Significant decrease of cerebral oxygen saturation during single-lung ventilation measured using absolute oximetry

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Background. Single-lung ventilation (SLV) during thoracic surgery causes important cardiopulmonary disturbances. Absolute cerebral oximetry was used to determine the incidence and magnitude of the decrease in cerebral oxygen saturation (SctO2) in patients undergoing SLV during thoracic surgery.

Methods. Data were obtained from 20 consecutive patients undergoing thoracic surgery and necessitating SLV of more than 1 h. The FORESIGHT™ (CASMED, USA) absolute oximeter was used to measure left, right, and average absolute SctO2 every 5 min from the awake state to extubation. Bispectral index and standard monitoring parameters were also recorded every 5 min. Blood gas analysis was performed every 15 min. Data median (IQR) (range) were analysed using repeated-measures ANOVA and Spearman’s correlation test, P<0.05.

Results. Patients [median age 65 yr (range 46–75)] showed an absolute SctO2 of 80% (78, 82) (74–87) in the awake state, which decreased to a minimum SctO2 value of 63% (57, 65) (53–73) during SLV to recover to an SctO2 of 71% immediately after extubation. During SLV all patients had a decrease of more than 15% of the initial SctO2 and 70% of patients had a decrease of more than 20%. The decrease in SctO2 was not correlated with any standard clinical parameters, for example, arterial pressure, blood loss, peripheral oxygen saturation, or PaO2.

Conclusions. Thoracic surgery with SLV seems to be associated with a significant decrease of SctO2 in the majority of patients. Parameters such as peripheral oxygen saturation or PaO2 which are used to guide SLV during thoracic surgery are not sufficient to detect significant cerebral oxygen desaturations.

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Cerebral oximetry relies on the property of near-infrared light to pass through the skull and to be absorbed by biological molecules in the brain. It is used to non-invasively measure changes in concentration of oxyhaemoglobin and deoxyhaemoglobin in the entire tissue bed at the microvascular level, that is, arterioles, venules, and capillaries. Since there is about three times more venous than arterial blood,1 near-infrared spectroscopy provides an instantaneous and continuous evaluation of the ratio between oxygen supply and demand in a delimited area of the frontal cortex.2 The risk of intraoperative cerebral ischaemia due to an imbalance between brain oxygenation and demand, which could previously go unnoticed, can be immediately detected with this technology.

Cerebral oximetry has been used to monitor cerebral oxygen saturation during cardiac,1 3–8 aortic arch,9 and abdominal10 11 surgeries and also during carotid endarterectomy12–18 and neurosurgery.19

Most thoracic surgeries require single-lung ventilation (SLV). However, SLV is associated with important physiological disturbances such as hypoxic pulmonary vasoconstriction (HPV) in the non-ventilated lung, pulmonary arteriovenous shunt of the deoxygenated blood, decrease in oxygen partial pressure,11 changes in alveolar–arterial oxygen tension, activation of inflammatory processes, or changes in cardiac output and pulmonary/systemic pressures. Prolonged SLV is associated with severe oxidative stress and free radical generation.20 SLV and lateral
position are also associated with a reduction in the functional residual capacity of the ventilated lung. Jugular bulb venous oxygen saturation (\(S_jO_2\)) has been recently found to decrease during lung surgery under SLV with sevoflurane- or propofol-based anaesthesia. 

The FORE-SIGHT® cerebral oximeter (CASMED, Branford, MT, USA) continually measures absolute brain oxygen saturation non-invasively without the need for baseline calibration. It uses four discrete wavelengths in order to achieve accurate measurements of oxyhaemoglobin and deoxyhaemoglobin and to compensate for interference from background light absorbers and for wavelength-dependent scattering losses. Sensors capture light by detectors positioned for optimal signal collection and subtraction of interference from non-brain tissues. The light signal is analysed by a patented algorithm to provide absolute brain oxygen saturation starting before anaesthesia induction until extubation. This absolute cerebral oximeter measures the absolute cerebral tissue oxygen saturation without the need for baseline calibration. The sensors were positioned bilaterally on the patients’ lower forehead and covered by an opaque plastic patch in order to prevent ambient light to affect the measurements. The anaesthetic management was not influenced by \(SctO_2\) values (values were hidden from the anaesthetist). BIS, peripheral oxygen saturation, mean BP, and heart rate (HR) were recorded every 5 min. In addition, arterial blood gas analysis \([pH, P\text{CO}_2, P\text{O}_2, \text{Na}^+, \text{K}^+, \text{Ca}^{2+}, \text{glucose, lactate, haematocrit (Hct), total haemoglobin concentration (THbc), } SO_2(\%)]\) was performed every 15 min.

