Cerebral circulation II: pathophysiology and monitoring

Andrea Lavinio

Addenbrooke’s Hospital, Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK
a.lavinio@addenbrookes.nhs.uk

Keywords: anaesthesia; cerebrovascular circulation; delirium

Learning objectives
By reading this article, you should be able to:

- Describe the pathophysiology of intraoperative cerebral desaturation events and its correlation with adverse neurological outcomes.
- Discuss the most relevant intraoperative neuro-monitoring modalities, including indications and patient selection, advantages and limitations of each modality.
- Interpret the main variables in neuromonitoring and discuss how they might inform optimisation of an individual’s physiology.

Cerebral circulation, adverse neurological outcomes and safe anaesthesia

The human brain is extremely susceptible to hypoperfusion and hypoxia. Intraoperative and perioperative cerebral desaturation events can be precipitated by common physiological changes associated with major surgery and general anaesthesia such as unstable haemodynamics, systemic desaturation, anaemia, hypocapnia, cardiac dysfunction and increased cerebral oxygen consumption. The depth and duration of cerebral desaturation events correlates with the incidence of severity of adverse neurological outcomes such as perioperative stroke, postoperative cognitive dysfunction (POCD) and postoperative delirium (POD). Stroke can be a devastating outcome for surgical patients and is associated with a significant increase in perioperative mortality and long-term disability. The incidence of perioperative stroke has been increasing during the past two decades despite advances in medical care, primarily as a result of the increased age and burden of comorbidities in patients undergoing major surgery. The risk of clinically silent stroke is estimated to be as high as 7% in patients aged ≥65 yrs undergoing major non-cardiac surgery. The risk of intraoperative stroke is

Key points

- Adverse postoperative neurological outcomes are common. In patients aged 65 yrs and older undergoing major non-cardiac surgery, the risk of a clinically silent stroke is 7%. There is a 20% incidence of postoperative cognitive decline in patients undergoing elective hip surgery.
- Adverse neurological outcomes correlate with the depth and duration of intraoperative cerebral desaturation events. These events can be detected by monitors such as near-infrared spectroscopy (NIRS).
- The safe conduct of anaesthesia relies on prompt recognition and correction of cerebral hypoperfusion, intracranial hypertension and metabolic disturbances such as hypoxia or hypoglycaemia.
- Processed EEG and NIRS intraoperative monitoring may reduce the risk of accidental awareness, improve early recovery times and reduce the incidence of postoperative delirium and postoperative cognitive dysfunction.

Andrea Lavinio MD FRCA FFICM RCPathME is a consultant in intensive care medicine and anaesthesia, clinical lead for organ donation and medical examiner at Cambridge University Hospitals NHS Foundation Trust. He is past lead of the Neurosciences and Trauma Critical Care Unit at Addenbrooke’s Hospital. His major clinical and research interests are neurocritical care, neuroanaesthesia and biotechnology for neuroprotection and early diagnosis of neurological injury.

Accepted: 11 February 2022
© 2022 British Journal of Anaesthesia. Published by Elsevier Ltd. All rights reserved.
For Permissions, please email: permissions@elsevier.com
considerably higher in patients undergoing aortic arch surgery, and in patient with a history of recent stroke.\(^4\) The timing of urgent procedures should be carefully evaluated at the light of this, and large-scale population analysis suggests that elective surgeries should be deferred until at least 9 months after a prior stroke.\(^4\)

Although the precise incidence of POCD and POD is difficult to assess because of methodological heterogeneity in published studies, the reported prevalence of POCD is approximately 20% in patients undergoing elective hip surgery and as high as 60% in patients undergoing cardiac surgery.\(^1\)

The term neuroprotection refers to the sum of therapeutic strategies intended to prevent or minimise injury to the nervous system. In the operating theatre, neuroprotection relies on three interlinked aspects:

- Prevention or rapid correction of cerebral hypoperfusion
- Optimisation of physiological and rapid correction of neurotoxic states, such as hypoxia, extreme hypocapnia and hypoglycaemia
- Prevention and treatment of intracranial hypertension in patients with acute encephalopathy undergoing non-deferrable surgical interventions

