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.

Br J Anaesth 2005; 94: 800–4

Keywords: brain, ischaemia; monitoring, bispectral index; surgery, endarterectomy

Accepted for publication: February 3, 2005

Carotid endarterectomy (CEA) reduces the risk of stroke in patients with symptomatic as well as asymptomatic carotid artery stenosis. Intraoperative stroke due to hypoperfusion during cross-clamping of the internal carotid artery is a major complication of CEA. 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 neuro-monitoring is desirable for identifying patients who will benefit from shunt placement. There are a number of intra-operative monitoring techniques currently in use for the detection of cerebral ischaemia. These include monitoring of neurological status in an awake patient, EEG, processed EEG, somatosensory evoked potentials, regional cerebral blood flow monitoring, stump pressure, jugular venous oxygen saturation and transcranial Doppler monitoring. In general, EEG is believed to be an accepted form of monitoring cerebrovascular insufficiency during CEA.

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. It has been suggested previously that the value of BIS may decrease as a result of cerebral ischaemia. In yet another case report BIS was the earliest indicator of acute perioperative stroke during removal of a
left ventricular assist device. 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 \(\sim 180\) mm Hg using volume expansion. During the procedure, 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.

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

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

<table>
<thead>
<tr>
<th>Gender</th>
<th>Mean age (yr)</th>
<th>Mean clamping time (min)</th>
<th>Contralateral stenosis</th>
<th>Shunt insertion</th>
<th>Overall mean BIS values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>65.4 (12)</td>
<td>19 (9)</td>
<td>37 (71.1%)</td>
<td>3</td>
<td>96 (2.9)</td>
</tr>
<tr>
<td>Female</td>
<td>65.0 (12)</td>
<td>19 (9)</td>
<td>15 (28.8%)</td>
<td>3</td>
<td>96 (2.9)</td>
</tr>
</tbody>
</table>

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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 to sedation or global cerebral depression. Our findings are consistent with one study in which no awake CEA patients showed correct response 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.

The EEG changes become apparent when CBF drops below 20 ml (100 g) 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%).²⁷ 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,³⁸ 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.²¹²² This also applies to the standard EEG⁴¹⁴² 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
BIS monitoring in awake carotid endarterectomy

from placement of a shunt. Although monitoring of neuro-
logical 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
monitoring as seen from our results.

Invasive monitoring during awake CEA is unreliable for the detection of
cerebrovascular insufficiency. Awake neurological testing
is the preferred method of monitoring in these patients.

Acknowledgements

This work was supported by grants from the Northern Brainwave Appeal
and the Newcastle Neurosurgery Foundation.

References

1 Anonymous. Randomised trial of endarterectomy for recently
symptomatic carotid stenosis: final results of the MRC European
endarterectomy in patients with symptomatic moderate or severe
stenosis. North American Symptomatic Carotid Endarterectomy
3 Halliday A, Mansfield A, Marro J, et al. Prevention of disabling and
fatal strokes by successful carotid endarterectomy in patients with-
out 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.
6 McKinsey JF, Desai TR, Bassiouny HS, et al. Mechanisms of neuro-
logic deficits and mortality with carotid endarterectomy. Arch Surg
1996; 131: 526–31
7 Hafner CD, Evans WE. Carotid endarterectomy with local anes-
8 Cho I, Smullens SN, Strelets LJ, Fariello RG. The value of intra-
operative EEG monitoring during carotid endarterectomy. Ann Neurol
1986; 20: 508–12
9 Myers RR, Stockard JH, Saidman LJ. Monitoring of cerebral perfusion
during anesthesia by time-compressed Fourier analysis of the
encephalogram. Stroke 1977; 8: 331–7
10 Prokop A, Meyer GP, Walter M, Erasmi H. Validity of SEP mon-
(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
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_{NO}_{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
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 endarterec-
17 Rampill IJ. A primer for EEG signal processing in anesthesia.
Anesthesiology 1998; 89: 980–1002
18 Merat S, Leveque JP, Le Gullu 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
20 Illig KA, Sternbach Y, Zhang R, et al. EEG changes during awake
21 Silbert BS, Koumoundouros E, Davies MP, Cronin KD. Comparison of
the processed electroencephalogram and awake neurological
assessment during carotid endarterectomy. Anaesth Intensive Care
1989; 17: 298–304
22 Silbirt BS, Kluger R, Cronin KD, Koumoundouros E. The pro-
cessed 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 brady-
arrhythmia in two patients with needle phobia. Br J Anaesth 2003; 91:
749–52
24 Sundt TM Jr, Sharbrough FW, Piepras DG, Kearns TP, Messick JM Jr,
O’Fallon WM. Correlation of cerebral blood flow and electroencephalographic changes during carotid endarterec-
tomy: with results of surgery and hemodynamics of cerebral ische-
25 Jansen C, Moll FL, Vermeulen FE, van Haelst JM, Ackerstaff RG.
Continuous transcranial Doppler ultrasonography and electroen-
cephalography during carotid endarterectomy: a multimodal mon-
itoring system to detect intraoperative ischemia. Ann Vasc Surg
1993; 7: 95–101
26 Kearse LA Jr, Martin D, McPeck K, Lopez-Brenahan M. Computer-
derived density spectral array in detection of mild analog electro-
encephalographic ischemic pattern changes during carotid
endarterectomy. J Neurosurg 1993; 78: 884–90
27 McFarland HR, Pinkerton JA Jr, Frye D. Continuous electro-
28 Pinkerton JA Jr. EEG as a criterion for shunt need in carotid
29 Plesits KA, Loubser P, Mizrahi EM, Kantis G, Jiang ZD, Howell JF.
Continuous electroencephalographic monitoring and selective
shunting reduces neurologic morbidity rates in carotid endarter-
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 dur-
32 Tempelhoff R, Modica PA, Grubb RL Jr, Rich KM, Holtmann B.
Selective shunting during carotid endarterectomy based on two-
channel computerized electroencephalographic/compressed spec-
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


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


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


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