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Cerebral oximetry

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Key points

- Cerebral oximeters enable continuous non-invasive monitoring of cerebral oxygenation.
- Cerebral oximeters utilize similar physical principles to pulse oximeters.
- Cerebral oximeters use the Beer–Lambert law and spatial resolution to provide estimates of cerebral haemoglobin oxygen saturation.
- Baseline cerebral oximetry values should be obtained before induction of anaesthesia.
- Cerebral oximetry values represent a balance between cerebral oxygen delivery and consumption.

The maintenance of adequate oxygen delivery to tissues and organs, especially the brain, is a fundamental objective of the anaesthetic process. The dangers of prolonged hypoxia and reduced oxygen delivery to the brain are well documented; however, the brain remains one of the least monitored organs during anaesthesia.[1]

Cerebral oximeters are non-invasive, continuous monitoring devices, used to monitor adequate cerebral oxygenation. They utilize similar physical principles to pulse oximeters. The first commercially available cerebral oximeters were used in the 1990s; however, Jobsis[2] first introduced the concept of using near-infrared spectroscopy (NIRS) to measure cerebral oxygenation in 1977. Although the majority of published data on cerebral oximetry have demonstrated improved outcomes among cardiac surgical patients, studies are emerging identifying improved outcomes in the non-cardiac surgical population.[3] Studies have demonstrated an increased incidence of adverse perioperative outcomes in patients who demonstrate substantial cerebral oxygen desaturation during surgery.[4]

This article aims to explain the underlying physical principles surrounding cerebral oximetry, and evaluate evidence supporting their use in different clinical situations.

Physics

Cerebral oximeters use NIRS to obtain continuous non-invasive measurements of cerebral oxygenation values.[5] Cerebral oximeters consist of a monitor that is connected to oximeter probes. Adhesive pads attach probes to the patient's scalp. Probes are most commonly applied to the scalp overlying the frontal lobe. Probes contain a fibreoptic light source and light detectors.[6] Light sources release light in the infrared range through a process of either stimulated emission of radiation or through light-emitting diodes.[7] Emitted light in the infrared range is able to penetrate the skull to reach underlying cerebral tissue. The skull is transparent to light in the near-infrared range.[1] Emitted light is either absorbed, redirected, scattered, or reflected.[8] When infrared light contacts haemoglobin, a change in the light spectrum occurs, depending upon the oxygenation status of the haemoglobin molecule.[8] Reflected light returns towards the surface and is detected by the light detectors within the oximetry probes.[8]

Cerebral oximeters calculate cerebral oxygenation using the Beer–Lambert Law.[9] The Beer–Lambert law is a combination of two physical laws.

Beer's law

The intensity of transmitted light decreases exponentially as the concentration of a substance the light passes through increases.

Two containers of equal size are filled with identical volumes of a solution. The concentration of solution in Figure 1A is less than the concentration of solution in Figure 1B. Light from identical light sources are shone through the containers. The amount of light passing through each container is detected by a photodetector. The amount of light reaching the photodetector in

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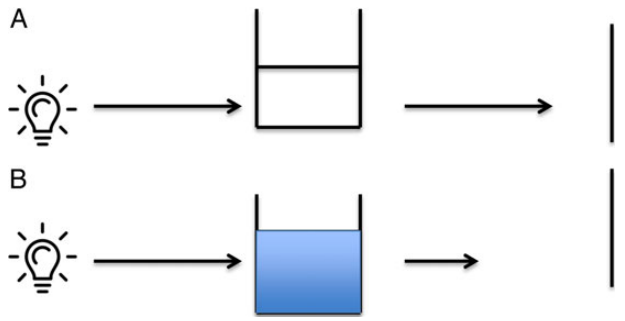

Fig 1 Diagrammatic representation of Beer's Law.

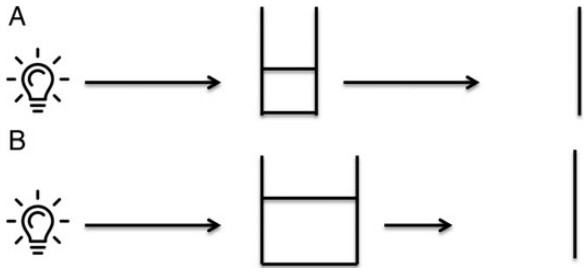

Fig 2 Diagrammatic representation of Lambert's Law.