Cerebral hypoperfusion is defined as a mismatch between cerebral blood flow (CBF) and cerebral metabolic demand. Hypoperfusion can therefore be caused by a critical reduction in CBF, an abnormally increased cerebral metabolic rate of oxygen consumption (CMRO\(_2\)) and/or hypoxia, or a combination of the above. A critical reduction in oxygen delivery to the CNS rapidly results in cellular energy failure, neuronal dysfunction and apoptosis (i.e. cytotoxic oedema). After cardiovacular arrest in patients at normothermia, loss of consciousness occurs within seconds and brain damage ensues within a few minutes. Given the time-sensitive vulnerability of the CNS to ischaemic insults, it is essential that cerebral hypoperfusion is promptly identified and corrected, either by restoration of cerebral perfusion pressure, correction of vascular obstruction and/or reduction of CMRO\(_2\) by titrating the depth of anaesthesia, controlling seizures and managing the patients’ temperature. Although clinical observation and neurological examination can reliably identify signs of cerebral hypoperfusion in patients who are awake and breathing spontaneously, instrumental intraoperative neuromonitoring can increase the level of safety for patients at risk of adverse neurological outcomes from general anaesthesia. A rapidly growing body of evidence indicates that adverse neurological outcomes are common and that they are associated with detectable intraoperative disturbances of CBF, cortical electrical activity, or both. The anatomy and the effects of vessel occlusion at different parts of the cerebral circulation has been detailed in a previous article in this journal.\(^5\) This paper provides an overview of the neuromonitoring modalities most relevant to current anaesthetic practice (Fig. 1).

**Indications and rationale of intraoperative neuromonitoring**

The indications for perioperative and intraoperative CBF monitoring can be summarised in the following subsections.

**Patients with acute encephalopathy**

These include patients with severe traumatic brain injury, intracranial space-occupying lesions with associated injuries requiring emergency extracranial surgical intervention, or both. A common clinical scenario is the patients with multiple trauma and traumatic brain injury associated with thoracic, abdominal and/or limb injuries requiring non-deferrable surgical intervention under general anaesthesia. These patients are vulnerable to secondary intraoperative neurological injury from a combination of intracranial hypertension crises, haemodynamic instability, or both. The accepted gold standard in this clinical scenario is invasive ICP monitoring.\(^7\)

Concomitant monitoring of ICP and MAP allows continuous assessment of cerebral perfusion pressure (CPP = MAP − ICP), which should be maintained above the lower limit of cerebral autoregulation, typically CPP >50–60 mmHg. When emergency surgery takes precedence over the insertion of invasive brain monitors (i.e. damage control laparotomy in an unstable trauma victim with severe brain injury), the use of non-invasive modalities such as transcranial Doppler (TCD), near-infrared spectroscopy (NIRS) and processed EEG (pEEG) is recommended.\(^6\)

**Patients at risk of compromised CBF secondary to selective vascular clamping, thromboembolic events, or both**

These patients (e.g. undergoing carotid endarterectomy or aortic arch repair) are at risk of suffering intraoperative cerebral hypoperfusion despite normal cardiac output and normal arterial blood pressure. Safe anaesthesia during surgical clamping of arteries supplying the CNS relies on prompt recognition of critical cerebral hypoperfusion and modulation of MAP by means of vasopressors to improve collateral CBF and/or shunting and/or reduction of CMRO\(_2\) by up-titration of anaesthetic agents and controlled temperature management.

Another category for whom intraoperative CBF monitoring should be strongly considered are patients with poorly controlled hypertension undergoing non-deferrable surgical procedures, as these patients may also experience selective

---

Fig 1 The oxygen extraction fraction (OEF) of the brain is the ratio between cerebral oxygen delivery and cerebral metabolic rate of oxygen (CMRO\(_2\)). Oxygen delivery can be compromised by a reduction in cerebral blood flow (CBF) or arterial content of oxygen (\([\text{CaO}_2]\)), leading to hypoperfusion. Prompt recognition of hypoperfusion allows the prevention of ischaemia by means of anaeasthetic titration, blood pressure, and temperature and ventilation management.
cerebral hypoperfusion despite normal arterial blood pressure because of a right shift of the cerebral autoregulation curve. Non-invasive CBF monitoring modalities such as TCD, NIRS and pEEG are most useful in this context, alongside invasive monitoring of arterial blood pressure and core temperature monitoring.7

Patients expected to experience a compromised cardiac output during surgery with arterial hypotension close or below the lower limit of autoregulation

