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Cerebral monitoring during carotid endarterectomy – a comparison between electroencephalography, transcranial cerebral oximetry and carotid stump pressure

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Summary

Objective. Various modalities are used for cerebral monitoring during carotid endarterectomy (CEA). The aim of this study was to evaluate whether transcranial cerebral oximetry (TCO) and carotid stump pressure (SP) are as accurate as electroencephalography (EEG) for monitoring cerebral ischaemia during carotid cross-clamping.

Methods. One hundred consecutive patients who underwent CEA were studied with continuous and simultaneous EEG and TCO. SP was measured for each patient. The percentage decrease of oxygenation on TCO was calculated during cross-clamping and surgery. EEG findings were used as the benchmark to detect cerebral ischaemia and were the indication for insertion of a temporary shunt. The relationship with TCO was observed in terms of percentage decrease in oxygenation.

Results. A total of 6 patients were shunted on the basis of their EEG changes. TCO changed more than 20% in these 6 patients, but an additional 12 patients had TCO changes with a normal EEG. This correlated with a decrease in blood pressure (BP) and was corrected by increasing the BP. The positive predictive values (PPVs) and negative predictive values (NPVs) for shunting based on TCO (as compared with EEG) were 33% and 100% respectively. Thirty-four patients had SP < 50 mmHg, of whom 4 were shunted based on EEG changes. Two of 66 patients with SP > 50 mmHg were shunted based on EEG changes. If a shunting policy had been based on a SP of 50 mmHg, 30 patients would have been shunted unnecessarily (PPV 12%), whereas the non-requirement for a shunt was predicted correctly in 64 of 66 patients (NPV 97%).

There were 2 major strokes: 1 contralateral on day 3 in a patient with bilateral severe stenoses, and 1 ipsilateral in a non-shunted patient with normal EEG, TCO and SP > 50 mmHg.

Conclusion. Compared with EEG, TCO is a practical and non-invasive monitoring system with a high sensitivity (100%) but a low specificity. TCO is more sensitive to a drop in BP and responds earlier to these changes than EEG. SP should not be used as the sole predictor for shunting during CEA.

Carotid endarterectomy (CEA) has clearly been established as beneficial in patients with symptomatic (moderate and high-grade) and asymptomatic (high-grade) carotid artery stenoses.[1-3] In all three of the latter studies perioperative stroke occurred in a small percentage (3 - 5%) of patients undergoing CEA, usually caused by an embolism or cerebral ischaemia.

Assessment of cerebral ischaemia during CEA has been unreliable[4,5] in predicting perioperative stroke.

Formal monitoring of brain function during CEA is not universally accepted. Most surgeons, however, use some cerebral monitoring technique when performing carotid surgery. Controversy remains concerning methods of intra-operative monitoring, criteria for shunt placement and optimal anaesthetic technique. The reported 1 - 3% risk of an embolism, damage to the arterial wall and the technical difficulties associated with shunt use brought into question the routine use thereof.[6] Stump pressure (SP) measurement using a 50 mmHg cut-off has been reported to be a reliable predictor of clamping ischaemia necessitating a shunt placement.[7,8]

Although more sophisticated monitoring mechanisms are being investigated, the EEG remains the most widely used monitor of cerebral function.[9]

Transcranial cerebral oximetry (TCO), based on the principles of near-infrared spectroscopy as first described by Jobsis[10] nearly 3 decades ago, is now available (INVOS 3100, Somanetics Corporation, Michigan, USA). This system monitors changes in the regional oxygen saturation (RSO_2), by non-invasive sampling of blood in the cerebral cortex.

This study was designed to evaluate the performance of the INVOS 3100 cerebral oximeter in detecting the development of cerebral ischaemia during carotid artery cross-clamping compared with EEG and SP.

Patients and methods

One hundred adults (72 males, 28 females) between the ages of 47 and 82 years (mean age 66 years), who underwent 100 CEAs over a 3-year period, were studied with continuous and simultaneous EEG and TCO monitoring. SP was measured in all patients and the stump pressure index (SPI) was calculated. All patients had general anaesthesia and were operated on by the same vascular surgeon (JvM). All patients were evaluated preoperatively by an experienced sonographer using duplex sonography. Seventy-five patients had symptomatic lesions (TIA in 60, CVA in 15) with stenoses > 70%, except for 4 patients who had stenoses measuring > 60%. Twenty-five patients had asymptomatic stenoses > 80%.

A 16-channel EEG was attached and monitored by an experienced neuro-technologist. Attenuation or loss of higher-frequency background activity and the appearance or increase of regional delta activity constitute the two principal changes associated with cross-clamping of the carotid artery.

Two cerebral oximeters (INVOS 3100) were used for simultaneous, bilateral RSO_2 monitoring. The sensors were applied to the forehead, 1 on either side of the midline, such that the light transmitters were placed at least 3 cm from the midline (Fig.1). In this process near-infrared light photons are injected into the skin over the forehead. After being scattered about inside the scalp, skull and brain, some fraction of the injected photons survives to return and exit from the skin ('reflectance'). By measuring the quantity of returning photons as a function of wavelength, one can infer the spectral absorption of the underlying tissue and make some conclusions about its average oxygenation.[11] There is a wide range of baseline RSO_2 values, varying from 47% to 86%. Peer-reviewed clinical studies[12-14] have shown that relative RSO_2 changes > 20% from baseline (or absolute values < 50%) are associated with increased long-term cognitive decline, frontal lobe injury, longer intubation time and longer intensive care unit (ICU) and hospital stays.

