SHORT REPORT

Extracerebral absorption of near infrared light influences the detection of increased cerebral oxygenation monitored by near infrared spectroscopy

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Abstract
The detection of increased cerebral oxygenation secondary to cerebral hyperaemia, induced by hypercapnia has been studied in anaesthetised patients using a near infrared, reflectance mode, cerebral oxygenation monitor (Invos 3100 Somanetics, Troy, Michigan, USA). Two studies were performed, with and without a pneumatic scalp tourniquet, to distinguish between extracranial and intracranial changes in tissue oxygenation. In the control study a mean increase in end tidal CO\(_2\) of 23.1 mm Hg was accompanied by a mean increase in middle cerebral artery flow velocity of 116%. Regional cerebral oxygen saturation (rSo\(_2\)) measured transcutaneously in the middle cerebral artery increased significantly from 70-5% to 74-6% (p = 0.001). During the second study with a scalp tourniquet inflated to maintain the extracranial tissues in a state of stable ischaemia a mean increase in end tidal CO\(_2\) of 22.3 mm Hg was accompanied by a mean increase in middle cerebral artery flow velocity of 121%. The change in rSo\(_2\) from 62-6% to 64-5% was not significant (p = 0.085). There was no correlation between the change in middle cerebral artery flow velocity and rSo\(_2\) in the control or scalp ischaemia group. This study shows that the Invos 3100 monitor is sensitive to tissue oxygenation but does not reliably detect changes in cerebral oxygenation as a result of profound cerebral hyperaemia. The contribution of extracerebral tissue to the attenuation of near infrared light and the lack of spatial resolution remain major problems to be overcome before this or other near infrared spectroscopy instruments can be introduced into clinical practice.

Methods
Eight patients (mean age 44.5 years, range 30–66 years) undergoing cervical or lumbar discectomy with no predisposition to cerebrovascular disease gave informed verbal consent to the study, which was approved by the local ethics committee. A uniform anaesthetic technique was employed. The electrocardiogram (Hewlett Packard 78553B, GMBH, Germany), arterial blood pressure (Dinamap 845 XT, Critikon, Tampa, FL, USA), regional cerebral O\(_2\) saturation (rSo\(_2\)), inspired O\(_2\) and CO\(_2\) concentrations, and end tidal CO\(_2\) (ETCO\(_2\)) concentrations (Nellcor N-1000, Hayward, CA, USA) were continuously monitored. The oximeter sensor was placed on the forehead, avoiding the midline and the temporalis muscle. Ipsilateral middle cerebral artery flow velocity was measured in the proximal middle cerebral artery at a depth of 5.0 to 6.0 cm with transcranial Doppler ultrasonography (PCDop 842, Scimed, Bristol, UK).

When ETCO\(_2\) was stable in the range 22–45 mm Hg five recordings were made. The inspired CO\(_2\) concentration was increased to 5% and when ETCO\(_2\) had reached a stable level for three minutes five further recordings were made. The study was then repeated with a pneumatic tourniquet

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Near infrared spectroscopy, a non-invasive technique for monitoring cerebral oxygenation and blood flow, semi-quantitatively estimates the relative concentrations of oxyhaemoglobin and deoxyhaemoglobin within an unspecified volume of tissue illuminated by near infrared light of varying wavelengths. Absorption of the near infrared light takes place in the arterial, capillary, and venous circulations of both the extracranial and intracranial tissues. The technique possesses no intrinsic compartmental or spatial resolution and thus to be clinically useful the effects of changes in extracranial blood flow and oxygenation must be either quantified or made negligible by the design of the optical sensor and its software.

We have examined the capacity of the Invos 3100 cerebral oximeter to detect profound increases in cerebral blood flow and oxygenation induced by hypercapnia before and after the application of a pneumatic scalp tourniquet which results in stable scalp ischaemia.

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inflated to a pressure of 200 mm Hg at the level of the supraorbital ridge for three minutes. Care was taken to ensure that the tourniquet did not impinge on the sensor.

A paired Student’s t test was used to examine for significant differences between the study variables under normocapnic and hypercapnic conditions. The relation between the percentage change in middle cerebral artery velocity and the change in rSo2 was studied with Pearson’s rank correlation.