These include patients undergoing cardiac surgery, patients with expected intraoperative haemorrhage and/or managed with controlled or deliberate hypotension. In this context, non-invasive CBF monitoring with pEEG, NIRS or TCD (or a combination of these modalities) may increase patient safety. Consider developing specialist skills required to interpret data from these devices.10,11

Patients at risk of POD, POCD and delayed emergence from anaesthesia

Older patients, patients with a history of cerebrovascular disease or pre-existing cognitive disfunction are at particularly high risk of suffering adverse postoperative neurological outcomes. The BALANCED trial identified a broad range of the depth of anaesthesia that be delivered safely when titrating volatile anaesthetic concentrations using pEEG (BIS target, 35–50).12 Current recommendations for standards of monitoring during anaesthesia and recovery recognise that pEEG monitoring may reduce the risk of accidental awareness and improve recovery times, and reduce the incidence of POD and POCD.13

Monitoring modalities

All available intraoperative CBF monitoring modalities are indirect, that is they do not directly measure CBF but rather the effects of changes of CBF on cortical oxygenation and oxygen extraction (NIRS), cortical electrical activity (pEEG) or flow velocities in the arteries of the circle of Willis (TCD). Intracranial pressure monitoring allows continuous assessment of CPP. The selection of CBF monitoring modality depends on the patient’s characteristics, type of surgery, local availability and expertise.

Optimising the patient’s physiology and preventing cerebral hypoperfusion relies on one hand on modulation of CBF (i.e. maintaining CPP above the lower limit of autoregulation, avoiding mechanical obstruction to venous outflow and attention to the timing of arterial clamping) and on the other hand on modulating cerebral metabolic demand (i.e. sedation, temperature management and avoidance of seizures). The most relevant neuromonitoring modalities are described in the following paragraphs (Table 1).

Intracranial pressure monitoring

International guidelines recommend invasive ICP monitoring in patients with severe brain trauma.14,15 Bridging veins run in the subdural and subarachnoid space, draining venous blood from the cerebral cortex into the venous sinuses.5 When ICP exceeds venous pressure, bridging veins collapse thereby affecting cerebral venous outflow and cerebral perfusion (CPP=MAP−ICP). Abnormally increased ICP can therefore precipitate cerebral hypoperfusion even in the presence of normal MAP. Cerebral hypoperfusion occurs as CPP decreases below the lower limit of autoregulation (i.e. CPP <50–60 mmHg) and global cerebral circulatory arrest occurs when ICP approaches mean arterial pressure.

In patients with brain oedema or space-occupying lesions, the presence of obliterated basal cisterns and obliterated cerebral sulci indicates that CSF cannot circulate freely between intracranial fossae and the spinal canal, and that untreated intracranial hypertension could lead to intracranial or cranio-spinal pressure gradients and CNS herniation (i.e. subfalcine, transtentorial or tonsillar herniation). In the presence of such radiological features of exhausted volume-buffering reserve, ICP should be controlled below 20–25 mmHg irrespective of CPP in order to minimise the risk of life-threatening herniation. This is typically achieved by means of anaesthetic titration, hypocapnia, osmotherapy, MAP augmentation and temperature management.

The two most widely used modalities for ICP monitoring are intraparenchymal bolts and external ventricular drains (EVD). One of the main advantages of intraparenchymal bolts is their relative ease of insertion at the bedside. This makes intraparenchymal bolts the preferred modality in emergency situations and in patients with small cerebral ventricles (i.e. younger patients with diffuse brain oedema) when the placement of an EVD in the absence of stereotactic navigation in an appropriately equipped neurosurgical operating theatre can prove technically challenging. External ventricular drains have the advantage of allowing CSF drainage as a treatment modality for intracranial hypertension but carry a higher risk of serious infective complications (i.e. ventriculitis).

In patients with non-traumatic encephalopathy at risk of intracranial hypertension (i.e. recent stroke, meningoen-ccephalitis) undergoing non-deferrable surgical procedures, intraoperative ICP and CBF monitoring may improve patient safety. In instances where invasive monitoring is not indicated or not immediately available, non-invasive estimation of ICP can be achieved using non-invasive modalities such as transcranial ultrasonography (TCD).

