Anterior communicating artery collateral flow protection against ischemic change during carotid endarterectomy

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The purpose of this study was to determine whether preoperative angiographic patterns of collateral cerebral blood flow correlate with protection against intraoperative electroencephalographic (EEG) evidence of cerebral ischemia caused by carotid artery cross-clamping during carotid endarterectomy. Previous studies have shown that contralateral carotid artery occlusion and intracranial stenoses are associated with cerebral ischemia during carotid endarterectomy; however, the angiographic collateral flow patterns associated with cerebral ischemia have not been identified. This paper reports a retrospective study of 67 patients who underwent two- to four-vessel carotid endarterectomy with 16-channel EEG monitoring. The angiograms were reviewed for extracranial occlusive disease and collateral flow patterns, and the EEG recordings were analyzed for ischemic changes during carotid artery cross-clamping. Statistical analysis was by Fisher's exact test.

Cross-filling of the anterior and middle cerebral arteries from the contralateral carotid artery through the anterior communicating artery correlated with a decreased incidence of EEG ischemic changes. Only 21% of patients with this collateral flow pattern showed ischemic changes compared to 50% of patients without this pattern (p < 0.03). Three angiographic findings occurring in combination on the side contralateral to surgery correlated with EEG ischemia: 1) occlusion of the contralateral internal carotid artery (five of seven or 71%, p < 0.03); 2) collateral flow from the external carotid circulation to the internal carotid circulation via the ophthalmic artery; and 3) collateral flow from the posterior circulation to the contralateral anterior circulation via the posterior communicating artery. The data presented here corroborate the correlation between contralateral carotid artery occlusion and cerebral ischemia during carotid endarterectomy. They also demonstrate that cross-filling of the anterior and middle cerebral arteries by the contralateral carotid artery protects against such ischemia. This collateral flow may serve as an indicator of tolerance to carotid artery cross-clamping.

Key Words • carotid endarterectomy • cerebral angiography • cerebral ischemia • collateral flow • electroencephalography

SUrgeons have been seeking preoperative information that could identify patients at risk for developing cerebral ischemia at carotid artery cross-clamping during carotid endarterectomy. Investigators have found that contralateral internal carotid artery occlusions and intracranial stenoses on preoperative angiograms are associated with impaired tolerance to carotid artery cross-clamping. No series has systematically reviewed and compared collateral cerebral blood flow as seen on preoperative angiograms with the incidence of intraoperative cerebral ischemia. In this retrospective study, we examined the preoperative cerebral angiograms of patients who underwent elective carotid endarterectomy to determine whether specific collateral flow patterns correlated with protection against intraoperative electroencephalographic (EEG) evidence of cerebral ischemia at carotid artery cross-clamping.

Clinical Material and Methods

Patient Population

Between November 10, 1986, and May 30, 1991, 65 patients underwent two- to four-vessel carotid angiography followed by carotid endarterectomy for symptomatic disease or severe carotid stenoses with residual lumina of less than 1.5 mm. Two patients had bilateral carotid endarterectomies 9 and 22 months apart, respectively. There were 22 women and 43 men, aged from 48 to 82 years (mean 65 years). Carotid endarterectomies were performed on the left side in 45 cases and on the right in 22. All patients signed an informed
consent form for angiography and carotid endarterectomy with EEG monitoring.

**Angiographic Findings**

Selective angiography of the common carotid and vertebral arteries without compression of the contralateral carotid artery was performed by transfemoral catheterization. Fifty-two patients had bilateral common carotid artery angiography, 14 had angiography of both common carotid arteries and one vertebral artery, and one had angiography of both common carotid arteries and both vertebral arteries. Standard cut film images were obtained with the use of contrast material and routine filming parameters. Angiographic findings were reviewed by a neuroradiologist and neurologist for extracranial occlusions and the following three collateral flow patterns: 1) cross-filling of the anterior and middle cerebral arteries through the anterior communicating artery; 2) flow to the anterior and posterior circulations through the posterior communicating artery; and 3) flow from the external to the internal carotid artery through the ophthalmic artery.

**Anesthesia Management**

All patients were monitored continuously with an electrocardiogram (EKG), a radial arterial catheter, a capnograph, and an oxygen analyzer. Prior to induction of anesthesia, 0.05 mg/kg of diazepam was given orally. Anesthesia was induced with 4 to 6 mg/kg of thiopental and maintained with 60% nitrous oxide in oxygen, a narcotic and muscle relaxant. Isoflurane or enflurane at delivered concentrations of 0.5% to 1.0% was added as required for blood pressure control. During carotid artery cross-clamping, a phenylephrine infusion was used to maintain the systolic arterial blood pressure at approximately 10% to 20% above average preoperative values.