Therefore, we hypothesized that absolute oximetry provides an adequate, non-invasive monitoring method to assess the incidence of a significant decrease in regional cerebral oxygen saturation (\(SctO_2\)) in patients undergoing SLV during thoracic surgery and assess its correlation with standard monitoring parameters.

Methods

This prospective observational-only study was approved by the local ethics committee and written informed consent was obtained from all patients before surgery. Data were obtained from 20 consecutive patients undergoing thoracic surgery and necessitating SLV of more than 1 h in the period of September–December 2007.

Before general anaesthesia, an epidural catheter was installed at T4,5; T5,6; or T6,7 level in the standard fashion for perioperative administration of 4–8 ml h\(^{-1}\) of bupivacaine 0.1% and fentanyl 3 \(\mu g\) ml\(^{-1}\). After premedication with midazolam 1–2 mg and radial arterial line placement, anaesthesia was induced with propofol 0.5–1.5 mg kg\(^{-1}\), sufentanil 0.5–1 \(\mu g\) kg\(^{-1}\) or fentanyl 4–7 \(\mu g\) kg\(^{-1}\), and rocuronium 0.6 mg kg\(^{-1}\). A left-sided double-lumen tube (DLT) was used for endotracheal intubation under fibreoptic assistance. The patient was then positioned in left or right lateral decubitus position depending on the side of the operated lung. Anaesthesia was provided using sevoflurane to maintain a bispectral index (BIS) level of 35–50 (Aspect A-2000 monitoring system, Aspect Medical System, MA, USA) in oxygen 100%. Standard monitoring consisted of five-lead electrocardiography, invasive blood pressure (BP), and peripheral oxygen saturation.

Additional doses of fentanyl to a total of 7–15 \(\mu g\) kg\(^{-1}\) or equivalent and rocuronium boluses were given at the discretion of the anaesthetist. During SLV, the lung protection ventilation strategy of low tidal volume and the use of PEEP was performed with a ventilatory frequency of 15; an \(F\text{O}_2\)=100% was used in all patients. Continuous positive airway pressure was applied for a limited period of time to the non-dependent lung when the peripheral oxygen saturation decreased below 90%.

Absolute oximeter was used to continuously measure absolute brain oxygen saturation starting before anaesthesia induction until extubation. This absolute cerebral oximeter measures the absolute cerebral tissue oxygen saturation without the need for baseline calibration. The sensors were positioned bilaterally on the patients’ lower forehead and covered by an opaque plastic patch in order to prevent ambient light to affect the measurements. The anaesthetic management was not influenced by \(SctO_2\) values (values were hidden from the anaesthetist). BIS, peripheral oxygen saturation, mean BP, and heart rate (HR) were recorded every 5 min. In addition, arterial blood gas analysis \([pH, P\text{CO}_2, P\text{O}_2, \text{Na}^+, \text{K}^+, \text{Ca}^{2+}, \text{glucose, lactate, haematocrit (Hct), total haemoglobin concentration (THbc), } SO_2(\%)]\) was performed every 15 min.

The average, left, and right \(SctO_2\) values were used for data analysis. Baseline \(SctO_2\) was defined as the highest \(SctO_2\) value obtained before SLV. Data were analysed using the SAS statistical package Jmp version 7 (SAS Institute, Cary, NC, USA). Descriptive statistics for patient characteristic, intraoperative, physiological, and \(SctO_2\) data are presented as median (IQR) (range) for continuous data and number (proportion) for nominal data. Comparisons of the differences between values at a specific time and at baseline for \(SctO_2\), \(SatO_2\), \(P\text{O}_2\), and \(P\text{CO}_2\) were assessed using repeated-measures ANOVA. The correlations between \(SctO_2\) decreases and standard monitoring parameters were considered as statistically significant, if the Spearman test P-value was <0.05.

Results

The study included nine women and 11 men aged 65 (57, 70) (46–75) yr (Table 1). The patients underwent lobectomy (n=17), chest wall resection (n=1), lobectomy and chest wall resection (n=1), lobectomy and peripheral oxygen saturation.

