Spectral analysis of EEG during carotid endarterectomy

Lou V. IVANOVIC, MD, Richard S. ROSENBERG, PhD, Vernon L. TOWLE, PhD, Alan M. GRAHAM, MD, Bruce L. GEWERTZ, MD, Christopher ZARINS, MD, Jean-Paul SPIRE, MD, Chicago, Illinois

Spectral analysis of the electroencephalogram (EEG) was monitored during 105 carotid endarterectomies. Seventy-eight percent of the patients showed no significant change in EEG spectral power as a result of clamping of the internal carotid artery. Two patterns of change were observed in the remaining 22% of patients: partial reduction (significant decrease of power in one or two of three frequency bands) and global reduction (significant decrease of power in all three frequency bands). High frequencies (over 10.5 Hz) changed more frequently with clamping than did low frequencies (less than 6 Hz), but reduction of high frequencies alone was tolerated with no postoperative deficits. The only non-shunted patient demonstrating global EEG reduction for the duration of carotid clamping suffered a transient hemiparesis. (Ann Vasc Surg, 1986, 1, 112-117).

KEY-WORDS: Carotid endarterectomy. — Electroencephalographic monitoring. — Spectral analysis. — Ischemia. — EEG.

Carotid endarterectomies are currently performed at a rate of more than 85,000 per year. Estimates of morbidity associated with the procedure range from 1 to 4%, with or without the use of an intraoperative shunt [1-4]. Despite theoretical benefits, shunt placement has not met with universal acceptance because it prolongs the operation, may be technically difficult, may damage the vessel, and has yet to have a consistently demonstrated effect on morbidity rates [5-6]. To avoid unnecessary shunting and associated risks, four techniques of monitoring of brain function have been used:

— measurement of the distal carotid stump back pressure [7];
— measurement of Xenon cerebral blood flow [8];
— monitoring of somatosensory evoked potentials [9];
— monitoring of cerebral function with electroencephalographic (EEG) techniques.

Increasing numbers of reports support the use of EEG monitoring during carotid endarterectomy [10-13]. Techniques have ranged from single channel EEG recording [14-15] to extensive cortical montages using either unprocessed EEG [16] or, more recently, spectral analysis of EEG [17]. Accurate EEG criteria for cerebral ischemia have yet to be satisfactorily determined. Most studies have compared EEG changes with estimates of cerebral perfusion [8-18]: few authors have compared monitoring techniques with outcomes [19-20].

We report our experience with spectral analysis of the EEG of 105 patients undergoing carotid endarterectomy. This on-line analysis of the EEG facilitated rapid and precise measurements of EEG changes. The specific purpose of this report is to better define the changes in the EEG associated with ischemia not to correlate EEG changes with any other clinical, angiographic, or intraoperative indicators.
CLINICAL MATERIAL AND METHODS

Spectral analysis of the EEG was obtained during carotid endarterectomy in 105 patients (63 males and 42 females) with an average age of 68 years. Indications for surgery included asymptomatic high grade stenosis (greater than 50% of luminal area) and transient or permanent neurological symptoms. All operations were performed under general anesthesia employing inhalation anesthetics (usually enflurane). EEG monitoring began before the incision was made and was terminated at skin closing. Upon awakening from anesthesia patients were examined for gross motor, sensory, and speech abnormalities.

The EEG was obtained from five Grass 9 mm gold cup electrodes affixed to the scalp with colloid. Inter-electrode impedance was maintained at less than 10 k ohm. Because the scalp distribution of EEG frequencies is only related to anatomical vascular perfusion in a general manner, we employed a single EEG channel from over the watershed area of perfusion between the anterior and posterior vascular supply of each hemisphere. The EEG signals from two channels (CE-P3 : C4-P4 : Fpz ground) were displayed on a monitor and digitized using an analyzer\(^1\) (bandpass 1 to 16 Hz, common mode rejection greater than 90 dB with 6 dB per octave roll-off). The analyzer provided successive compressed spectral arrays (averaged over 30 second epochs) on a strip chart employing hidden line suppression. Simultaneously, a histogram of the power spectrum of six pre-selected frequency bands was displayed on a separate monitor, updated every three seconds, and printed every three minutes. We averaged the power into three frequency bands: low (delta and theta, 0.25 to 6.0 Hz); middle (alpha, 6.0 to 10.5 Hz); and high (sigma and beta, 10.5 to 16.0 Hz). The histograms were used to calculate changes in power for each of the frequency bands. The average power for the 90 sec before clamping was compared to the 90 sec after clamping to minimize long-term trends such as changes in the level of anesthesia.

The intraoperative shunting decisions were based on:

— preoperative angiographic evidence of contralateral carotid occlusion or intracerebral stenosis;

— recent stroke (within 6 weeks);

— changes in spectral EEG parameters with clamping of the internal carotid artery. A total of 34 patients were shunted, 19 on the basis of preoperative criteria alone.