Figure 1A is greater than the amount of light reaching the detector in Figure 1B. As the concentration of a substance increases, the amount of light absorbed by the substance increases and the amount of light detected by the photodetector decreases.

Lambert's law

The intensity of transmitted light decreases exponentially as the distance travelled by the light through a substance increases.

Two containers of differing size are each filled with volumes of solution of identical concentration. Light from identical light sources are shone through each container. The amount of light passing through each container is detected by a photodetector. Light passing through the container in Figure 2A has less distance to travel through the substance, than light passing through the container in Figure 2B. The amount of light reaching the photodetector in Figure 2A is greater than that in Figure 2B. As the distance a light travels through a substance increases, the amount of light absorbed increases, and the amount of light detected by the photodetector decreases.

According to these laws, an amount of a substance, that is, oxygen, can be determined by how much light the substance absorbs.[10]

Near-infrared light with a wavelength of 650–940 nm is able to penetrate the skull to underlying cerebral tissue.[9] Primary light absorbing molecules within tissues are metal complex chromophores: haemoglobin, bilirubin, and the cytochromes.[1] Haemoglobin exists in either an oxygenated or deoxygenated form. The absorption spectra for each haemoglobin state are different. The absorption spectrum for deoxygenated haemoglobin is 650–1000 nm and oxygenated haemoglobin 700–1150 nm.[1] The isobestic point where the absorption spectra for oxygenated and deoxygenated haemoglobin are the same can be used to calculate total tissue haemoglobin concentration (Fig. 3).[1]

Extracranial blood is a potential source of error in cerebral oximetry measurements. In order to limit this, cerebral oximeters

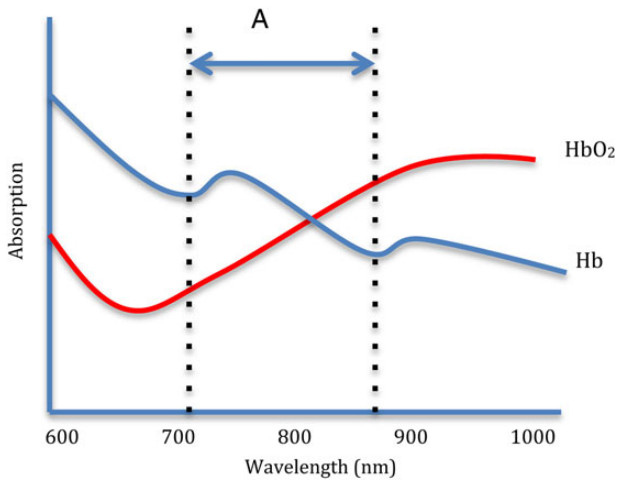

Fig 3 Absorption spectra for oxygenated and de-oxygenated haemoglobin. Area A represents light wavelengths used by Cerebral oximeters.

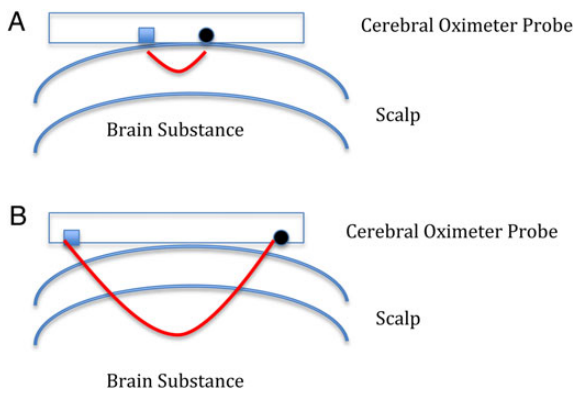

Fig 4 Diagrammatic representation of Spatial Resolution.

utilize multiple probes[6] and a process of spatial resolution.[4] Spatial resolution is based on a principle that the depth of tissue investigated is directly proportional to the distance between the light emitter and light detector (Fig. 4).[11] Increasing the distance between the emitter and detector will increase the depth of tissue sampled.

