBF in the left hemisphere decreased by 17%, whereas a slight increase is seen in the anterior part of the right MCA. C: Tomogram performed 3 weeks after the acute stroke showing an unchanged asymmetrical pattern. D: Measurement of CBF following an intravenous injection of 1 gm Diamox (acetazolamide) showing an overall increase in CBF except for the right MCA territory, where even a reduction is seen in the anterior watershed area. E and F: These CBF studies were performed 1 (E) and 9 months (F) postoperatively. The tomographic flow maps show no significant asymmetries, and are considered normal.
diffuse, often partial, loss of neuronal cells with survival of glia cells and vasculature (incomplete infarction). The low flow in this case reflects a lowered metabolic demand of the remaining tissue. Such areas with persisting low flow and yet a normal CT scan are commonly seen in patients with completed stroke and also in some patients with TIA’s. If incomplete infarction is the sole cause of a reduced flow, the remaining nervous tissue elements might be expected to show a qualitatively normal vasomotor reactivity. Thus, flow increase would result from application of a vasodilator such as acetazolamide, and a flow decrease from a vasoconstrictor such as theophylline.

Potentially reversible hemodynamic insufficiency is a rare condition in chronic cerebrovascular disease seen only in patients with multiple severely stenosing or occluding lesions of the cerebral arteries. Characteristic of this state is a high rate of oxygen extraction, as demonstrated in low-flow areas in a patient with symptoms of hemodynamic insufficiency studied by positron emission tomography by Baron, et al., in 1981; they coined the term “misery perfusion” for this chronic condition. If the reduced flow is solely due to chronic misery perfusion the functional tests should elicit a reduced, abolished, or even a paradoxical response.

In our patient, paradoxical responses were found in the critical area. This points to a severely reduced perfusion pressure approaching the critical level of about 35 mm Hg, at which cellular function is depressed by hypoxia. This is demonstrated by the loss of consciousness in some patients at this level when subjected to carotid endarterectomy during local anesthesia. In our patient, the MABP beyond the stenosis was 31 mm Hg.

Regional misery perfusion caused by such low pressure leads to vasodilatation explaining the abnormal responses to vasoactive drugs with intracerebral steal and inverse steal phenomena. Final evidence of misery perfusion was provided by the finding of a practically normal flow tomogram postoperatively. The only abnormality still present, a slight diffuse flow reduction in the upper part of the right hemisphere, is probably due to a mild degree of neuronal cell loss and may explain the slight residual neurological symptoms.

Selection of Surgical Procedure

Fear of ischemic damage to the brain as a consequence of clamping the ICA during carotid endarterectomy has caused most surgeons to use an intracarotid shunt during the operation either routinely or selectively. The necessity of using a shunt has been disputed by other groups, who have obtained excellent results without the use of a shunt in selected series.

Analysis of the operative complication rate encountered by the different clinics does not show a consistent pattern allowing any definite conclusion. From the literature, however, the inference seems justified that

References


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