**Operative Procedure and Electroencephalography**

Endarterectomy of the carotid bifurcation and the initial segment of the internal carotid artery was performed. An intracarotid artery shunt was placed after carotid artery cross-clamping if the EEG showed patterns of cerebral ischemia.

Twenty-three gold cup EEG electrodes* filled with conduction gel were secured to the scalp with collodion according to the International 10–20 System. Impedances were measured at less than 2000 ohm. Sixteen anteroposterior bipolar and two EEG referential channels were recorded.† Two additional channels monitored the arterial blood pressure and the EKG. The high-frequency filter was set at 70 Hz and the time constant at 0.3 seconds. A 60-Hz notch filter was used as needed. A 3-minute baseline EEG recording was obtained prior to induction of anesthesia, and EEG data were recorded continuously from the time of anesthesia induction throughout the surgical procedure, until the patient was awake and following commands appropriately. The intraoperative EEG recording was interpreted either by an EEG technologist or electroencephalographer who was present throughout the recording. Electroencephalographic pattern changes indicative of cerebral ischemia at carotid artery cross-clamping were defined according to the criteria established by Sharbrough, et al.,10 and Chiappa, et al.4: diminution or loss of beta and alpha frequencies or an increase in theta and delta slowing. These changes could be generalized, lateralized, or focal. The EEG tracings were analyzed for cerebral ischemic changes during the operation, and a final interpretation describing the details of the EEG recording, including documentation of cerebral ischemic changes during carotid artery cross-clamping, was entered into the patient's medical record. The EEG interpretation was performed without knowledge of the angiographic findings.

**Data Analysis**

The patients were reviewed in the following manner. First, we identified from the EEG reports those patients with and without patterns indicative of cerebral ischemia during carotid artery cross-clamping. We then analyzed in detail the cerebral angiograms of each patient. Finally, we compared the EEG results and the angiographic findings to determine whether specific collateral blood flow patterns protected against cerebral ischemia at carotid artery cross-clamping. Fischer's exact test was used for statistical analysis of the correlation of blood flow patterns and EEG change.

**Results**

**Collateral Blood Flow Patterns and Absence of EEG Evidence of Ischemia**

Ischemic pattern changes were noted on the EEG recordings at carotid artery cross-clamping in 21 (31%) of the 67 operations. One collateral blood flow pattern correlated with a decreased incidence of such changes: cross-filling of the anterior and middle cerebral arteries from the contralateral internal carotid artery through the anterior communicating artery. This collateral blood flow pattern was present in 43 (64%) of the 67 cases. Only nine (21%) of the 43 patients with this flow pattern developed an ischemic change compared to 12 (50%) of the 24 without this pattern (p < 0.03, sensitivity 74%, specificity 57%, predictive value positive 79%).

Our data on posterior to anterior circulation collateral flow on the side of surgery showed a trend toward protection against an ischemic EEG change. This trend did not achieve statistical significance due to the relatively small number of patients (15 of 67, or 22%) who had three- or four-vessel cerebral angiography. Collateral blood flow from the external to the internal carotid artery on the side of surgery did not protect against an ischemic EEG change.

**Collateral Blood Flow Patterns and Presence of EEG Evidence of Ischemia**

Three angiographic findings on the side contralateral to surgery correlated with an increased likelihood of an

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* Cup electrodes, Model E5GH, manufactured by Grass Instrument Co., Quincy, Massachusetts.
† Electroencephalograph, Model 4321, manufactured by Nihon-Kohden America, Inc., Irvine, California.
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ischemic EEG change. The principal angiographic abnormality was contralateral occlusion of the internal carotid artery. The other two findings were compensatory collateral flow that occurred in the case of occlusion or severe stenosis of the contralateral carotid artery: flow from the external to the internal carotid artery by retrograde flow through the ophthalmic artery, and flow from the posterior to the anterior circulation through the posterior communicating artery.

