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Bispectral index monitoring may not reliably indicate cerebral ischaemia during awake carotid endarterectomy†

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Background. Intraoperative ischaemia during carotid cross-clamping in patients undergoing carotid endarterectomy (CEA) is a major complication and prompt recognition of insufficient collateral blood supply is crucial. Electroencephalogram (EEG) is believed to be one of the useful forms of monitoring cerebrovascular insufficiency during CEA. The aim of this study was to evaluate the utility of bispectral index (BIS) monitoring, a processed EEG parameter, for the reliable detection of intraoperative cerebral ischaemia during awake CEA.

Methods. We monitored 52 patients continuously with the BIS monitor together with assessment of neurological function (contralateral upper and lower limb strength and the verbal component of the Glasgow Coma Scale for speech) in patients undergoing awake CEA.

Results. Overall mean BIS value in all patients was 96 (SD 2.9). In five patients who showed clinical evidence of cortical ischaemia during carotid cross-clamping, there was no change in the original range of BIS values throughout the procedure (96.7 [3.2]). In one patient BIS values decreased to 38 about 5 min after the incision and recovered within the next 10 min. The mean BIS value in the remaining 46 patients who did not develop clinical signs of ischaemia was 95.4 (2.6). Three cases are presented which demonstrate the inability of the BIS monitor to detect cerebral ischaemia.

Conclusions. Lack of correlation of BIS with the signs of cerebral ischaemia during CEA makes it unreliable for detection of cerebrovascular insufficiency. We conclude that awake neurological testing is the preferred method of monitoring in these patients.

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Carotid endarterectomy (CEA) reduces the risk of stroke in patients with symptomatic[1 2] as well as asymptomatic[3 4] carotid artery stenosis. Intraoperative stroke due to hypoperfusion during cross-clamping of the internal carotid artery is a major complication of CEA.[5 6] The prompt and reliable recognition of insufficient collateral blood supply is crucial for a good neurological outcome in these patients. With the use of an intraluminal shunt, there is a risk of embolization and undetected shunt malfunction. Therefore proper neuromonitoring is desirable for identifying patients who will benefit from shunt placement. There are a number of intraoperative monitoring techniques currently in use for the detection of cerebral ischaemia. These include monitoring of neurological status in an awake patient,[7] EEG,[8] processed EEG,[9] somatosensory evoked potentials,[10] regional cerebral blood flow monitoring,[11] stump pressure,[12] jugular venous oxygen saturation[9 13] and transcranial Doppler monitoring.[14 15] In general, EEG is believed to be an accepted form of monitoring cerebrovascular insufficiency during CEA.[16]

The bispectral index (BIS) is a processed EEG parameter which is statistically derived from an empirical database using a proprietary methodology to calculate indices of the EEG power spectrum, burst synchronization and phase coupling. The stepwise development of BIS has been detailed by Rampil.[17] It has been suggested previously that the value of BIS may decrease as a result of cerebral ischaemia.[18] In yet another case report BIS was the earliest indicator of acute perioperative stroke during removal of a

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left ventricular assist device.[19] The development of clinical ischaemia in awake CEA patients presents a unique opportunity to evaluate utility of BIS as an indicator of cerebral ischaemia. We hypothesized that BIS will correlate with clinical signs of cerebral ischaemia during carotid cross-clamping for CEA in awake patients.

Subjects and methods

After approval by the Joint Ethics Committee, 52 patients undergoing awake CEA under local anaesthesia participated in this study. Each patient presented for an elective CEA within the indications established by the European Carotid Surgery Trial (ECST)/North American Symptomatic Carotid Endarterectomy Trial (NASCET) studies, or as a part of the Asymptomatic Carotid Surgery Trial (ACST). All patients gave written informed consent for the BIS monitoring during the procedure.

Five-lead ECG, pulse oximetry for oxygen saturation and invasive measurement of mean arterial blood pressure were performed for all patients. For local/regional anaesthesia a mixture of lidocaine 1% with epinephrine and bupivacaine 0.25% was infiltrated around the wound edges, into the wound and the carotid sheath as required. During the procedure each patient received oxygen at 4–8 litre min^{-1} via a facemask or nasal prongs. One or more intravenous access lines were inserted and normal saline was given intravenously. Blood pressure was allowed to fluctuate spontaneously unless ischaemia developed, in which case it was elevated to a systolic pressure of ∼180 mm Hg using volume expansion. During the operation, the patients' neurological functions were continuously assessed. Contralateral upper and lower limb function and strength was assessed as normal, reduced or absent. Speech was assessed using the verbal component of the Glasgow Coma Scale. Neurological examination was conducted every 30 s when carotid clamps were applied. An ischaemic deficit was defined as any decrease in lower or upper limb power, confusion or dysphasia. If a severe neurological deficit occurred, a Javid shunt was inserted. The Bispectral Index A-2000 Monitor (Aspect Medical Systems, MA) was used in all the patients during carotid cross-clamping. A BIS Zip prep sensor was placed on the patient's forehead as recommended in the manufacturer's guidelines. All patients were continuously monitored before, during and after the cross-clamping. During the procedure the BIS monitor was connected to a laptop computer which recorded data every minute in real time.

