CARBOXYHAEMOGLOBIN CONCENTRATIONS, PULSE OXIMETRY AND ARTERIAL BLOOD-GAS TENSIONS DURING JET VENTILATION FOR Nd-YAG LASER BRONCHOSCOPY†

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SUMMARY

Oxygen saturation measured with pulse oximetry (SpO₂) is overestimated in the presence of carboxyhaemoglobin (COHb). Smoke produced during laser resection of tracheobronchial malignancies may increase concentrations of COHb. We have measured COHb concentrations in 14 patients undergoing laser resection and compared SpO₂ with functional oxygen saturation (SaO₂) to ascertain if pulse oximetry is an accurate monitor of oxygen saturation. During the procedure frequent changes occur in ventilatory mechanics. Arterial blood-gas tensions were measured to see if gas exchange was satisfactory. Mean preoperative COHb was 1.4%. There was no significant change in COHb in any patient at any stage during treatment. The highest value was 2.05%. The mean difference between SaO₂ and SpO₂ was 1.13% (95% confidence interval 0.70–1.56%). Oxygen saturation may therefore safely be monitored by pulse oximetry in patients managed by our technique. Empirical setting of a jet ventilator provided acceptable blood-gas tensions, although sometimes it was necessary to increase the FIO₂ to > 0.3 to maintain oxygenation.

KEY WORDS


During the past decade, endoscopic laser therapy has become an established palliative treatment for patients with tracheobronchial malignancy. The thermal effects of the neodymium (Nd) YAG laser may be used to resect and cauterize intraluminal tumour from the large airways and, in appropriately selected patients, it is possible to palliate haemoptysis, breathlessness and other obstructive symptoms [1]. Patients with tumours obstructing the central airways appear to be particularly suitable for laser treatment. They are frequently close to asphyxiation at the time of referral and prompt restoration of an airway with the laser may provide a dramatic and sustained clinical improvement [2, 3].

Although treatment may be given under local or general anaesthesia, the techniques using general anaesthesia are thought to offer greater operative safety [4]. Maintaining adequate gas exchange during the initial stage of treatment may be difficult, especially in patients with impending asphyxia. This is complicated further by the need to maintain a low inspired oxygen concentration (FIo₂) to reduce the risk of fire.

Pulse oximetry is a convenient method of monitoring arterial oxygenation during the procedure. The pulse oximeter determines arterial saturation by measuring the absorption of selected wavelengths of light passed through perfused tissues. However, only two wavelengths are used, 660 nm and 940 nm, and the oximeter distinct-


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guishes only between deoxyhaemoglobin (Hb) and oxyhaemoglobin (HbO$_2$) [5,6]. Smoke is produced during lasering and may result theoretically in increased concentrations of carboxyhaemoglobin (COHb). Because COHb absorbs almost identically to HbO$_2$ at 660 nm, saturation determined by pulse oximetry (Sp$_{O_2}$) is overestimated in the presence of COHb [7], and patients may be hypoxic even though the Sp$_{O_2}$ is normal.

We assessed, therefore, the validity of pulse oximetry by measuring formation of COHb and comparing Sp$_{O_2}$ with functional oxygen saturation (Sa$_{O_2}$) [8] measured directly from arterial blood samples obtained in patients undergoing treatment with a Nd–YAG laser.

**PATIENTS AND METHODS**

After Ethics Committee approval and written informed patient consent had been obtained, we studied 21 patients undergoing palliative laser resection of endobronchial tumours. Arterial blood-gas tensions and Sp$_{O_2}$ were measured in all patients and in 14, COHb, methaemoglobin (MetHb), and Sa$_{O_2}$ concentrations were measured also.

