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An Electroencephalographic Filter–Processor as an Indicator of Cerebral Ischemia during Carotid Endarterectomy

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A one-channel electroencephalographic filter-processor (EFP)[1]‡ was compared with simultaneous 16-channel EEG recordings and regional cerebral blood flow (rCBF) measurements in 70 patients undergoing carotid endarterectomy to evaluate the efficacy of the EFP in detecting hemispheric cerebral ischemia during carotid artery occlusion.

METHODS

In 15 patients, the two EFP leads were applied symmetrically over the left and right parietal regions as specified in the operating manual. In 55 patients, central and parietal leads were applied unilaterally over the affected hemisphere.

Baseline awake tracings were obtained before the induction of anesthesia, and continuous monitoring was maintained until after tracheal extubation. Particular attention was directed to the EFP and the EEG at the time of carotid occlusion. The EEG was evaluated by an electroencephalographer (FWS) and the EFP by an anesthesiologist (RFC). The criteria for a change indicative of ischemia in the EEG included a reduction in amplitude of the higher-frequency components and the appearance of high-voltage rhythmic slow waves, later replaced by lower-voltage arrhythmic slow waves. The EFP was considered to change only when an obvious decrease in baseline appeared. EEG and EFP tracings at the time of carotid occlusion were correlated with simultaneous arterial blood-gas, temperature, and rCBF measurements. After intracarotid injection of ^{133}Xe the washout curve from the affected hemisphere was analyzed by a tabletop computer to yield rCBF within 1–2 min.[2]

Anesthetic management typically included induction with thiopental, tracheal intubation following an appropriate dose of pancuronium, light levels of inhalational anesthesia with halothane or enflurane, and maintenance of normocarbia by the addition of CO_2 to the inspired gases. Arterial pressure was continuously measured via a cannula in the radial or dorsalis pedis artery, and maintained at preoperative levels. A V_5 electrocardiogram lead was continuously monitored.

Transient cerebral ischemia occurs frequently during the period of carotid occlusion for carotid endarterectomy. Clinical monitoring techniques to help identify the patients in whom such ischemia occurs include neurologic evaluation of the patient during regional anesthesia, measurement of internal carotid artery stump pressure, measurement of regional cerebral blood flow (rCBF), and the use of the electroencephalogram (EEG). This study compares the use of a simplified EFP system in monitoring such patients for the occurrence of cerebral ischemia with our usual techniques of monitoring the standard EEG and regional cerebral blood flow.

RESULTS

Bilateral Leads

The use of a recording electrode over each hemisphere as specified by the manufacturer was relatively ineffective in detecting hemispheric ischemia. Transient cerebral ischemia at carotid clamping was evident by EEG and rCBF (<18 ml/100 g/min) in four

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‡ Currently marketed as the "Cerebral Function Monitor" by Devices Limited, 501 George Street, New Brunswick, New Jersey 08903.

0003-3022/79/0700/0077 $00.65

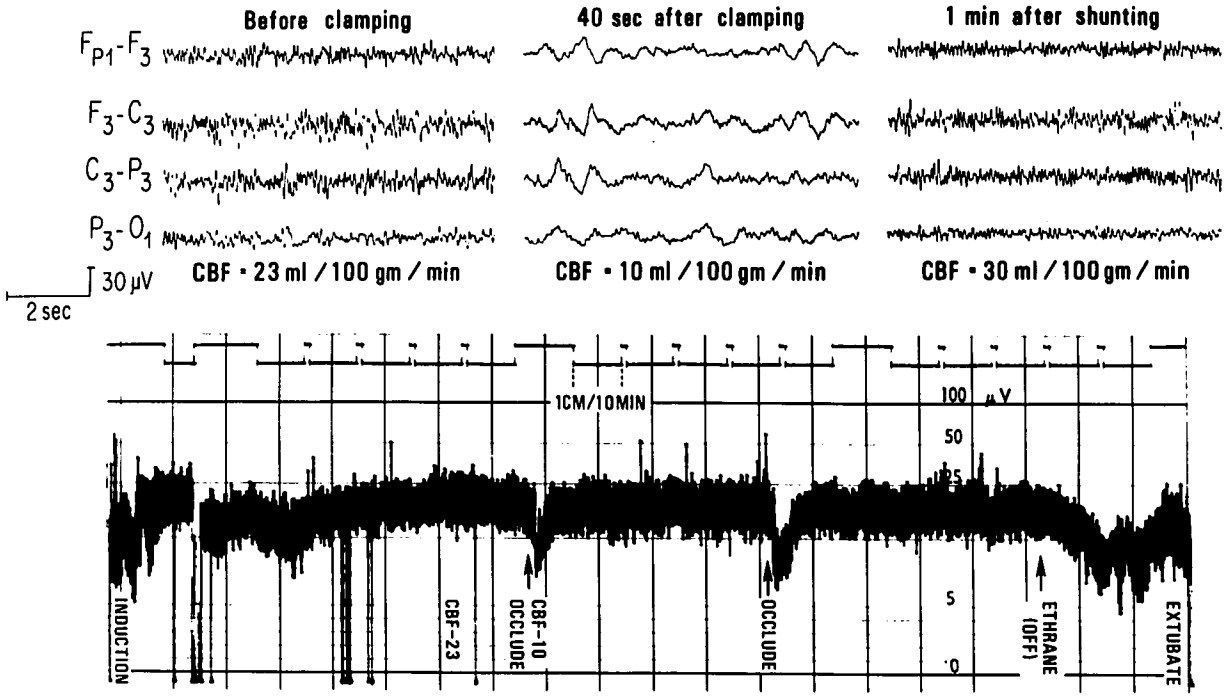

FIG. 1. Occlusion changes in both EEG and EFP during left carotid endarterectomy. The change in EFP baseline produced by thiopental can be seen at induction. Marked changes in both EFP and EEG can be seen at carotid occlusion. At removal of the shunt and again as the anesthetic level was lightened near the end of the operation, the EFP again changed (as did the EEG, which is not shown at these times).

of the 15 patients; the EFP baseline failed to decrease in three of these four cases.