Results

Table 1 shows the characteristics of all patients (*n*=52) in this study. All values are expressed as mean (SD). The mean BIS value in all patients (*n*=52) was 96 (2.9) (range 86–98). Five patients developed clinical cerebral ischaemia, ranging from mild limb weakness to profound weakness and speech dysfunction, during the clamping period. The mean BIS value in these five patients was 96.7 (3.2). The ischaemic deficit was reversed following clamp removal in all patients. A Javid shunt was inserted in three patients. The BIS values remained steady in all three patients who had shunts inserted. In one patient BIS values decreased to 38, coincident with a decrease in the level of consciousness about 5 min after the incision, and recovered within the next 10 min. This patient is described below as patient 3. The mean BIS value in the remaining 46 patients who did not develop clinical ischaemia during carotid cross-clamping was 95.4 (2.6). No permanent postoperative deficits occurred in any of the patients enrolled in the study. A brief description of three patients is presented below.

Table 1 Patient characteristics (*n*=52). Data are mean (SD) unless otherwise stated

Mean age (yr)	65.4 (12)
Mean clamping time (min)	19 (9)
Gender	
Male	37 (71.1%)
Female	15 (28.8%)
Contralateral stenosis	32 (61.5%)
Shunt insertion	3
Overall mean BIS values	96 (2.9)

Patient 1

A male patient aged 65 yr underwent awake left CEA under local anaesthesia. Eight weeks before this surgery, he had suffered hemiplegia and expressive dysphasia from which he had made full recovery. He had a history of hypertension for 9 yr. He had 80% stenosis of the left internal carotid artery (ICA) and <60% stenosis of the right ICA assessed by colour Doppler done preoperatively for diagnosis. BIS monitoring was used for continuous cerebral monitoring together with neurological assessment during the awake procedure. After 17 min of cross-clamping, the patient developed subtle neurological changes. He was a few seconds slower in responding to questions and could not tell which day of the week it was. At this time his BIS value remained in the range 90–98. After 25 min of cross-clamping he became dysphasic and confused. His BIS values showed no change. The patient's condition gradually improved over the next 10 min with insertion of shunt. He was able to work out which day of the week it was. At this point the BIS values displayed no further change and were constantly noted in the same original range. This patient was then sedated with midazolam 0.15 mg kg^{-1}. At this time BIS values dropped down stepwise to a range of 70–80. The rest of the procedure was uneventful. After cross-clamp release, no neurological or haemodynamic changes were noted. His postoperative recovery was also uneventful and he was discharged on the second postoperative day.

Patient 2

A male patient aged 66 yr with a history of hypertension and angina on effort and >90% stenosis of right ICA underwent a right-sided CEA under local anaesthesia. Intraoperative BIS values were in the range 86–94. The patient was responding correctly to all questions and obeying commands. This patient developed a left-sided hemiparesis and dysphasia immediately after cross-clamping but was fully conscious. At this point BIS values showed no change. A shunt was inserted in this patient with recovery of hemiparesis and speech over next 15 min. The shunt was removed 25 min later. BIS values remained in the original range of 86–94 throughout the procedure. The patient was kept in recovery for 2 h for close neurological and haemodynamic assessment, after which he was sent to the ward. He was discharged on the third postoperative day.

Patient 3

A female patient aged 72 yr underwent awake CEA. She had a history of non-insulin-dependent diabetes mellitus and hypertension. She had 70–80% stenosis of the left ICA and <40% stenosis of the right ICA. About 5 min after the incision, BIS values demonstrated a sharp fall from 92–98 to the low sixties. The patient became confused and dysphasic while the BIS values dropped further to 38–42. The patient gradually recovered over the next 10 min and it was decided to continue with the surgery. At this time BIS values returned to the normal range of 90–98. The remaining procedure was uneventful. No shunt was required during carotid cross-clamping in this patient.

