Brain tissue oxygenation in patients with cerebral occlusive disease and arteriovenous malformations

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Summary

It is not clear if ventilation with oxygen increases brain tissue oxygen pressure ($P_{O2}$) during ischaemia. We have measured brain tissue $P_{O2}$ carbon dioxide pressure ($P_{CO2}$) and pH during baseline anaesthesia and oxygen ventilation in non-ischaemic control patients ($n=9$), patients with cerebral occlusive disease ($n=11$) and patients with arteriovenous malformations (AVM, $n=12$). The same anaesthetic treatment was given to all groups and anaesthesia was constant during the study. Arterial pressure, brain temperature and arterial blood-gas tensions were similar between groups. Under baseline conditions, brain tissue $P_{O2}$ was mean 4.2 (SD 1.4) kPa in the controls and was 70% lower in patients with ischaemia and AVM. Patients with occlusive disease also had elevated tissue $P_{CO2}$ and acidosis. During oxygen ventilation, $P_{O2}$ increased to 7.5 (2.9) kPa in controls and this was 50% greater than the increase in the ischaemia and AVM patients. The results showed that baseline tissue oxygenation and increases in $P_{O2}$ during hyperoxia were attenuated in patients with ischaemia or AVM. (Br. J. Anaesth. 1997; 78: 169–171)

Key words

Under normal conditions, brain tissue $P_{O2}$ is reported to be in the range 3.3–5.2 kPa in animals and patients.1–3 Tissue oxygenation may be inhibited by cerebral occlusive disease or by arterial venous malformations (AVM), which attenuate cerebral perfusion pressure by producing a low resistance shunt for blood flow.4–6 It has been reported that the upper limit of tissue oxygenation is controlled in normal brain tissue during oxygen ventilation, but that these regulating mechanisms are missing after head injury.3 Little is known of tissue changes in $P_{O2}$ during hyperoxia in tissue affected by occlusive disease or AVM. The purpose of this study was to evaluate the effect of oxygen ventilation in patients with cerebral occlusive disease and AVM compared with non-ischaemic controls.

Patients and methods

The studies were approved by the University of Illinois Institutional Review Board for Clinical Research and informed consent was obtained. Patients in group 1 ($n=9$) served as controls for the study. None of these patients bled or had clinical signs of ischaemia before surgery. Neurosurgery was performed in these patients for clipping of cerebral aneurysms. Patients in group 2 ($n=11$) had evidence of cerebral ischaemia, as determined by neurological examination or the presence of transient ischaemic episodes. Decreased regional cerebral perfusion was confirmed in these patients by single photon emission computed tomography (SPECT) or cerebral angiography. Six of these patients were undergoing extracerebral to intracerebral vascular bypass, two patients cerebral aneurysm surgery with confirmed cerebral vasospasm and three patients had a cerebral embolism. Patients in group 3 ($n=12$) were undergoing neurosurgery for AVM resection. Nine of these patients had previous neuroradiological AVM embolization procedures performed before AVM resection.

All patients were anaesthetized with thiopentone 3–5 mg kg$^{-1}$ and fentanyl 10–15 μg kg$^{-1}$. Tracheal intubation was facilitated with vecuronium 0.1 mg kg$^{-1}$ and the lungs ventilated with 0.5–1.5% isoflurane and oxygen in room air (inspired oxygen fraction = 0.4). Oesophageal temperature was measured and allowed to decrease to approximately 34 °C. Arterial carbon dioxide tension ($P_{CO2}$) was adjusted to 3.9–4.6 kPa. Monitoring included mean radial arterial pressure (MAP) measured by a Datex Ultima (Helsinki, Finland).