<table>
<thead>
<tr>
<th>Table 1 Patient characteristics. Data are given as median (1st quartile, 3rd quartile) (range) or value (proportion). SLV, single-lung ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td>Male sex</td>
</tr>
<tr>
<td>ASA grade</td>
</tr>
<tr>
<td>Surgery</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Surgery duration (min)</td>
</tr>
<tr>
<td>SLV duration (min)</td>
</tr>
</tbody>
</table>
chest wall resection ($n$=1), and lobectomy and total lung decortication ($n$=1). The length of surgery was 137 (104, 168) (71–380) min with a length of SLV of 97 (60, 136) (34–153) min. All surgeries but one were uneventful and required no blood transfusion. One patient had a significant blood loss and required a transfusion of six packed red cells.

The patients had an $\text{SctO}_2$ of 80% (78, 82) (74–87) in the awake state, which decreased to a minimum $\text{SctO}_2$ of 63% (57, 65) (53–73) during SLV. This is equivalent to a decrease of $\text{SctO}_2$ by 22% (18, 27) (16–32). In 40% of the patients, $\text{SctO}_2$ decreased to absolute values lower than 60%. Seventy per cent of the patients had a maximum decrease of more than 20% in comparison with the baseline $\text{SctO}_2$ (Fig. 1). Within 5 min after the end of SLV, the patients recovered to an $\text{SctO}_2$ value of 68 (66, 70) (59–80). At the time of extubation, that is, 30 (24, 34) (10–65) min after the end of SLV, no patient had recovered to the baseline values, with a median $\text{SctO}_2$ of 71% (67, 73) (62–83). There was no significant difference between the $\text{SctO}_2$ of the site of surgery and the opposite site.

The patients showed a peripheral saturation of 99% (99, 99) (98–99) in the awake state (Fig. 2). During SLV, the peripheral saturation decreased to a value of 95% (86, 97) (84–99). In total, six (0, 3) patients reached a minimum saturation below 90% and needed PEEP of 6 mm Hg to the non-ventilated lung. Patients showed an arterial oxygen concentration ($P_{aO_2}$) of 426 mm Hg (343, 480) (220–567) in the awake state (Fig. 3A). There was a decrease in $P_{aO_2}$ during SLV with minimum values of 89 mm Hg (73, 112) (52–484). At the end of the surgery, $P_{aO_2}$ recovered to values not significantly different from the awake state at 361 mm Hg (238, 425) (173–480). The initial arterial carbon dioxide concentration ($P_{aCO_2}$) was 6.5 (5.7, 6.9) (5.2–8.2) kPa and did not show significant changes during SLV (Fig. 3B).

The maximum decrease in $\text{SctO}_2$ was not found to correlate significantly with any patient characteristic data such as age or sex, intraoperative variable such as length of surgery, standard clinical variables such as arterial pressure or peripheral oxygen saturation, and blood gas variables such as systemic oxygen saturation, CO2 pressure, haemoglobin, or Hct (Table 2).

**Discussion**

In this observational study in thoracic surgery with SLV, all patients underwent a significant cerebral desaturation of at least 15% from their baseline value at the awake state. Seventy per cent of the patients showed a reduction of...
20% or more of $\text{SctO}_2$. A significant proportion of the patients (40%) reached a minimum absolute cerebral saturation below 60%. The cerebral saturation of the patients had not recovered fully at the time of extubation. There was no correlation to standard clinical variables.

Cerebral oximetry has been used extensively in cardiac surgery because of the high incidence of postoperative cognitive dysfunction and cerebral vascular accidents. A review of the clinical efficiency of near-infrared spectroscopy in cardiac surgery based on 48 studies indicated that using a threshold equivalent to a decrease of 20% from the baseline value before intervention to reverse

![Graph A](A) Arterial oxygen concentration (median, 1st quartile, 3rd quartile): $\text{SaO}_2$ during awake state ($n=19$), during SLV: after 15 ($n=19$), 30 ($n=17$), 45 ($n=16$), 60 ($n=16$), 75 ($n=13$), 90 ($n=11$), 105 ($n=8$), 120 ($n=6$), and 135 ($n=5$) min and at the end of surgery. *P<0.003 to baseline. (B) Arterial carbon dioxide concentration (median, 1st quartile, 3rd quartile): $\text{SaO}_2$ during awake state ($n=19$), during SLV: after 15 ($n=19$), 30 ($n=17$), 45 ($n=16$), 60 ($n=16$), 75 ($n=13$), 90 ($n=11$), 105 ($n=8$), 120 ($n=6$), and 135 ($n=5$) min and at the end of surgery.