Oclusion of the contralateral internal carotid artery was present in seven (10%) of the 67 cases. There was an associated ischemic EEG pattern change at cross-clamping in five (71%) of these seven operations, while only 16 (27%) of 60 patients without an occlusion developed ischemic changes (p < 0.03, sensitivity 24%, specificity 96%, predictive value positive 71%). In the two patients with contralateral carotid artery occlusion who did not develop ischemic EEG changes, the angiogram did not demonstrate the source of collateral blood flow that prevented ischemia. All patients with contralateral internal carotid artery occlusions showed cross-filling from the side of surgery to the contralateral side through the anterior communicating artery, but no patient exhibited cross-filling from the side of occlusion to the side of surgery.

The two compensatory collateral routes (external to internal carotid artery and posterior circulation to the contralateral anterior circulation) were present together and in combination with a contralateral occlusion of the internal carotid artery in four cases, all of which had an ischemic EEG change at cross-clamping. These collateral flow patterns occurred together in two other patients. One patient had severe contralateral carotid artery stenosis with a residual lumen of less than 1 mm. This patient did not have cross-filling through the anterior communicating artery and developed ischemic EEG changes at cross-clamping. The other patient had a contralateral carotid artery stenosis with a residual lumen of 2 mm, exhibited cross-filling through the anterior communicating artery, and did not develop ischemic EEG changes.

Two patients had only one of these compensatory collateral flow patterns. In one patient, the external to internal carotid artery collateral flow was present in combination with occlusion of the contralateral carotid artery; ischemic EEG changes did not occur with cross-clamping. In the second patient, there was collateral flow from the posterior to the contralateral anterior circulation and the contralateral internal carotid artery was stenotic with a 2-mm residual lumen. There was no cross-filling through the anterior communicating artery and ischemic EEG changes developed with cross-clamping.

Discussion

Investigators assessing the perioperative morbidity and mortality risks of carotid endarterectomy have studied preoperative angiographic findings of the extracranial carotid artery and intracranial cerebral vasculature by examining the relationship between atherosclerotic lesions and risk. Occlusion of the contralateral internal carotid artery has consistently emerged as an increased risk factor for surgery, whether this risk was defined by postoperative mortality, neurological morbidity, or intraoperative EEG evidence of cerebral ischemia at carotid artery cross-clamping. Other preoperative angiographic findings reported as predictive of increased perioperative morbidity and mortality include the presence of atherosclerotic disease in other major extracranial vessels, intracranial vascular stenoses, especially in the region of the siphon of the internal carotid artery, extensive involvement of the vessel to be operated on, the presence of a thrombus or ulceration in the stenotic lesions, and a "slow" or "stagnant" flow. Some authors have postulated that collateral cerebral blood flow through the anterior and posterior communicating arteries protects against cerebral ischemia during carotid endarterectomy. However, no detailed study looking at angiographic flow characteristics in patients with cerebrovascular disease undergoing carotid endarterectomy has previously been performed to support this view.

Our data identified one preoperative angiographic cerebral blood flow pattern that protects against intraoperative ischemic EEG changes during carotid artery cross-clamping. Cross-filling of the anterior and middle cerebral arteries on the side of surgery from the contralateral internal carotid artery through the anterior communicating artery was more frequently present in patients who did not develop ischemic EEG changes with carotid artery cross-clamping than in those who did. This finding is consistent with previous arteriographic studies of collateral flow, which demonstrated that the anterior communicating artery is the dominant contributor to collateral flow through the circle of Willis. Patients with ischemic EEG patterns at cross-clamping had less frequent angiographic evidence of cross-filling through the anterior communicating artery.

We corroborated the findings of other investigators that occlusion of the contralateral carotid artery was associated with an increased likelihood of EEG pattern changes indicative of cerebral ischemia at cross-clamping. Moreover, we found that this increased incidence of ischemic EEG change was not diminished by the presence of collateral blood flow to the contralateral hemisphere, either from the external carotid artery to the internal carotid artery through the ophthalmic artery or from the posterior to the contralateral anterior circulation through the posterior communicating artery. Thus, in the setting of an occluded contralateral internal carotid artery, these collateral routes at best provided only marginal circulatory compensation to that hemisphere and did not supply perfusion to the opposite side during carotid artery cross-clamping. In these cases, cerebral blood flow to the side of carotid artery occlusion was largely supplied by cross-filling through the anterior communicating artery from the stenosed internal carotid artery undergoing arteriotomy. Therefore, EEG patterns of ischemia developed when the primary source of cerebral perfusion was clamped. While our study did not address the perioperative risk of neurological morbidity and mortality, our findings indicate that collateral flow through the
anterior communicating artery, as seen by preoperative cerebral angiography, decreases the risk of intraoperative cerebral ischemia.

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