EEG findings were used as the benchmark to detect cerebral ischaemia during this period. Patients were shunted when EEG findings indicated cerebral ischaemia.

The relationship with TCO was described in terms of the decrease in percentage oxygenation. The relationship with SP was described in terms of the traditional cut-off value of 50 mmHg. SP reflects the systolic pressure at that moment and therefore might be an unreliable value if the blood pressure (BP) is at an extreme, either low or high. The relationship of carotid stump pressure (systolic) to the mean arterial pressure may be more accurate in predicting cerebral ischaemia than SP alone.

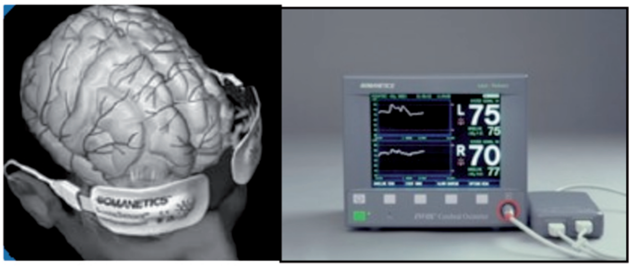

Fig. 1. INVOS 3100 SomaSensors on both sides of the forehead and the absolute RSO_2 values.

Standard endarterectomy was performed through a longitudinal arteriotomy. The majority of arteriotomies were sutured with a dacron patch. Primary suturing was done only when it was possible to use the eversion technique.

Results

CEA was completed successfully in all patients. A total of 6 patients (6%) were shunted on the basis of EEG changes. In all cases of EEG changes, transcranial oximetry showed a change greater than 20%. The baseline RSO_2 varied from 47% to 86%. The mean duration of cross-clamping of the carotid artery was 18 minutes. In 12 patients (12%) the decrease in oxygenation as measured by TCO (at any time during cross-clamping) was greater than 20% without EEG changes. This correlated with a decrease in BP and was corrected by increasing the BP.

The results are shown in Tables I and II. TCO versus EEG showed a sensitivity of 100% (6 patients had EEG changes and those 6 all had oxygenation decreases > 20%) and a specificity of 87.2% (82 of 94 patients had oxygenation decreases < 20% and no EEG changes). The 'false-positives' amounted to 66.6% (N = 12/18) and the 'false-negatives' to 0% (0/6), with a positive predictive value (PPV) of 33.3% (6/18) and a negative predictive value (NPV) of 100% (82/82).

SP versus EEG showed a PPV of 12%. Thirty patients would have been shunted unnecessarily with a SP < 50 mmHg. The NPV was 97%, with 64 of 66 patients correctly predicted (SP > 50 mmHg) not in need of a shunt.

Ninety-eight patients left the hospital without a clinically detectable, new neurological deficit. Two major strokes occurred, 1 contralateral on day 3 in a shunted patient with bilateral severe stenosis, and 1 ipsilateral with dysphasia on day 1 in a non-shunted patient (EEG and TCO normal, SP 61 mmHg). Minor complications were 1 neck haematoma, 1 patient with hoarseness that cleared up and 1 patient with neuralgia over the operative scar that subsequently cleared up.

Discussion

The principal goal of monitoring during CEA is to identify possible causes of neurological impairment sufficiently early to allow prompt correction of the cause. Monitoring

TABLE I. COMPARATIVE RESULTS – TCO AND OTHER MODALITIES WITH EEG

EEG changes	TCO changes (%)	Stump pressure (mmHg)	Stump pressure index	Shunt
Yes	**> 20**	**22**	**0.22**	**Yes**
Yes	**> 20**	**54**	**0.61**	**Yes**
Yes	**> 20**	**40**	**0.65**	**Yes**
Yes	**> 20**	**40**	**0.56**	**Yes**
Yes	**> 20**	**75**	**0.79**	**Yes**
Yes	**> 20**	**30**	**0.31**	**Yes**
6/100 EEG changes	**18 patients > 20%**	**34 patients < 50 (22 - 49)**	**SPI of the same 34 patients 0.22 - 0.67**	**6/100 shunted 94/100 not shunted**

ECG = electroencephalograph; TCO = transcranial cerebral oximetry.

TABLE II. COMPARATIVE RESULTS – CHANGE IN REGIONAL SATURATION v. EEG

RSO_2	Total	EEG abnormal	EEG normal
> 20%	**18**	**6**	**12**
< 20%	**82**	**0**	**82**
	100	**6**	**94**

RSO_2 = regional oxygen saturation; EEG = electroencephalograph.

during the surgical procedure to detect ischaemia (to determine the need for placement of a shunt) or emboli as the cause of the impairment will lead to the treatment and/or prevention thereof. Nevertheless, the benefit of shunting must be weighed against the small risk of causing cerebral embolisation with shunting and the fact that most intraoperative strokes are thromboembolic (as seen with transcranial Doppler scanning) rather than haemodynamic in cause.