Cerebral oximeters use mathematical algorithms involving subtraction of values obtained from the emitters near and far from the photodetector to limit contamination from extracranial blood, and obtain a reading representative of cerebral oxygenation values. There are numerous commercially available cerebral oximetry devices for clinical use. Inter-device variability with regard to measurements exists. Variability occurs as a result of different wavelengths of light emitted by the probes, different light sources,[4] and different mathematical algorithms used to obtain cerebral oxygenation values.

Cerebral oximetry values are derived mainly from venous blood, and in contrast to pulse oximeters are independent of pulsatile blood flow.[12] Cerebral oximetry values reflect a balance between oxygen consumption and oxygen delivery to the brain.

Clinical interpretation of cerebral oximetry measurements

Baseline cerebral oximetry values should be obtained before induction of anaesthesia. Normal values range from 60% to 80%;

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however, lower values of 55–60% are not considered abnormal in some cardiac patients.[8]

Adequate cerebral oxygenation is dependent upon adequate cerebral blood flow and oxygen content. Factors affecting either of these will result in a reduction in cerebral oxygenation and a reduction in cerebral oximetry values. Anatomical variations, for example, an incomplete Circle of Willis, or severe carotid artery stenosis can create errors in cerebral oximetry values; therefore, it is recommended that cerebral oximetry is performed bilaterally. Table 1 summarizes some factors that may result in reduced cerebral oxygenation values caused by alterations in blood flow or oxygen content.

Table 1 Factors resulting in reduced cerebral oxygenation values

Cerebral blood flow	Oxygen content
Cardiac output	Haemoglobin concentration
Acid–base status	Haemoglobin saturation
Major haemorrhage	Pulmonary function
Arterial inflow/venous outflow obstruction	Inspired oxygen concentration

Cerebral oximetry values must not be interpreted in isolation; alterations in cerebral oximetry measurements must take into consideration all available clinical information and physiological state of the patient. One of the most common limitations in cerebral oximetry monitoring has been the absence of an intervention protocol to treat a decrease in regional brain oxygenation.[1] Denault and colleagues[13] have devised a potential treatment algorithm based on optimizing cerebral oxygen delivery and consumption to treat a reduction in cerebral oximetry values (Fig. 5).