Premedication comprised i.m. atropine 0.6 mg 1 h before induction. On arrival of the patient in the bronchoscopy room, an electrocardiograph, non-invasive arterial pressure monitor and a pulse oximeter (Nellcor N100) were attached. The oximeter finger probe was placed on the index finger of the dominant hand and a cannula placed in the radial artery on the other side. After preoxygenation, anaesthesia was induced with i.v. etomidate 14–28 mg and alfentanil 1–2 mg i.v. Atracurium in bolus doses was administered to produce neuromuscular block as assessed by peripheral nerve stimulator. Anaesthesia was maintained with an infusion of propofol commenced immediately after induction. When relaxation was produced the rigid bronchoscope was passed into the trachea and a jet ventilator (Accutronic VS 150s) attached to the side arm. The ventilator was adjusted to a rate of 60 b.p.m., an inspiratory time of 30% of each cycle and a driving pressure of 1.5–2.0 bar. Care was taken to observe good chest movement with ventilation. Shortly before lasering commenced, $F_{I_0}$ was reduced to 0.3. If the Sp$_{O_2}$ decreased to less than 90% lasering was stopped and $F_{I_0}$ was increased until saturation was satisfactory. Arterial blood samples were taken at the following times: before induction, breathing air; before induction, breathing 100% oxygen; every 30 min thereafter during the procedure; 1–2 h after operation, breathing air. Corresponding Sp$_{O_2}$ measurements were made with the exception of the postoperative values. Using a Radiometer OSM3 haemoximeter, COHb, Sa$_{O_2}$, and MetHb were measured twice on each blood sample and the mean of the two values noted.

All patients were treated with the 1.318-μm output beam of a specially designed continuous wave Nd–YAG laser (Medilas 2; MBB-Medizintechnic). Treatments were given under general anaesthesia using a combination of flexible and rigid bronchoscopes. After induction of anaesthesia, the trachea was intubated with a rigid Shapshay laser bronchoscope (Storz; Model 10317 LA) and the lungs jet-ventilated with an oxygen–air mixture. A fibreoptic bronchoscope with a 2.6-mm diameter biopsy channel (Pentax FB-19H) was passed inside the lumen of the rigid instrument and the optical fibre which transmits the laser beam was passed down the channel of the flexible bronchoscope. Laser irradiation was given at powers ranging from 10 to 20 W in pulses of up to 1 s. At the end of treatment, coagulated tumour debris was removed with flexible and rigid biopsy forceps.

The total energy (J) delivered by the laser was recorded for each patient and the operator graded the amount of smoke produced on a three-point scale: large, moderate and small. The Sp$_{O_2}$ and Sa$_{O_2}$ values were recorded and presented graphically by the method described by Bland and Altman [9] (fig. 2). A paired $t$ test was used to compare preoperative COHb with the greatest value recorded subsequently for each patient.

**RESULTS**

COHb values were measured in 14 patients (10 male). All had a history of smoking, but none had

| TABLE I. Patient data (mean (range)) for the 14 subjects in whom HbCO was measured |
|-------------------------------------|-------------------------------|-----------------|----------------|
| Age (yr)                           | Duration of anaesthetic (min) | Amount of smoke | Laser energy (J) |
| 60.9 (43–71)                       | 108 (47–153)                  | Small = 4       | 7145            |
|                                    |                               | Moderate = 8    | (3093–14785)    |
|                                    |                               | Large = 2       |                 |
smoked within 10 days of the procedure. Patient data are shown in table I. Mean preoperative COHb was 1.4%. There was no consistent or important change in any patient at any stage during treatment (fig. 1). The greatest value was 2.05% — a preoperative value.

In five volunteers who were habitual smokers mean COHb concentrations were 6.2% before and 7.2% immediately after one cigarette. In patients, the mean difference between \( S_aO_2 \) and \( SpO_2 \) was 1.13% (fig. 2) with a 95% confidence interval of 0.70–1.56%.

In addition to these 14 patients, measurements of arterial blood-gas tensions were made in a further seven. In one patient, the arterial cannula was placed after induction and pre-induction values were not available. In the other 20 patients before induction, mean \( PaO_2 \) was 10.6 kPa breathing air with three subjects having a \( PaO_2 < 8 \) kPa. Of the 68 arterial blood-gas measurements during anaesthesia, 11 were of \( PaO_2 < 8 \) kPa, two with \( SpO_2 < 90 \). MetHb concentrations averaged 0.5% (range 0.2–0.9%) (table II). Postoperative \( PaO_2 \) breathing room air was < 8 kPa in three patients. In one, the preoperative value was unknown; in another it was 9.5 kPa, and in the third the preoperative value was similar—7.1 kPa, compared with 7.2 kPa after operation. This last patient developed airway obstruction soon after tracheal extubation, with a \( PaCO_2 \) of 7.8 kPa. A bronchoscope was re-inserted and secretions were removed. After a short period of ventilation and treatment with bronchodilators, blood-gas values improved. There were no other postoperative respiratory problems. Mean \( PaCO_2 \) before operation was 4.9 kPa (range 3.1–5.7 kPa) and, of the readings during anaesthesia, the minimum value was 2.6 kPa and the maximum 8.8 kPa. After operation, with the exception of the patient who required ventilation, the smallest value was 3.5 kPa and the greatest 5.5 kPa.