Discussion

We present results in 52 patients who underwent continuous BIS monitoring and neurological assessment during elective awake CEA. In five patients who showed ischaemic changes in the form of neurological deficits, BIS values did not change from the baseline level, and dropped only in response to sedation or global cerebral depression. Our findings are consistent with one study in which no awake CEA patients manifested global EEG changes with cross-clamping of the carotid artery,[20] and there are two previous reports[21 22] of failure of processed EEG compared with awake neurological assessment for the detection of cerebral ischaemia. In patient 3, BIS values decreased with the level of consciousness of the patient at the beginning of the procedure and returned to normal as the patient recovered gradually. This could have been due to an embolus or vasovagal syncope, which has been previously reported due to venipuncture in a patient with suspected needle phobia,[23] or to a possible intravascular effect of local anaesthesia.

The correlation of standard EEG and a decreased cerebral blood flow (CBF) during CEA has been well established.[24] The EEG changes become apparent when CBF drops below 20 ml $(100\ g)^{-1}\ min^{-1}$ although individual variations may be seen. While there are no large studies that document improved neurological outcome with EEG monitoring during CEA, there is convincing evidence that persistent EEG abnormalities that occur intraoperatively are sensitive in detecting intraoperative strokes.[25] It is widely accepted that EEG attenuation occurs with progressive decrease in CBF with disappearance of α and β rhythms and increase in delta rhythm.[26] In one study, the use of EEG monitoring and selective shunting was associated with a reduction in the frequency of carotid shunts (49% *vs* 12% in the selective shunting group) and a decline in combined major neurological morbidity and mortality (2.3% *vs* 1.1%).[8] Thus EEG is believed to be a sensitive detector of cerebral ischaemia and a valuable tool for determining the need for shunting during CEA.[27–29] Similarly, processed EEG has been reported to detect cerebral ischaemia during CEA successfully.[30–32] The BIS specifically decomposes the EEG, quantifying the level of synchronization in the signal together with the traditional amplitude and frequency variables, thereby providing a more complete description of complex EEG patterns. It is a proprietary quantitative EEG variable that is derived using a complex algorithm from time, frequency and bispectral domains from a two-channel EEG. The BIS algorithm was designed specifically to quantify depth of anaesthesia in operating theatre settings. However it has been increasingly used in intensive therapy units to titrate sedatives and quantify the level of sedation in critically ill patients.[33–35] Furthermore, acute decreases of the BIS values have been shown to be related to severe cerebral ischaemia,[18] specifically in carotid endarterectomy patients.[36] In one case report, an acute decrease in BIS, which coincided with a decrease in cerebral haemoglobin saturation detected by near-infrared spectroscopy, suggesting a reduction in cerebral blood flow, was shown to be associated with acute slowing of the raw EEG waveforms.[37] The same group used BIS monitoring combined with near-infrared spectroscopy to detect cerebral ischaemia during cardiac surgery in 65 children.[38] Recently BIS has been reported as detecting cerebral hypoperfusion in a patient with a history of chronic renal failure undergoing construction of arteriovenous shunt who had had an intracranial haematoma evacuated 1 month earlier.[39] A marked decrease in bispectral index by cervical haematoma reducing cerebral perfusion pressure has been reported in a patient with a ruptured abdominal aortic aneurysm undergoing aneurysmectomy.[40] The authors suggest that the BIS monitor may be a simple and convenient monitor for cerebral ischaemia detection. However, our results show that there was no correlation between BIS values and neurological assessment in any of the patients who developed a clinically apparent ischaemic deficit during the clamping period. Although processed EEG has been shown to be an accurate monitor of neurological function and a reliable indicator of whether a shunt is required during CEA, there have been reports of its failure to detect ischaemic episodes during CEA.[21 22] This also applies to the standard EEG[41 42] and perhaps to BIS monitoring as seen by our results.

In our study, physical examination during awake carotid endarterectomy allowed prompt accurate identification of patients with cerebral ischaemia who would clearly benefit from placement of a shunt. Although monitoring of neurological function of the awake patient tests gross functions, it is easy to perform and more sensitive than both EEG and BIS monitoring as seen from our results.

In summary, our findings suggest that BIS monitoring during awake CEA is unreliable for the detection of cerebrovascular insufficiency. Awake neurological testing is the preferred method of monitoring in these patients.