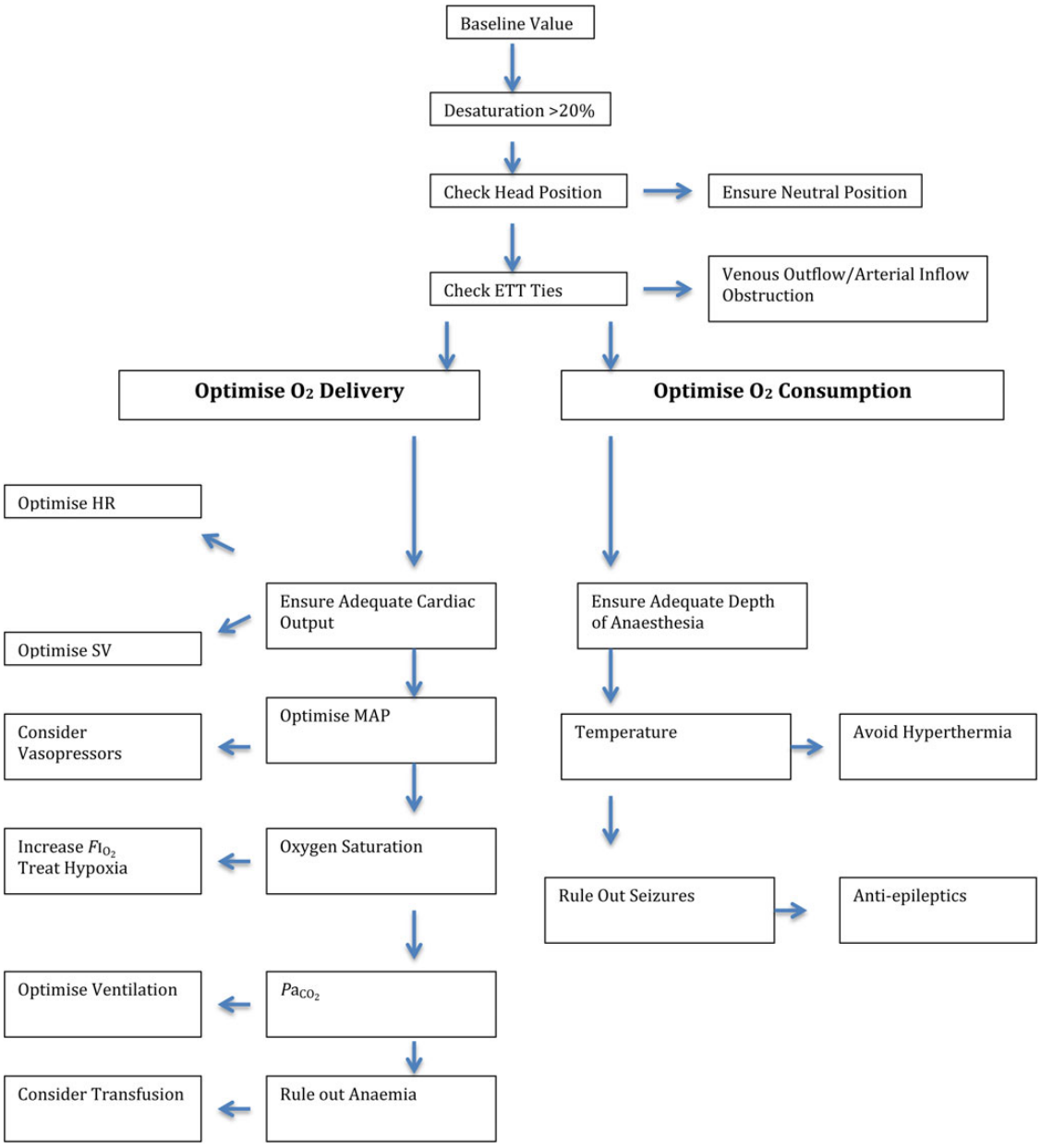

Fig 5 Treatment algorithm for managing cerebral desaturation. Adapted from original by Denault and colleagues.[13]

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Limitations in cerebral oximetry measurements

All monitoring devices have limitations. Limitations associated with cerebral oximetry include:

(i) Blood from an extracranial source can create erroneously low measurement.[4]
(ii) Electrosurgical equipment, that is, diathermy, can affect the accuracy of measurement.[4]
(iii) Cerebral oximeters only measure regional cerebral oxygenation. Large areas of the brain remain unmonitored.[4]
(iv) Cerebral oximeters are unable to identify a cause for the desaturation.[14]

Clinical applications

Questions have been raised with regard to the clinical utility of cerebral oximetry monitoring.[1] An increasing number of studies are demonstrating the ability of cerebral oximetry monitoring to detect clinically silent episodes of cerebral ischaemia.[1] Cerebral oximeters have the potential to be an important safeguard for cerebral function.[1]

Cardiac surgery

Patients undergoing cardiac surgery are at risk of adverse perioperative neurological events. Cerebral oximetry monitoring can be used, potentially reducing the incidence of these devastating events.

Coronary artery bypass surgery

Studies have been conducted investigating cerebral oximetry in patients undergoing cardiac surgery. Salter and colleagues[15] carried out a study involving 265 patients undergoing coronary artery bypass surgery (CABG) surgery. Patients were randomized to two groups. Cerebral oximetry was used in both groups. One group received cerebral oximetry monitoring and interventions to improve cerebral oximetry values if they decreased by 20% from a baseline preoperative measurement. The second group was a control group. The study found an association between cerebral desaturation and early postoperative cognitive dysfunction. However, the study did not identify an association between the use of a cerebral oximetry-guided intervention protocol, and a reduction in the incidence of postoperative cognitive dysfunction.[15]

Persistent postoperative cognitive dysfunction after cardiac surgery is controversial. Meta-analyses[16] have identified that persistent cognitive decline is not as common as previously thought. Some patients may even show an improvement in cognitive function after CABG surgery.