After craniotomy, a $P_{O2}$, $P_{CO2}$, pH and temperature sensor (Paratrend, Biomedical Sensors, Malvern, PA) was inserted into cortex tissue (diameter = 0.5 mm). The sensor is a sterile, disposable device comprised of two modified optical fibres.
Table 1  Mean arterial pressure (MAP), arterial oxygen and carbon dioxide partial pressures and pH, tissue carbon dioxide partial pressure, pH and brain temperature during 40% (baseline) and 100% oxygen ventilation (oxygen) in controls, and in those with cerebral occlusive disease (COD) and arteriovenous malformations (AVM) (mean ± SD). $p_{O_2}$ = arterial $O_2$, $p_{CO_2}$ = arterial $CO_2$, $pH_t$ = arterial pH, $p_{CO_2}$tissue = tissue $CO_2$, $pH_t$ = tissue pH. *$P<0.05$ compared with baseline, †$P<0.05$ compared with control

<table>
<thead>
<tr>
<th>Group</th>
<th>Treatment</th>
<th>n</th>
<th>MAP (mm Hg)</th>
<th>$p_{O_2}$ (kPa)</th>
<th>$p_{CO_2}$ (kPa)</th>
<th>$pH_t$</th>
<th>Brain temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Baseline</td>
<td>9</td>
<td>86 (15)</td>
<td>24.9 (7.3)</td>
<td>4.3 (0.4)</td>
<td>7.47 (0.04)</td>
<td>6.4 (0.8)</td>
</tr>
<tr>
<td></td>
<td>Oxygen</td>
<td></td>
<td>87 (15)</td>
<td>54.0 (7.6)*</td>
<td>4.3 (0.6)</td>
<td>7.43 (0.07)</td>
<td>6.3 (0.8)</td>
</tr>
<tr>
<td>COD</td>
<td>Baseline</td>
<td>11</td>
<td>88 (12)</td>
<td>29.2 (4.1)</td>
<td>4.5 (0.4)</td>
<td>7.42 (0.06)</td>
<td>9.2 (4.9)†</td>
</tr>
<tr>
<td></td>
<td>Oxygen</td>
<td></td>
<td>88 (12)</td>
<td>58.7 (3.3)*</td>
<td>4.8 (0.3)</td>
<td>7.38 (0.03)</td>
<td>9.1 (3.7)†</td>
</tr>
<tr>
<td>AVM</td>
<td>Baseline</td>
<td>12</td>
<td>80 (8)</td>
<td>23.3 (4.7)</td>
<td>4.3 (0.7)</td>
<td>7.43 (0.07)</td>
<td>6.7 (1.2)</td>
</tr>
<tr>
<td></td>
<td>Oxygen</td>
<td></td>
<td>81 (8)</td>
<td>52.3 (8.4)*</td>
<td>4.3 (0.5)</td>
<td>7.44 (0.05)</td>
<td>6.5 (1.2)</td>
</tr>
</tbody>
</table>

for measurement of $p_{CO_2}$ and pH, a miniaturized Clark electrode for $p_{O_2}$ measurement and a thermocouple for measurement of temperature. The sensor was calibrated with three precision gases supplied with the monitor before insertion into the patient. The gases are: 1 = 2% carbon dioxide, 15% oxygen, balance nitrogen; 2 = 5% carbon dioxide, 15% oxygen, balance nitrogen; 3 = 10% carbon dioxide, 15% oxygen, balance nitrogen. The calibration range and 95% confidence limits for each sensor have been determined in *vitro* testing: oxygen (range 0–15.7 kPa, 95% confidence limits +0.1 kPa); carbon dioxide (range 1.3–10.5 kPa, 95% confidence limits +0.4 kPa); pH (range 6.80–7.80, 95% confidence limits +0.03). The 0% to 90% response time for each sensor is: oxygen = 70 s, carbon dioxide = 143 s, pH = 78 s. All monitored variables were collected by computer using Labview (National Instruments, Austin, TX) every 10 s.

When the sensor was inserted, baseline tissue gas tensions, pH and temperature, MAP and blood-gas tensions were measured after a 30-min equilibration period. Inspired oxygen fraction was increased from 0.4 to 1.0 for 10 min and then returned to baseline period. Samples for arterial blood-gas measurements were collected by computer using Labview (National Instruments, Austin, TX) every 10 s.