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References

1 Anonymous. Randomised trial of endarterectomy for recently symptomatic carotid stenosis: final results of the MRC European Carotid Surgery Trial (ECST). *Lancet* 1998; **351**: 1379–87

2 Barnett HJ, Taylor DW, Eliasziw M, *et al*. Benefit of carotid endarterectomy in patients with symptomatic moderate or severe stenosis. North American Symptomatic Carotid Endarterectomy Trial Collaborators. *N Engl J Med* 1998; **339**: 1415–25

3 Halliday A, Mansfield A, Marro J, *et al*. Prevention of disabling and fatal strokes by successful carotid endarterectomy in patients without recent neurological symptoms: randomised controlled trial. *Lancet* 2004; **363**: 1491–1502

4 Anonymous. Endarterectomy for asymptomatic carotid artery stenosis. Executive Committee for the Asymptomatic Carotid Atherosclerosis Study. *JAMA* 1995; **273**: 1421–8

5 Thompson JE. Carotid endarterectomy, 1982—the state of the art. *Br J Surg* 1983; **70**: 371–6

6 McKinsey JF, Desai TR, Bassiouny HS, *et al*. Mechanisms of neurologic deficits and mortality with carotid endarterectomy. *Arch Surg* 1996; **131**: 526–31

7 Hafner CD, Evans WE. Carotid endarterectomy with local anesthesia: results and advantages. *J Vasc Surg* 1988; **7**: 232–9

8 Cho I, Smullens SN, Streletz LJ, Fariello RG. The value of intraoperative EEG monitoring during carotid endarterectomy. *Ann Neurol* 1986; **20**: 508–12

9 Myers RR, Stockard JJ, Saidman LJ. Monitoring of cerebral perfusion during anesthesia by time-compressed Fourier analysis of the electroencephalogram. *Stroke* 1977; **8**: 331–7

10 Prokop A, Meyer GP, Walter M, Erasmi H. Validity of SEP monitoring in carotid surgery. Review and own results. *J Cardiovasc Surg (Torino)* 1996; **37**: 337–42

11 Hirofumi O, Otone E, Hiroshi I, *et al*. The effectiveness of regional cerebral oxygen saturation monitoring using near-infrared spectroscopy in carotid endarterectomy. *J Clin Neurosci* 2003; **10**: 79–83

12 Finocchi C, Gandolfo C, Carissimi T, Del Sette M, Bertoglio C. Role of transcranial Doppler and stump pressure during carotid endarterectomy. *Stroke* 1997; **28**: 2448–52

13 Crossman J, Banister K, Bythell V, Bullock R, Chambers I, Mendelow AD. Predicting clinical ischaemia during awake carotid endarterectomy: use of the $S_{\mathrm{jv}_{\mathrm{O}_2}}$ probe as a guide to selective shunting. *Physiol Meas* 2003; **24**: 347–54

14 Dunne VG, Besser M, Ma WJ. Transcranial Doppler in carotid endarterectomy. *J Clin Neurosci* 2001; **8**: 140–5

15 Ackerstaff RG, Moons KG, van de Vlasakker CJ, *et al*. Association of intraoperative transcranial doppler monitoring variables with stroke from carotid endarterectomy. *Stroke* 2000; **31**: 1817–23

16 Findlay JM, Marchak BE, Pelz DM, Feasby TE. Carotid endarterectomy: a review. *Can J Neurol Sci* 2004; **31**: 22–36

17 Rampil IJ. A primer for EEG signal processing in anesthesia. *Anesthesiology* 1998; **89**: 980–1002

18 Merat S, Levecque JP, Le Gulluche Y, Diraison Y, Brinquin L, Hoffmann JJ. [BIS monitoring may allow the detection of severe cerebral ischemia.] *Can J Anaesth* 2001; **48**: 1066–9

19 Welsby IJ, Ryan JM, Booth JV, Flanagan E, Messier RH, Borel CO. The bispectral index in the diagnosis of perioperative stroke: a case report and discussion. *Anesth Analg* 2003; **96**: 435–7

20 Illig KA, Sternbach Y, Zhang R, *et al*. EEG changes during awake carotid endarterectomy. *Ann Vasc Surg* 2002; **16**: 6–11

21 Silbert BS, Koumoundouros E, Davies MJ, Cronin KD. Comparison of the processed electroencephalogram and awake neurological assessment during carotid endarterectomy. *Anaesth Intensive Care* 1989; **17**: 298–304

22 Silbert BS, Kluger R, Cronin KD, Koumoundouros E. The processed electroencephalogram may not detect neurologic ischemia during carotid endarterectomy. *Anesthesiology* 1989; **70**: 356–8

23 Win NN, Kohase H, Miyamoto T, Umino M. Decreased bispectral index as an indicator of syncope before hypotension and bradycardia in two patients with needle phobia. *Br J Anaesth* 2003; **91**: 749–52