Transcranial Doppler

Transcranial Doppler ultrasonography allows non-invasive, real-time monitoring of cerebral blood flow velocities (CBFv) in major intracranial vessels. Transcranial Doppler may be beneficial in confirming flow to both cerebral hemispheres during anagrepe cerebral perfusion such as during aortic arch surgery and in detecting cerebral emboli during surgical manipulation. Cerebral vessels are identified based on anatomical landmarks, probe angulation, insonation depth, direction of flow and responses to dynamic manoeuvres such as carotid compression. Continuous intraoperative monitoring of CBFv is performed by means of specially designed headbands and probe holders. The most common intra-operative set-up consists of probes secured at the temporal acoustic window to monitor middle cerebral artery (MCA) flow velocities. This can be done unilaterally (this is often the preferred configuration during intraoperative monitoring for carotid endarterectomies) or bilaterally. Interpretation of TCD findings should take into account the patient’s age, sex and other physiological variables known to affect normal CBFv. Normal MCA flow velocity is lowest at birth (25 cm s−1), peaks at the age of 6 (100 cm s−1) and decreases to about 40–50 cm s−1 during adulthood and old age.
<table>
<thead>
<tr>
<th>Modality</th>
<th>Main indications</th>
<th>Overview</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near infrared spectroscopy (NIRS)</td>
<td>Any procedure at risk of POD, POCD and perioperative stroke (older patients, history of cerebrovascular disease or cognitive decline, major surgery).</td>
<td>Differential absorption of near-infrared light by oxyhaemoglobin and deoxyhaemoglobin (rSO₂).</td>
<td>Safe, easy to use, low cost. Provides continuous information on adequacy of cerebral oxygen delivery.</td>
<td>Determines oxygenation under the optodes (i.e. regional). Requires further validation.</td>
<td>A reduction of rSO₂ of &gt;80% from baseline or an absolute value below 50% indicates cerebral hypoperfusion.</td>
</tr>
<tr>
<td>Processed electroencephalography (pEEG)</td>
<td>Any procedure at risk of POD, POCD and perioperative stroke.</td>
<td>Proprietary algorithmic analysis of EEG (e.g. PSI, BIS). A reduction in indices during steady anaesthetic state correlates with critical reduction in CBF.</td>
<td>Safe, easy to use, low cost. Detects patients at risk of oversedation, delayed emergence or awareness.</td>
<td>Maps frontal cortical activity. Rapidly evolving technology. Requires further validation.</td>
<td>A reduction of PSI/BIS &gt;30% indicates cerebral hypoperfusion. SR &gt;50% indicates close-to-maximum suppression of CMRO₂.</td>
</tr>
<tr>
<td>Transcranial Doppler (TCD)</td>
<td>Aortic arch and carotid surgery. Patients at risk of intracranial hypertension in whom invasive ICP monitoring is not indicated.</td>
<td>Pulsed Doppler probes assess flow velocities in the circle of Willis.</td>
<td>Allows continuous assessment of cerebral autoregulation, detection of emboli and non-invasive ICP monitoring.</td>
<td>Technically challenging. Normal or high flow velocities do not necessarily indicate adequate perfusion (i.e. vasospasm). No information on oxygen extraction and adequacy of perfusion.</td>
<td>A reduction MCAfv &gt;50% from baseline or a value below 25 cm s⁻¹ indicates high risk of postoperative stroke. Reduced or absent diastolic flow indicates ICP close or exceeding diastolic blood pressure.</td>
</tr>
<tr>
<td>Intracranial pressure (ICP)</td>
<td>Extracranial surgery in patients at risk of intracranial hypertension (i.e. damage-control or orthopaedic surgery after major trauma).</td>
<td>Intraparenchymal or intraventricular pressure monitoring allows prompt identification of CBF compromise caused by intracranial hypertension.</td>
<td>Well validated in traumatic brain injury. Continuous assessment of CBF. EVDs allow correction of ICP by means of CSF drainage.</td>
<td>Invasive. Potentially significant complications (bleeding, infection). Does not assess adequacy of oxygen delivery.</td>
<td>ICP &gt;20 mmHg indicates a risk of herniation. CPP &lt;50 mmHg indicates risk of cerebral hypoperfusion.</td>
</tr>
</tbody>
</table>
Intraoperative changes from baseline measurements and asymmetrical findings are more informative than absolute values, which may also be affected by anatomical variability and insonation technique and angle. During carotid endarterectomy, a decrease in MCA mean flow velocity below 50% of baseline (or below 25 cm s⁻¹) during clamping is associated with severe ischaemia and high risk of postoperative stroke. This reduction in CBF can be mitigated by blood pressure augmentation with vasopressors to maximise collateral flow, or by intraoperative arterial shunting. Transcranial Doppler monitoring used during carotid endarterectomy and aortic arch surgery can also detect shunt malposition or occlusion, intraoperative emboli generating a characteristic high-intensity transient signal (HITS), postoperative carotid occlusion and hyperaemia.