\(1\) OTE Berg Fourier.

RESULTS

Three patterns of EEG response to clamping of the internal carotid artery were found:

— Mild or no power reduction. The EEG spectral power change did not exceed 50% for any frequency band.
— Marked power reduction. A reduction of EEG spectral power by more than 50% in one or two frequency bands.

— Global power reduction. Reduction by more than 50% of EEG power in all three frequency bands.

A mild power reduction or no significant change of the EEG was observed in 82 patients (78%), and was the most commonly observed pattern. There were no post-operative deficits in this group of patients. Shunts were placed in 19 cases based on pre-operative clinical or angiographic criteria.

Marked power reduction was observed in 12 patients (11%), five of whom were shunted based on preoperative criteria. Shunting caused a gradual reversal of the power reduction in all five of the cases, which was complete within five minutes after opening of the shunt. The seven unshunted patients showed initial and then intermittently recurrent reductions of power. There were no post-operative deficits in this group.

Global power reduction occurred in 11 patients (11%) after clamping of the carotid artery. Ten of these patients were shunted; much of the low frequency EEG reduction was reversed within five minutes, although 7 patients demonstrated sustained high frequency reductions. EEG power then remained at near pre-clamp levels throughout the remainder of the surgery, except during removal of the shunt (Figs. 1 and 2). The postoperative neurologic examination was unremarkable in these patients.

The only post-operative deficit observed in the series was exhibited by a patient who could not be shunted for technical reasons. His EEG remained suppressed for the 45 minutes of carotid occlusion (Fig. 3). Upon awakening from anesthesia, this patient demonstrated a left hemiparesis (leg greater than arm) and a dense homonymous hemianopsia, both of which gradually cleared within 24 hours. The patency of the operated carotid was confirmed by real-time imaging.

The three frequency bands were differentially affected by clamping. High frequency activity was the most susceptible to reduced blood flow, showing a
greater incidence and degree of reduction. If high frequencies were stable after clamping, it was unlikely that reduction of low or middle frequencies occurred. The amount of EEG power reduction for each of the three frequency bands is shown for the 23 patients with EEG changes in Figure 4. Of interest was the tendency for more patients to show a reduction of high frequencies after clamping. None of the patients with marked power reduction (group 2) showed less than a 40% reduction of high frequency activity. In contrast, only thirteen patients showed a greater than 40% reduction in low frequencies. This group was comprised of the eleven patients with global reduction (group 3) plus two borderline patients who had greater than 40% reductions of all frequencies. One of these borderline patients was shunted based on preoperative criteria, and the other had a very transient reduction of activity confined to the side of the surgery which resolved within minutes after clamping and before a shunt was placed.

**DISCUSSION**

Several studies which have compared the monitoring of raw EEG tracings with processed EEG techniques have found the latter to be superior both in terms of sensitivity to changes and the ease with which changes can be noted [12, 19, 21, 22]. A retrospective review of our data indicated that we were able to rapidly detect an on-line drop of 20% in power in individual frequency bands using spectral analysis. This change was not evident when viewing the raw EEG display. Although the experienced observer could detect similar changes in the hidden line suppression display (Fig. 1), only the histogram display clearly communicated minute changes (Fig. 2).
Selective reduction of EEG spectral power was not equal in all frequency bands. In cases of significant EEG change there was a tendency for frequencies above 10.5 Hz to be reduced by clamping of the internal carotid artery, whereas frequencies below 6.0 Hz appeared more resistant to reduction. This is in agreement with Faught [23], who reported the loss of high frequencies as a sensitive measure of cerebral ischemia. However, he found that the loss of fast activity alone was not associated with residual neurologic deficits. Our data support this contention in two ways:

— seven group 2 patients who were not shunted had reduced high frequencies throughout clamping of the carotid artery, yet demonstrated no postoperative deficits;

— seven of the shunted patients in group 3 had selective reduction of high frequency activity even after shunting (Fig. 1) and also had no postoperative deficits. Conversely, we observed that decreases in the power of the most robust low frequency band were always associated with reduction of middle and high frequencies, suggesting that reduction of low frequencies is an early sign of ischemic damage.

It has been suggested that cortical ischemia is reflected by a «EEG slowing» [24]. Some analogy to this phenomenon could be found among patients displaying selective power reduction, in which the power of high or middle frequencies was reduced with little or no change in the power of the low frequency band. However, true «slowing», as indicated by a decrease in power of high frequencies in conjunction with an increase in power of the low frequency band, was rare in our study, with only three patients showing significant increases in the low frequency band after clamping. Our amplifier time constant of 0.1 sec may have contributed to this finding by attenuating low frequency activity.