Table 2 Correlation between $\text{SctO}_2$ and selected intraoperative parameters

<table>
<thead>
<tr>
<th>Correlation tests (Spearman)</th>
<th>$R^2$</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.19</td>
<td>0.06</td>
</tr>
<tr>
<td>Maximum decrease in $\text{SctO}_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery duration</td>
<td>0.002</td>
<td>0.871</td>
</tr>
<tr>
<td>SLV duration</td>
<td>0.001</td>
<td>0.89</td>
</tr>
<tr>
<td>Relative peripheral saturation decrease</td>
<td>0.02</td>
<td>0.59</td>
</tr>
<tr>
<td>Relative haemoglobin decrease</td>
<td>0.00</td>
<td>0.95</td>
</tr>
<tr>
<td>Relative haematocrit decrease</td>
<td>0.08</td>
<td>0.23</td>
</tr>
<tr>
<td>Relative $\text{PaCO}_2$ decrease</td>
<td>0.00</td>
<td>0.87</td>
</tr>
<tr>
<td>Relative $\text{PaO}_2$ decrease</td>
<td>0.07</td>
<td>0.29</td>
</tr>
<tr>
<td>Relative mean pressure</td>
<td>0.21</td>
<td>0.08</td>
</tr>
<tr>
<td>Bispectral index</td>
<td>0.0012</td>
<td>0.828</td>
</tr>
</tbody>
</table>
desaturation decreased the incidence of neurological complications, the incidence of renal failure, the length of the intensive care unit, the total hospital stay, and surgical costs.  

Cerebral oximetry raised a great interest in vascular surgery because carotid cross-clamping may seriously impair brain oxygenation. A threshold of 20% below the pre-clamp $\text{SctO}_2$ value was found to have high specificity, but a different sensitivity (30% vs 80%) depending on the study, to identify patients with neurological complications, with low positive and high negative predictive values. The decrease in $\text{rSO}_2$ was also found to correlate with the clinical and EEG signs of cerebral ischaemia and the requirement for placing a Javid shunt.

In patients undergoing non-cardiac surgery, cerebral oxygen desaturation of more than 20% from baseline was equally associated with a high incidence of postoperative cognitive dysfunction and major cerebral dysfunction. In major abdominal surgery of older patients, managing anaesthesia based on cerebral saturation monitoring resulted in shorter hospital stays and less cognitive dysfunction. In prolonged abdominal surgery in older patients, the decrease in cerebral oximetry was almost always associated with a major or continuing haemorrhage and a significant decrease in haemoglobin levels. In our study, no correlation between cerebral desaturation and $\text{Hct}$ or haemoglobin changes was found.

Our hypothesis to apply cerebral oximetry in thoracic surgery with SLV was based on the presumption that SLV causes numerous pathophysiological changes which might have an impact on cerebral saturation. Even though gravity and HPV in the non-ventilated lung redirect part of the blood flow to the ventilated lung, there is nevertheless a pulmonary arteriovenous shunt of the deoxygenated blood through the non-ventilated lung representing 20–25% of the cardiac output. This shunt is responsible for a decrease of about 200 mm Hg in the oxygen partial pressure. SLV in the lateral position is also associated with a reduction in the functional residual capacity of the ventilated lung, changes in alveolar–arterial oxygen tension, activation of inflammatory processes, or changes in cardiac output and pulmonary/systemic pressures. Prolonged SLV is associated with severe oxidative stress and free radical generation.

The changes observed during thoracic surgery do not seem to be influenced by the lateral position; we applied cerebral oximetry in five patients undergoing surgery in the lateral position without SLV before this study. None of these patients showed changes of $\text{SctO}_2$ of more than 10% throughout surgery.

This study showed that most of the patients (70%) undergoing thoracic surgery with prolonged (>1 h) SLV underwent a cerebral desaturation >20% from their baseline. This level of cerebral deoxygenation is usually accepted as the threshold of cerebral ischaemia and is believed to be associated with high incidence of postoperative cognitive dysfunction and major cerebral dysfunction.

However, the present study was observational only. In order to determine the absolute safe threshold for cerebral oximetry, a measure of the cognitive impairment such as the Folstein Mini Mental Test performed before and after the surgery would be required.

In conclusion, thoracic surgery with SLV is associated with a significant decrease of $\text{SctO}_2$ of at least 15% in all patients. Further research on the postoperative complications and cognitive dysfunctions is mandatory in order to determine the correlation between brain desaturation and cognitive and other impairments in patients after thoracic surgery with SLV.

**Funding**

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