Transcranial Doppler can also be used to estimate ICP in patients at risk of developing intracranial hypertension during surgery. An increase in ICP gradually impairs CBF with a typical TCD pattern that can identify life-threatening intracranial hypertension crises and allowing prompt treatment with agents that decrease ICP (Fig. 2).

**Processed EEG**

Electroencephalography records electrical activity generated by cerebral neurones, in the form of potential differences between electrodes positioned over the scalp. Electroencephalography signals are digitised, amplified, filtered and displayed as waveforms of varying morphologies and frequencies. In standard EEG, EEG waveforms are interpreted by visual inspection and quantitative analysis by an appropriately trained practitioner. ¹⁵

Processed EEG devices were developed as depth-of-anaesthesia monitors that could be easily applied to patients undergoing surgical procedures and interpreted with minimum training. These devices record and process brain arterial activity from frontal EEG electrodes, returning a calculated parameter – typically ranging from 0 to 100 – as a surrogate for the drug effects on the entire CNS. ¹⁷ A recent study compared indices obtained from commercially available EEG devices: patient state index (PSI; Masimo Corp., Irvine, CA, USA); bispectral index (BIS; Medtronic, Minneapolis, MN, USA); entropy index (Entropy; Datex Ohmeda, Helsinki, Finland). ¹⁸ The authors concluded that although all monitors distinguished EEG changes occurring before anaesthesia and during loss of response to stimuli, PSI and BIS best detected suppressed periods and might be preferable for older patients with risk factors for intraoperative awareness or increased sensitivity to anaesthesia.

International guidelines on standards of clinical monitoring during anaesthesia and recovery recommend pEEG monitoring when using TIVA with neuromuscular block, and state that pEEG monitoring may be helpful in targeting anaesthesia delivery in other circumstances. ¹⁹ It is recognised that pEEG monitoring may not only reduce the risk of accidental awareness and improve early recovery times, but also reduce the incidence of POD and POCD. In the largest randomised study of pEEG vs standard care, there was a statistically significant reduction in POCD from 14.7% to 10.2% at 3 months postoperatively in patients managed with intraoperative pEEG monitoring. ²⁰ A subgroup analysis of the BALANCED trial indicated that the incidence of POD in the BIS 50 group was 19% and in the BIS 35 group was 28% and that patients in the BIS 50 group demonstrated significantly better cognitive function at 1 yr. ²¹

Burst suppression is an EEG pattern characterised by periods of electrical activity alternating with periods of no activity in the brain. Suppression rate (SR) is defined as the rate of time of isoelectric EEG and time of electrical activity (i.e. SR=100% indicates an isoelectric EEG). Because maximal CMRO₂ suppression occurs around or above SR=50%, pEEG monitoring can also be useful to monitor CMRO₂ suppression caused by anaesthetic agents and hypothermia.

Lastly, adverse intraoperative events unrelated to titration of anaesthetic agents such as cerebral ischaemia or hypoperfusion, gas embolism and unrecognised haemorrhage can produce rapid reductions in pEEG indices and should alert the anaesthetist. Anaesthetists should not rely solely on index values displayed by pEEG monitors. Rather, they should develop a basic understanding of EEG waveforms and the interpretation of information from power spectral analysis, density spectral array (‘spectrograms’) and relative band powers.