**DISCUSSION**

The effect of abnormal haemoglobins on \( SpO_2 \) depends on how their light absorption compares with that of Hb and HbO\(_2\) at 660 nm and 940 nm [5]. COHb absorbs almost identically to HbO\(_2\) at
660 nm and the pulse oximeter responds almost as if it were HbO2. Various formulae have been calculated to account for the COHb, but fractional $S_aO_2$ [8] approximates to $(S_{PO_2} - 0.9 \ S_aCO_2)$ [7, 10] where $S_aCO_2$ is the percentage of COHb. Therefore, in patients with increased COHb the pulse oximeter overestimates oxygen saturation of blood. Furthermore, the oxyhaemoglobin dissociation curve is shifted to the left [11] in the presence of COHb, thus decreasing oxygen delivery to the tissues. Methaemoglobin (MetHb) may also have an effect [12], but this was not present in significant amounts in our patients.

The OSM3 haemoximeter measures the absorption by haemoglobin of light at six different wavelengths and can determine accurately the concentrations of Hb, HbO2, MetHb and COHb. The functional $S_aO_2$ is then calculated: HbO2/(HbO2 + Hb). The fractional $S_aO_2$ is HbO2/(HbO2 + Hb + COHb + MetHb) and therefore takes account of the presence of abnormal haemoglobins; for our patients this was approximately 0.98 of the functional $S_aO_2$.

Smoke is generated by laser resection of tumours in the upper airway. It may obscure the operator’s view of the airway to an extent that has prompted the design of a special ventilator to remove the smoke [13]. It has also been suggested previously that laser therapy may result in increased concentrations of COHb [14]. If this were to occur in patients whose oxygen saturation was monitored by pulse oximetry, they might be hypoxic even though $S_{PO_2}$ records normal values. It is possible that different types of laser may result in different degrees of smoke generation; it is not possible, therefore, to extrapolate our data to all patients who receive laser bronchoscopy. However, our results are in agreement with those of Brutinel, McDougall and Cortese [14], who found no change in COHb in patients who received therapy with a Molelectron Nd-YAG laser operating at a wavelength of 1.064 μm.

Several anaesthetic techniques of ventilation have been developed for this procedure [15–22]. We used a total i.v. anaesthetic and mechanical ventilation through the side arm of a Storz rigid bronchoscope. The mechanics of ventilation change frequently during the procedure. The passage of the fibreoptic scope through the rigid scope alters the compliance and resistance of the system and blood, secretions and debris also interfere with ventilation. The distribution within the airways and alveoli of any carbon monoxide produced depends largely on the pattern of ventilation. Although ventilator settings were constant, because of the factors listed above, ventilation was variable and could not be standardized. It cannot be assumed that other ventilation techniques will produce the same results, but we have no reason to suspect that an alternative method providing good gas exchange and subject to the same sources of variability would result in substantially greater concentrations of COHb.

Oxygenation was adequate and was monitored satisfactorily by pulse oximetry. $P_{aCO_2}$ was generally within acceptable values when good chest movement was observed. Although our patients had compromised airways, in all but one, postoperative arterial blood-gas values comparable to preoperative values were achieved breathing air ($F_{1O_2}$ 0.21) within 1–2 h. There was no evidence that the procedure caused short-term respiratory embarrassment in the postoperative period.

This study has shown that treatment with a Nd–YAG laser operating at a wavelength of 1.318 μm did not produce clinically significant concentrations of COHb with the anaesthetic and ventilation techniques used. Pulse oximetry may therefore be used reliably and accurately to monitor oxygen saturation during treatment. Empirical settings of a jet ventilator provided acceptable blood-gas values, despite changes in ventilatory mechanics, although sometimes it may be necessary to increase $F_{1O_2}$ to > 0.3 to maintain oxygenation.

**REFERENCES**