The transient neurologic deficit exhibited by the patient who could not be shunted in spite of displaying global EEG reduction supports the need for shunting in selected patients undergoing carotid endarterectomy. Our observation of this pattern in 11% of our patients is consistent with other studies that concluded that 9 to 16% of unselected carotid procedures will require shunting based on EEG changes alone [10, 12, 13]. Some authors have argued that the EEG is too sensitive for such a decision, in that EEG-based polemics may cause the placement of too many shunts [25-26]. The selection of an appropriately conservative EEG criterion can overcome this problem.

Still at issue is whether patients with partial EEG reduction should be shunted. We observed no morbidity among the six patients with marked power reduction (group 2) who were not shunted. However, five patients showing this EEG pattern were shunted based on preoperative criteria which may have prevented postoperative deficits. A larger series of patients is needed to refine the decision making process for this group.

Because global reduction of EEG spectral power was associated with a transient post-operative neurologic deficit, we conclude that shunts should be placed when this pattern is seen in response to clamping of the internal carotid artery.

Global EEG reduction appears to be an early sign of cerebral compromise, and ischemia-related deficits should not arise if the pattern is rapidly reversed. Although other patterns of EEG reduction in conjunction with preoperative risk factors may also warrant the placement of a shunt, we found no evidence that shunts should be placed in patients manifesting no changes in EEG or isolated reductions in high frequencies.

REFERENCES


RESUMEN: Un análisis espectral de las ondas electroencefalográficas fue llevado a cabo perioperatoriamente en 105 enfermos (63 varones y 42 mujeres) con edad media de 68 años durante una EA carotidea. La clínica previa de estos enfermos incluía no sólo lesiones estenosantes severas, sino también ataques isquémicos transitorios o déficits neurológicos permanentes. En todos se utilizó una anestesia general. La monitorización del electroencefalograma se empezó antes de la incisión y finalizó con el último punto de piel. El trazado electroencefalográfico se obtuvo mediante 5 electrodos de oro de 9 mm, tipo Grass, fijados a la calota. Se utilizó un solo canal por cada área de perfusión. El trazado electroencefalográfico de los dos canales se visualizó en un monitro y mediante un analizador de Fourier OTE Berg se efectuó el estudio espectral. Este proporciona series de bandas espectrales periódicamente (media de 30 seg.). De forma simultánea se obtenen histogramas de los potenciales del espectro de 6 bandas de frecuencia preseleccionadas y grabadas cada 3 min. Se dividió el espectro en 3 bandas de frecuencias: baja (delta y teta 0.25 a 6 Hz); media (alfa 6 a 10.5 Hz) y alta (sigma y beta 10.5 a 16 Hz). Los histogramas se utilizaron para medir los cambios de potenciales de frecuencia de bandas. Hubo 3 patrones de respuesta al clampaje carotídeo: 1) moderada o nula alteración; 2) marcada reducción de los potenciales y 3) reducción global. En el grupo I se incluyen 82 pacientes sin ningún déficit postoperatorio. Se utilizó el shunt en 19 enfermos según los criterios anteriormente expuestos. El grupo II hubo 12 enfermos, 5 con shunt y es de notar que en estos 5 enfermos se normalizaron las alteraciones electroencefalográficas. No hubo tampoco déficit neurológico postoperatorio. En el grupo con reducción global se incluyeron 11 enfermos, en los 10 en que se utilizó el shunt, con ello se consiguió una normalización de las alteraciones de la banda de baja frecuencia, pero en 7 persistieron las alteraciones en la banda de alta frecuencia. Hubo un enfermo con déficit neurológico postoperatorio, en el que no se pudo utilizar el shunt por problemas técnicos, estando su EEG alterado durante 45 min. De las tres bandas, la de alta frecuencia fue la más sensible a la reducción del flujo. Ninguno de los enfermos incluidos en el grupo II mostró una reducción menor del 40% de la actividad de alta frecuencia; en contraste, sólo 13 mostraron una cifra superior al 40% de reducción. Parece claro que el procesoamiento de los potenciales del EEG es superior en términos de sensibilidad al simple trazado. En nuestro estudio el trazado simple no fue capaz de detectar reducciones del 20%, que sí fueron captadas por la técnica del análisis espectral y, sobre todo del histograma. A pesar de que la alta frecuencia fue la más sensible al clampaje, la reducción de estas frecuencias no se asoció con déficits neurológicos. En este estudio sólo se vieron 3 enfermos con una disminución de los potenciales de alta frecuencia en conjunción con aumento de los de baja frecuencia, en contraste con otros autores que quieren ver en esta combinación signos de isquemia cortical. El hecho del déficit neurológico en un enfermo con disminución de potenciales y sin shunt, sugiere la necesidad de éste en casos seleccionados de EA carotidea. Aunque otros parámetros pueden ser factores que nos obligan a utilizar el shunt, parece claro que ante una ausencia de cambios en el EEG o alteraciones aisladas en potenciales de alta frecuencia, no es necesaria la utilización de la cánula.