**Near-infrared spectroscopy**

Modern NIRS is a well-established technology for the detection of cerebral desaturation after cardiac surgery, and it is increasingly being adopted to measure cerebral tissue oxygen saturation during general anaesthesia in a variety of surgical settings. ¹ Adhesive sensors are applied to the forehead of the patient and emit near-infrared light (700–1000 nm) that can penetrate through the scalp and the skull, illuminating

---

**Fig 2** Transcranial Doppler (TCD) findings with increasing ICP and progressively compromised cerebral perfusion pressure (CPP). **LOW ICP:** in healthy brains, normal CBFv waveforms closely resemble that of arterial blood pressure waveform (note continuous diastolic flow); **HIGH ICP:** as ICP increases, diastolic CBFv becomes progressively compromised; **ICP ≥ DBP:** as ICP exceeds diastolic blood pressure (DBP) diastolic flow drops to zero. **ICP ≈ MAP:** as ICP approaches mean arterial pressure and CPP approaches zero cerebral circulatory arrest can be demonstrated by a pattern of diastolic flow reversal. CBFv, cerebral blood flow velocity; MCA, middle cerebral artery.
cerebral tissue. The dominant absorbers in the human body in the near-infrared wavelengths are oxygenated and deoxy-
genated haemoglobin. The refracted light is captured by de-
tectors (‘deep’ and ‘shallow’ detectors) in NIRS sensors, allowing the calculation of relative percentage of oxy-
haemoglobin or deoxyhaemoglobin in the brain, and relative changes in arterial and venous blood content.

Tissue oxygen saturation (rSO₂) is defined as the percent-
age of oxyhaemoglobin over the sum of oxy- and deoxy-
haemoglobin in pooled arterial, capillary and venous blood in the illuminated brain region. Tissue oxygen saturation is a measure of oxygen extraction fraction (OEF), representing an indicator of adequacy of metabolic demand (CMRO₂) and oxy-
gen delivery to the brain.

The calculation of rSO₂ relies on proprietary processing al-
gorithms that vary between manufacturers, and rSO₂ values are not considered to be interchangeable between devices. A recent normative study based on the O3 Regional Oximetry device (Masimo Corporation) returned normal rSO₂ average values of 68%, with no rSO₂ value below 56% for awake healthy volunteers. Most clinical studies refer to changes in rSO₂ values compared with the individual baseline readings, with changes in cerebral tissue oxygen saturation to <80% of baseline or lower than 50% (absolute) associated with an increased incidence of adverse neurological outcomes such as POD and stroke. Two studies with 126 participants showed that active cerebral NIRS monitoring may reduce the incidence of POCD. 1

Conclusions

Safe anaesthesia relies on prompt recognition and treatment of cerebral hypoperfusion. Intracranial pressure monitoring is essential in the anaesthetic management of patients with traumatic brain injury undergoing non-deferrable extracra-
nial surgery. Near-infrared spectroscopy and TCD monitoring have an established role in cardiac, aortic arch and carotid surgery. Processed EEG monitoring is recommended in all patients undergoing surgical procedures under TIVA and neuromuscular block. Moreover, NIRS and pEEG monitors are rapidly evolving, non-invasive modalities that provide the anaesthetist with continuous information on the adequacy of cerebral perfusion and anaesthetic depth. These physiological variables correlate with clinically relevant adverse neurological outcomes, and their use of pEEG and NIRS monitors should be seriously considered in all patients at risk of POCD, POD and perioperative stroke.

Declaration of interests

The authors declare that they have no conflicts of interest.

MCQs

The associated MCQs (to support CME/CPD activity) will be accessible at www.bjaed.org/cme/home by subscribers to BJA Education.

References


2. Neuro VI. Perioperative covert stroke in patients under-


4. Vilisides PE, Moore LE, Whalin MK et al. Perioperative care of patients at high risk for stroke during or after non-


9. Agarwal S, Kendall J, Quarterman C. Perioperative man-

10. Lewis C, Parulkar SD, Beбавy J, Sherwani S, Hogue CW. Cerebral neuromonitoring during cardiac surgery: a crit-

11. Gaudino M, Benesch C, Bakaeen F et al. Considerations for reduction of risk of perioperative stroke in adult patients undergoing cardiac and thoracic aortic operations: a sci-


14. Checketts MR, Alladi R, Ferguson K et al. Recommenda-

15. Chesnut R, Aguilera S, Buki A et al. A management algo-


17. Pålæ S, Schneider G. Bis and state entropy of the EEG — comparing apples and oranges. Br J Anaesth 2015; 115: 164–6

18. Eagleman SL, Drover CM, Li X, Maclver MB, Drover DR. Offline comparison of processed electroencephalogram monitors for anaesthetic-induced electroencephalo-

19. Lucas DN, Russell R, Bamber JH, Elton CD. Recommenda-

BJA Education | Volume 22, Number 7, 2022