Monitoring of brain function is characterised by the need for adequate spatial and temporal resolution, and the technique must be sensitive to haemodynamic and thromboembolic causes of stroke. No perfect monitoring device has yet been developed and therefore controversy continues as to which type of monitoring is adequate and whether it even makes a significant difference.

Monitoring of the conscious patient[15,16] provides a unique opportunity to determine the time of onset of a neurological deficit and to deduce the likely cause. Intraoperative neurological deficit is most often associated with carotid artery dissection or clamp release (83%) and only rarely with cross-clamping (17%).[17] Pruitt[18] found that in 5% of 1 009 CEAs, the EEG showed cerebral ischaemia but the clinical status of the patients did not change at all. In 4% of the cases the EEG remained normal, whereas the clinical status showed obvious cerebral ischaemia.

TCO was evaluated with regional anaesthesia by Samra *et al.*[19] and Roberts *et al.*[20] They found that RSO_2 had an inter-subject variability in the pre-clamp period. Samra *et al.*[19] took a decrease in RSO_2 of 20%, or an absolute reading of less than 50%, as indicative of cerebral ischaemia, resulting in a false-negative rate of 2.6% and a false-positive rate of 66.7%. Roberts *et al.*[20] used a decrease of ≥ 27% in RSO_2 as indication for a shunt and had no false-negative or false-positive results in 45 patients. A possible explanation was the shorter duration of cross-clamping, and it was demonstrated that permanent sequelae result from a combination of both the magnitude and duration of ischaemia. It was concluded that a change in RSO_2 after carotid cross-clamping can be used as a trend monitor and when used with a decrease ≥ 20%, is similar to EEG and somatosensory evoked potential (SSEP) monitoring.

Mental status evaluation during carotid cross-clamping in the awake patient remains the gold standard with which other methods of monitoring should be compared.[21,22]

With patients under general anaesthesia, controversy continues as to the value of EEG (or for that matter any other type of monitoring), particularly in patients who have a pre-existing neurological deficit.[23,24] Nevertheless, intraoperative assessment with EEG has withstood the test of time as a widely applied and readily available method for determining cross-clamp-dependent ischaemia and the need for a shunt.[25,26] Under general anaesthesia, monitoring with EEG remains the gold standard.[27] The need for trained personnel to interpret the raw data and the cost involved is a disadvantage, but computer-assisted techniques have been introduced to address these problems.

Under general anaesthesia there may be a lag between the onset of cerebral ischaemia and recognisable EEG changes. These changes related to the level of anaesthesia are gradual and generalised, and should not be confused with the changes caused by cross-clamping which are either sudden in onset or progress rapidly and are usually focal or predominant on one side. EEG reliably monitors cortical function, but does not always provide useful information on changes confined to the depths of sulci, the subcortical grey matter, or to the deeper structures such as the internal capsule. Anaesthetic depth must be carefully controlled at levels that do not induce slow-wave activity. Maintenance of normocapnia, normovolaemia, normal body temperature and mean arterial pressure in the upper portion of the patient's pre-operative range is important to the interpretation of the EEG.[28] Finally, the lowered cerebral metabolic rate may actually reduce the damaging effect of cerebral ischaemia.[29]

In our study of 100 patients TCO was evaluated under general anaesthesia, with EEG monitoring as the benchmark for detecting cerebral ischaemia during cross-clamping of the carotid artery for CEA. In all 6 cases where EEG changes necessitated the placement of a shunt, TCO showed a decrease greater than 20%. Twelve patients had a decrease of more than 20% in RSO_2, but with no change on the EEG monitor, and consequently no shunt was placed. This gave us a 66.6% false-positive rate and 0% false-negative results.

SP measurement is a simple and inexpensive operative monitoring technique that requires no additional fixed equipment or personnel. It has been very widely investigated and validated by different authors over the past 30 years and is still currently used, although there is no general consensus on the appropriate SP cut-off value indicating the need for shunting.[30,31] In concurrence with McCarthy *et al.*,[32] we were not able to establish a better predictor of adverse outcome by calculating the SPI versus the use of SP. In doing 629 CEAs under regional anaesthesia, Hafner and Evans[33] showed an overshunting rate of 86% with SP measurement. We showed that 30 patients would have been shunted unnecessarily at a cut-off < 50 mmHg and 2 patients would not have been shunted with significant EEG changes indicative of cerebral ischaemia. Our PPV was 12% and our NPV 97%. Cao *et al.*[8] reported on 168 patients with a PPV of 40% and an NPV of 100%.

Conclusion

In conclusion, we believe that compared with EEG under general anaesthesia, TCO is a practical and non-invasive monitoring system with a high sensitivity but a low specificity. TCO is also more sensitive to a decrease in BP than EEG and responds earlier to these BP changes than EEG. Early recognition of RSO_2 changes and intervention to correct them may prevent EEG changes and consequent shunting in these patients. SP and the SPI should not be used as the sole predictor for shunting during CEA.

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