24 Sundt TM Jr, Sharbrough FW, Piepgras DG, Kearns TP, Messick JM Jr, O'Fallon WM. Correlation of cerebral blood flow and electroencephalographic changes during carotid endarterectomy: with results of surgery and hemodynamics of cerebral ischemia. *Mayo Clin Proc* 1981; **56**: 533–43

25 Jansen C, Moll FL, Vermeulen FE, van Haelst JM, Ackerstaff RG. Continuous transcranial Doppler ultrasonography and electroencephalography during carotid endarterectomy: a multimodal monitoring system to detect intraoperative ischemia. *Ann Vasc Surg* 1993; **7**: 95–101

26 Kearse LA Jr, Martin D, McPeck K, Lopez-Bresnahan M. Computer-derived density spectral array in detection of mild analog electroencephalographic ischemic pattern changes during carotid endarterectomy. *J Neurosurg* 1993; **78**: 884–90

27 McFarland HR, Pinkerton JA Jr, Frye D. Continuous electroencephalographic monitoring during carotid endarterectomy. *J Cardiovasc Surg (Torino)* 1988; **29**: 12–18

28 Pinkerton JA Jr. EEG as a criterion for shunt need in carotid endarterectomy. *Ann Vasc Surg* 2002; **16**: 756–61

29 Plestis KA, Loubser P, Mizrahi EM, Kantis G, Jiang ZD, Howell JF. Continuous electroencephalographic monitoring and selective shunting reduces neurologic morbidity rates in carotid endarterectomy. *J Vasc Surg* 1997; **25**: 620–8

30 Ashburn MA, Mitchell LB, Dean DF, String ST, Callahan A. The power spectrum analyser as an indicator of cerebral ischaemia during carotid endarterectomy. *Anaesth Intensive Care* 1985; **13**: 387–91

31 Tempelhoff R, Modica P, Grubb R Jr, Rich K. Early detection of cerebral ischaemia by computerized EEG monitoring. Results during 132 carotid endarterectomies. *J Cardiothorac Anesth* 1989; **3**: 72

32 Tempelhoff R, Modica PA, Grubb RL Jr, Rich KM, Holtmann B. Selective shunting during carotid endarterectomy based on two-channel computerized electroencephalographic/compressed spectral array analysis. *Neurosurgery* 1989; **24**: 339–44

33 De Deyne C, Struys M, Decruyenaere J, Creupelandt J, Hoste E, Colardyn F. Use of continuous bispectral EEG monitoring to assess depth of sedation in ICU patients. *Intensive Care Med* 1998; **24**: 1294–8

34 Simmons LE, Riker RR, Prato BS, Fraser GL. Assessing sedation during intensive care unit mechanical ventilation with the Bispectral

Index and the Sedation-Agitation Scale. *Crit Care Med* 1999; **27**: 1499–1504

35 Triltsch AE, Welte M, von Homeyer P, *et al*. Bispectral index-guided sedation with dexmedetomidine in intensive care: a prospective, randomized, double blind, placebo-controlled phase II study. *Crit Care Med* 2002; **30**: 1007–14

36 el Dawlatly AA. EEG bispectral index during carotid endarterectomy. *Middle East J Anesthesiol* 2003; **17**: 287–93

37 Hayashida M, Chinzei M, Komatsu K, *et al*. Detection of cerebral hypoperfusion with bispectral index during paediatric cardiac surgery. *Br J Anaesth* 2003; **90**: 694–8

38 Hayashida M, Kin N, Tomioka T, *et al*. Cerebral ischaemia during cardiac surgery in children detected by combined monitoring of BIS and near-infrared spectroscopy. *Br J Anaesth* 2004; **92**: 662–9

39 Morimoto Y, Monden Y, Ohtake K, Sakabe T, Hagihira S. The detection of cerebral hypoperfusion with bispectral index monitoring during general anesthesia. *Anesth Analg* 2005; **100**: 158–61

40 Umegaki N, Hirota K, Kitayama M, Yatsu Y, Ishihara H, Mtasuki A. A marked decrease in bispectral index with elevation of suppression ratio by cervical haematoma reducing cerebral perfusion pressure. *J Clin Neurosci* 2003; **10**: 694–6

41 van Alphen HA, Polman CH. The value of continuous intraoperative EEG monitoring during carotid endarterectomy. *Acta Neurochir (Wien)* 1988; **91**: 95–9

42 Kearse LA Jr, Lopez-Bresnahan M, McPeck K, Zaslavsky A. Preoperative cerebrovascular symptoms and electroencephalographic abnormalities do not predict cerebral ischemia during carotid endarterectomy. *Stroke* 1995; **26**: 1210–14