Data are reported as mean (SD). Differences in mean values between the three groups were analysed by analysis of variance with post hoc testing if a significant $F$ value was found. Differences between baseline and oxygen administration were analysed using paired $t$ tests. If data distribution failed the underlying assumptions for normality and equal variance, non-parametric analyses using Kruskal–Wallis or Wilcoxon tests were performed.

**Results**

Under baseline conditions, the physiological variables in table 1 were similar in control, ischaemic and AVM patients. With administration of 100% oxygen in the inspired gases, $p_{O_2}$ increased in all three groups to a similar degree. The response to oxygen ventilation in a normal patient is shown in figure 1. Tissue $p_{O_2}$ increased in these patients during the increase in $p_{O_2}$, but there was no change in tissue $p_{CO_2}$ or pH. Figure 2 show mean tissue $p_{O_2}$ data for all patients. Under baseline conditions, tissue $p_{O_2}$ decreased in ischaemic and AVM patients compared with controls, and the increase in $p_{O_2}$ during oxygen administration was attenuated in ischaemic and AVM patients during hypoxia. Tissue $p_{CO_2}$ increased and pH decreased in ischaemic patients during the baseline period but neither variable changed during oxygen ventilation (table 1).
Discussion

In non-ischæmic patients, we found a baseline tissue $P_{O_2}$ of 4.2 kPa. This is consistent with previous reports.1–3 During hyperoxia, tissue $P_{O_2}$ increased to 7.5 kPa in non-ischæmic patients. This agrees with the conclusions of Meixenberger and colleagues5 that local mechanisms regulate the upper limit of tissue oxygenation. Tissue oxygenation decreased significantly in patients with cerebral occlusive disease and AVM under baseline conditions and during oxygen ventilation. This indicates that mechanisms which promote tissue oxygenation are attenuated in occlusive disease and AVM.

Previous studies have suggested that cerebral occlusive disease and AVM produce different types of ischaemia. Acute and chronic brain ischaemia during brain artery occlusion is associated with a decrease in $P_{O_2}$, an increase in $P_{CO_2}$ and acidosis.1,8–11 This is accompanied by loss of cerebrovascular reactivity to increases in $P_{CO_2}$.12 In contrast, with an AVM, cerebral tissue perfusion pressure and blood flow are decreased because of shunting of arterial blood flow away from normal tissue.4–6,13 Although AVM have been described as producing vascular paralysis and ischaemia,4,14 studies have shown that carbon dioxide reactivity and pressure autoregulation are intact.5,6 In spite of the reported differences between these two types of ischaemia, we found that the tissue oxygenation response to oxygen ventilation was attenuated in both groups. This suggests that inadequate brain tissue oxygen delivery is a consistent problem in patients with cerebral occlusive disease and AVM.

In this study, patients with occlusive disease had significantly increased tissue $P_{CO_2}$ and decreased pH. This supports previous reports that carbon dioxide clearance is attenuated and metabolic acidosis may be present in these regions.9,11,15,16 In contrast, in tissue adjacent to an AVM, $P_{CO_2}$ and pH did not differ from control values, possibly because decreased tissue metabolism would lower carbon dioxide production and normalize pH in hypoxic tissue.17 One concern is that the lack of change in brain tissue $P_{CO_2}$ and pH results from a lack of sensitivity of the sensors rather than absence of a tissue change. However, in previous studies we have shown that tissue $P_{CO_2}$ and pH change in patients during hypercapnic challenge.9 This supports the fact that the lack of changes in tissue $P_{CO_2}$ and pH during increases in oxygen ventilation were accurate.

In summary, these results showed that brain tissue $P_{O_2}$ was lower in patients with cerebral occlusive disease and AVM compared with non-ischæmic patients. During oxygen ventilation, tissue $P_{O_2}$ increased (4.6 kPa) in control patients; this was significantly greater than the response in patients with occlusive disease and AVM. Simultaneous measurements of tissue $P_{CO_2}$ and pH indicated that the metabolic characteristics of occlusive disease and AVM were different but that inadequate tissue oxygenation was a consistent problem in both groups.

References