Deep hypothermic circulatory arrest

A number of cardiac surgical procedures are performed using cardiopulmonary bypass (CPB). Certain complex procedures, however, require a cessation of all blood flow. Deep hypothermic circulatory arrest describes the rapid reduction in core body temperature, followed by the cessation of CPB. The brain is vulnerable to ischaemia during this time. Cerebral oximetry monitoring may provide a means of monitoring and detecting the onset of cerebral ischaemia.[1] However, there is insufficient evidence surrounding the sensitivity of cerebral oximetry monitoring during profound hypothermia (temperatures <25°C).

Vascular surgery

Carotid endarterectomy

Carotid endarterectomy is associated with postoperative stroke. Monitoring devices are commonly used to detect periods of cerebral ischaemia. Common monitoring devices include transcranial Dopplers, EEGs, and monitoring of somatosensory evoked potentials (SSEPs).

Transcranial Dopplers provide an indirect measure of cerebral blood flow by measuring blood velocity in a cerebral artery. Measurements are obtained through transcranial windows. Transcranial windows are found across the thinnest parts of the skull—the temporal bone, or where bone is absent—the orbit. One-fifth of patients lack a transcranial window, and as a result, transcranial Doppler studies cannot be used.[1] SSEPs and EEG monitoring are affected by anaesthetic agents and surgical diathermy.[1] Cerebral oximetry monitoring can be used as a tool for detection of cerebral ischaemia.

A reduction in cerebral oximetry values >12% from a baseline preoperative value has been identified as a reliable, sensitive, and specific threshold for detection of brain ischaemia.[1] A reduction in cerebral oximetry values after cross-clamping of the internal carotid artery may indicate the need for shunt placement during the procedure. Moritz and colleagues[17] compared different monitoring modalities in identifying cerebral ischaemia during carotid surgery. Results highlighted similar accuracy for the detection of onset of ischaemia with transcranial Doppler and cerebral oximetry monitoring, least accuracy was identified for SSEP monitoring.

Carotid endarterectomy hyperperfusion syndrome

Carotid endarterectomy hyperperfusion syndrome is caused by an increase in cerebral blood flow after repair of carotid stenosis. It occurs as a result of impaired cerebral auto-regulation. The syndrome is characterized by headache, cerebral oedema, seizures, intracerebral haemorrhage, and death.

A correlation exists between cerebral oxygen saturation values and changes in cerebral blood flow after de-clamping of the internal carotid artery.[1] Cerebral oximetry could be used to identify patients at risk of cerebral hyperperfusion syndrome.[18]

Paediatrics

Neonates born prematurely have impaired cerebral auto-regulation and are at risk of intraventricular haemorrhage and periventricular leucomalacia.[9] Periventricular leucomalacia is usually diagnosed by transcranial ultrasound. Areas of ischaemia are identified in white matter surrounding the lateral ventricles. By the time a diagnosis of periventricular leucomalacia has been made, permanent neurological damage such as visual disturbance and cerebral palsy has occurred. Changes in cerebral oxygen values as detected by cerebral oximeters provide an indirect measure of alterations in cerebral blood flow. Continuous cerebral oxygenation monitoring may enable the early detection and prevention of periventricular leucomalacia and intraventricular haemorrhage.[9]

Additional uses

Cerebral oximetry monitoring is being increasingly used to monitor the adequacy of tissue and organ perfusion when placed on sites other than the scalp.[1] NIRS is being investigated as a

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potential marker of perfusion for hepatic, renal, and splanchnic tissues.[1]

NIRS is further being evaluated as a potential screening tool for the need for blood transfusion in trauma patients at risk of haemorrhagic shock.[1]

Conclusion

Cerebral oximetry is a simple, non-invasive monitoring methodology that may improve patient outcome in a variety of different clinical situations; evidence for its use beyond cardiac surgery is continuously emerging. This article has highlighted some of the increasing roles and evidence for cerebral oximetry in clinical practice, further research is required to validate cerebral oximetry monitoring in improving patient outcomes in both cardiac and non-cardiac surgical patients.[3]

Declaration of interest

None declared.