Unilateral Leads

With both EFP recording electrodes over the affected hemisphere, neither the EEG nor the EFP changed in 44 of 55 cases (table 1). In 11 patients, EEG changes and rCBF measurements indicated cerebral ischemia during carotid clamping; the EFP baseline decreased for nine of the 11 (*e.g.*, fig. 1). The two patients whose EFPs did not change manifested only loss of higher-frequency waves (10–15 Hz) from the standard 16-channel EEG. The rCBF values of these patients were 7 and 15 ml/100 g/min.

TABLE 1. Comparison of Electroencephalogram (EEG) and Electroencephalographic Filter-processor (EFP) Changes at Carotid Occlusion in 55 Patients Undergoing Elective Carotid Endarterectomy

	Number of Patients	rCBF <18 ml/100 g/min
Occlusion changes in both EEG and EFP	9	9
Occlusion changes in EEG without EFP change	2	2
Occlusion changes in neither EEG or EFP	44	3
TOTAL	55	14

* Internal-carotid-artery shunt used in all patients in whom rCBF < 18 ml/100 g/min.

Some changes in EFP tracings during changing anesthetic depths were very similar to those obtained during hemispheric ischemia. It was necessary to maintain a steady level of anesthesia during the period of carotid occlusion in order to be able clearly to interpret the EFP tracing.

DISCUSSION

Reliable monitoring techniques during carotid endarterectomy are more likely to reduce intraoperative complications by identifying periods of cerebral ischemia. They would also be expected to provide more precise criteria for whether a shunt is necessary, an important point because shunt placement itself is not without risk. Further, the knowledge that cerebral ischemia has *not* occurred during occlusion permits an unhurried, careful performance of endarterectomy, including a vein graft when necessary. The purpose of this study was to evaluate the usefulness of the EFP in detecting the occurrence of cerebral ischemia compared with the previously reported reliability of the 16-channel EEG and rCBF measurements.[3]

The relative efficacies of the EEG, rCBF, and stump pressures in detecting hemispheric cerebral ischemia have recently been examined.[4] Measurement of stump pressure alone may not be reliable as an indicator of perfusion of the affected side during carotid clamping.[4] The other two techniques, the EEG and

rCBF determinations, are felt by many to be expensive, cumbersome and elaborate, and have not gained wide acceptance for these reasons. This study, then, sought to determine the usefulness of a piece of equipment that might provide the clinician with a simpler means of detecting cerebral ischemia. We found the device to be mechanically and electrically reliable, relatively easy to use, and a reasonably accurate indicator of hemispheric cerebral ischemia in the circumstances of this study. Other electroencephalographic signal processors are in limited use, but were not tested in this study.[5]

With unilateral lead application, the EFP detected cerebral ischemia in nine of 11 patients who had ischemia by EEG and rCBF criteria. In addition to low rCBF values, the two patients whose EFPs did not change showed loss of higher-frequency waves (10–15 Hz) from the standard 16-lead EEG. Since this is the upper-frequency range at which the EFP pass band filter begins signal rejection, it is not surprising that their disappearance should cause little change in the EFP record. Perhaps more obvious changes would have appeared in both the EEG and the EFP over a few more minutes had not shunts been placed in both patients.

As with interpretation of the EEG during carotid endarterectomy, proper EFP interpretation requires a steady anesthetic level. Shortly before the end of the operation, a drop in the EFP baseline relating to EEG changes seen during emergence from anesthesia could frequently be seen. These changes do not indicate hemispheric ischemia. The changes are bilateral on the EEG and are transient. Many times during the course of management of these patients, the EFP baselines changed substantially. With the benefit of the 16-channel EEG, it was clear that the changes were bilateral, and were concurrent with changes in anesthetic concentrations in the course of routine management. Without the EEG to confirm bilaterality, such EFP baseline changes could easily be misinterpreted as ischemia. For this reason, the EFP can be relied upon only during the actual occlusion of the carotid artery. The anesthetic level should be held as steady as possible during this time.

Critical rCBF during halothane anesthesia has been previously reported to be 18 ml/100 g/min.[3] Patients who have hemispheric blood flows of 18–24 ml/100 g/min may or may not show EEG signs of ischemia.[3] There were four patients in this study with rCBF values <18 ml/100 g/min whose EEGs did not show signs of ischemia within 2 min. All of these patients received enflurane anesthesia. Perhaps enflurane anesthesia somehow reduced "critical" rCBF. A review of our experience in this regard is in progress.

We conclude the following: 1) bilateral symmetrical application of the EFP leads was inadequate for detection of hemispheric cerebral ischemia during carotid endarterectomy; 2) the EFP with unilateral lead placement was not as sensitive as the combination of the 16-channel EEG and rCBF measurement in the detection of cerebral ischemia. The EFP did, however, identify cerebral ischemia in those cases in which obvious EEG changes occurred, but was inadequate to detect subtle EEG changes of ischemia; 3) changes in the EFP tracing due to changing anesthetic depth can very closely resemble those seen with cerebral ischemia during carotid clamping; thus, anesthetic level must be steady during this part of the operation; 4) a diagnosis of hemispheric ischemia in the setting of this clinical situation could be made on the basis of the EFP tracing *only* at the time of carotid occlusion.

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