Results
The table summarises the results. The mean increase in ETco2 was 23.1 (SD 4) mm Hg in the control study and 22.3 (3) mm Hg when the scalp tourniquet was inflated. (In one patient without a satisfactory acoustic window for transcranial Doppler, ETco2 rose by 20 mm Hg without the tourniquet and by 23 mm Hg with the tourniquet, and therefore, his rSo2 results are included.) There was no significant difference between the mean increase in middle cerebral artery velocity in the two studies (p = 0.21). There was a significant increase in mean rSo2 from 70.5% to 74.6% in the control study (p = 0.001, figure). Under conditions of stable extracranial ischaemia, however, no significant change in rSo2 was detected in response to hypercapnia. (Mean rSo2 increased from 62.6% to 64.5%, p = 0.085, figure.) There was no correlation between the changes in middle cerebral artery velocity and rSo2 in the control (r = 0.229, p = 0.621) or scalp ischaemia (r = 0.183, p = 0.398) groups.

Discussion
Carbon dioxide is a potent cerebral vasodilator. The increase in cerebral blood flow mediated by cortical arteriolar dilatation in response to increased CO2 does not increase cerebral metabolic requirements for oxygen. This results in an increased cerebral blood volume of oxygenated arteriolar blood and an increase in the saturation of cerebral venous blood secondary to increased blood flow with constant O2 extraction. It follows that rSo2 should increase significantly in response to hypercapnia and there should be a close relation between increased flow velocity detected by transcranial Doppler and increased cerebral oxygenation detected by near infrared spectroscopy.

Assuming that 70% of cerebral blood volume is venous and 30% arterial and that normal jugular venous oxygen (SjO2) saturation lies in the range 54% to 75% then the normal range for rSo2 should lie between 67% and 85%. Mean rSo2 in our control study was 70.5%. The increase in middle cerebral artery velocity in the two studies is compatible with an increase in global cerebral blood flow of about 120%. Assuming no appreciable change in the distribution of cerebral blood volumes or the oxygen dissociation curve for haemoglobin and a mean SjO2 in the midrange of normal (65%) during normocapnia, we estimate that a 120% increase in cerebral blood flow would increase rSo2 from 76% to 88%. With the same rationale, the mean normocapnic value for rSo2 of 70.5% should have increased to 86%. Although the increase in rSo2 from 70.5% to 74.6% in the
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control study was significant it clearly does not reflect the magnitude of change predicted and further, there was no correlation between changes in middle cerebral artery flow velocity and rSO2 in either study.

In an attempt to overcome the problems of extracerebral attenuation of near infrared light and to increase the degree of spatial resolution the cerebral oximeter used in this study has two receiving optodes placed 3 and 4 cm from the emitting optode. Subtraction of the absorption characteristics detected at the proximal optode from those at the distal optode should reflect changes taking place in cerebral tissue alone. With this optode arrangement we have previously shown that the induction of scalp ischaemia causes a significant reduction in rSO2 as measured by the Invos 3100. This may mean the mathematical algorithm that computes rSO2 may not compensate for the changes in scalp oxygenation. It seems unlikely that the baseline mean rSO2 of 62-6% in the second study reflects true regional O2 saturation in the stable anaesthetised patient. Nevertheless, the principle of the proximal and distal path lengths should apply to the new stable conditions with the sensor capable of detecting the cerebral hyperaemia unaffected by extracranial change. The small and statistically insignificant increase in rSO2 to 64-5% in the presence of scalp ischaemia strongly suggests that the increase in rSO2 seen in response to hypercapnia in the absence of the tourniquet is largely due to changes in scalp oxygenation.

With this optode arrangement, the Invos 3100 monitor will detect tissue hypoxia deep to the scalp under conditions identical with those described. We speculated whether the monitor was detecting changes in haemoglobin oxygenation in the diploic frontal bone and underlying dura, in the cerebral cortex, or in both. The failure to detect changes in oxygenation in response to hypercapnia with scalp ischaemia suggests that very little of the near infrared light signal change is taking place in the cerebral cortex and that hypercapnia does not increase blood flow to the skull. In similar work Harris and Bailey failed to detect any significant response to hypercapnia using a sensor configuration with a smaller separation between the light source and the two receivers. It is possible that this sensor geometry was successful in excluding hyperaemic change in the scalp while remaining insensitive to change in the cerebral substance.

The problem of extracerebral attenuation of near infrared light in near infrared spectroscopy is not simply a theoretical consideration. Those patients most likely to benefit from this monitoring are also those most likely to have local change in the extracranial tissues—for example, after head injury or craniotomy—and systemic changes in cardiac output, peripheral resistance, and cutaneous vasodilatation, which also affect the extracranial tissues. Until the problems of quantifying and interpreting changes in rSO2 under physiological and pathological conditions have been overcome near infrared spectroscopy monitors of this sort cannot be recommended for routine clinical monitoring. Other instruments with similar technology should be tested equally rigorously.

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