MCQs

The associated MCQs (to support CME/CPD activity) can be accessed at https://access.oxfordjournals.org by subscribers to *BJA Education*.

Podcasts

This article has an associated podcast which can be accessed at http://www.oxfordjournals.org/podcasts/bjaed_cerebral_oximetry.mp3.

References

1. Murkin JM, Arango M. Near-infrared spectroscopy as an index of brain and tissue oxygenation. *Br J Anaesth* 2009; **103**(Suppl.): i3–13
2. Jobsis FF. Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. *Science* 1977; **198**: 1264–7
3. Troianos C. Cerebral oximetry may provide helpful information. *APSF Newsletter* 2009, Spring
4. Davie S, Grocott H. Impact of extracranial contamination on regional cerebral oxygen saturation. A comparison of three cerebral oximetry technologies. *Anesthesiology* 2012; **116**: 834–40
5. Toet MC, Lemmers PM. Brain monitoring in neonates. *Early Hum Dev* 2009; **85**: 77–84
6. Brazy JE, Vander-Vliet FJ. Clinical application of near-infrared spectroscopy to neonatal intensive care. In: Kim Y, Spelman FA, eds. *Images of the Twenty-First Century. Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Seattle, WA, 9–12 November 1989, **Vol. 11**. New York: IEEE, 1989; 337–8
7. Somanetics Corporation. Invos System; 2009. Available from http://www.somanetics.com/invos (accessed 22 April 2016)
8. Vretzakis G, Georgopoulou S, Stamoulis K *et al*. Cerebral oximetry in cardiac anaesthesia. *J Thorac Dis* 2014; **6**(Suppl. 1): s60–9
9. Elser H, Holditch-Davis D, Brandon D. Cerebral oxygenation monitoring. A strategy to detect IHV and PVL. *Newborn Infant Nurs Rev* 2011; **11**: 153–9
10. Owen-Reece H, Smith M, Elwell CE *et al*. Near infrared spectroscopy. *Br J Anaesth* 1999; **82**: 418–26
11. Germon TJ, Evans PD, Barnett NJ, Wall P, Manara AR, Nelson RJ. Cerebral near infra-red spectroscopy: emitter–detector separation must be increased. *Br J Anaesth* 1999; **82**: 831–7
12. Frost E. Cerebral oximetry. Emerging applications for an established technology. *Anaesthesiology News* 2012; October: 27–34
13. Denault A, Deschamps A, Murkin JM. A proposed algorithm for the intraoperative use of cerebral near-infrared spectroscopy. *Semin Cardiothorac Vasc Anaesth* 2007; **11**: 274–81
14. Burns A, Norwood B, Bosworth G, Hill L. The cerebral oximeter: what is the efficacy? *AANA J* 2009; **72**: 137–44
15. Salter JP, Guarino T, Stack J *et al*. Cerebral oxygen desaturation predicts cognitive decline and longer hospital stay after cardiac surgery. *Ann Thorac Surg* 2009; **87**: 36–44, discussion 44–5
16. Cormack F, Shipolini A, Awad WI *et al*. A meta-analyses of cognitive outcome following coronary artery bypass graft surgery. *Neurosci Biobehav Rev* 2012; **36**: 2118–29
17. Moritz S, Kasprzak P, Arit M, Taeger K, Metz C. Accuracy of cerebral monitoring in detecting cerebral ischaemia during carotid endarterectomy: a comparison of transcranial Doppler sonography, near-infrared spectroscopy, stump pressure, and somatosensory evoked potentials. *Anesthesiology* 2007; **107**: 563–9
18. Ogasawara K, Konno H, Yukawa H, Endo H *et al*. Transcranial regional cerebral oxygen saturation monitoring during carotid endarterectomy as a predictor of post operative hyperperfusion. *Neurosurgery* 2003; **53**: 309–14, discussion 314–5

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