The purpose of this study was to assess the clinical usefulness of near-infrared spectroscopy (cerebral oximetry) in patients presenting to the emergency department (ED) with carbon monoxide (CO) intoxication. Eighteen patients with a diagnosis of CO intoxication who presented to our ED during 2013 were included in this prospective study. All patients were treated and monitored according to the standard recommendations for CO intoxication. In addition, cerebral oxygen saturation (ScO₂) was measured using near-infrared spectroscopy, also known as cerebral oximetry. Minimum and maximum ScO₂ values from the right and left frontal region were recorded using cerebral oximetry from immediately after presentation to the ED until discharge. Patient blood carboxyhemoglobin (COHb) levels before and after oxygen treatment were compared with the cerebral oximetry measurements. At the time of admission, mean blood (COHb) values were 29.3% ± 6.7%, and ScO₂ values were 59.0 ± 4.0 in the right frontal region and 60.9 ± 5.1 in the left. When blood COHb levels had returned to normal following oxygen therapy, ScO₂ values were 75.9 ± 6.1 (65.5–90.5) in the right frontal region and 74.9 ± 7.8 (62.0–90.0) in the left. The differences in ScO₂ values before and after oxygen therapy were statistically significant (P ≤ 0.005). Assessment of patients exposed to CO gas using cerebral oximetry can provide information about cerebral oxygen saturation. Blood COHb level measurement is still the best method for diagnosing CO intoxication; however, cerebral oximetry, a non-invasive technique, may be an effective method for assessing cerebral oxygen saturation. (doi: 10.2302/kjm.2014-0010-OA, Keio J Med 64 (4) : 57–61, December 2015)

Keywords: carbon monoxide, intoxication, cerebral oximetry, cerebral oxygenation

Introduction

CO is a colorless, odorless, nonirritating gas produced primarily as a result of incomplete combustion of carbonaceous fossil fuels. CO poisoning is a major public health problem in Turkey and the developing countries. The risk of poisoning rises in winter months in homes heated using coal-burning stoves.¹ Because of the COHb that forms in the blood on exposure to CO, the requisite amount of oxygen cannot be transported to the tissues. Consequently, CO compromises the retention, transport, and use of oxygen in the body. This process accounts for CO-related hypoxia, ischemia, and tissue death. Organs with high metabolic activity, such as the brain and heart, are those most affected by CO intoxication.² The basis of treatment for CO intoxication is the minimization of damage through elimination of the CO and the reversal of cellular metabolic dysfunction.³ Patients

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must be removed from the environment containing CO (without endangering the lives of the rescue team), and even in mild cases, 100% oxygen at high flow must be administered using a mask attached tightly to the face. Oxygen must be administered until COHb levels return to normal (less than 5%). Hyperbaric oxygen therapy is required if loss of consciousness occurs (even if only temporary), if the patient is pregnant, if ischemic heart disease or arrhythmias are present, or if findings persist despite oxygen therapy.\(^4\) Even though COHb levels are used in patient monitoring, they may not always correlate well with clinical symptoms. Although COHb levels are normal in some patients admitted to intensive care, loss of consciousness is a sign of poor cerebral oxygenation.\(^5\) For this reason, we believe that the measurement of cerebral oxygenation using CO oximetry in cases of CO intoxication may be useful in terms of clinical follow-up.

Cerebral oximetry is a neurological monitoring technique developed in the 1970s for adult and pediatric cardiac surgery. This technology is still used today in fields such as non-cardiac surgery, resuscitation, trauma, and neurology.\(^6,7\) The INVOS-5100c COx device utilizes near-infrared spectroscopy (NIRS) technology to measure mixed venous–arterial (70/30) oxygen saturation in the frontal lobes of the cerebral cortex. This primarily venous oxygen saturation level is a function of local tissue oxygen consumption and therefore of oxygen delivery, making this measurement a reliable reflection of perfusion. Each probe consists of an adhesive strip housing a single near-infrared light transmitter and two sensors, allowing light to penetrate the skin, skull, and cortical brain tissue. The near-infrared light is scattered by the tissues and follows a parabolic path. Using two sensors allows measurement of hemoglobin saturation of the blood in the skin and skull in one sensor, and in the skin, skull, and frontal cortex tissue in the other sensor. The frontal cortex oxygen saturation is calculated by subtracting the first signal from the second. Limits of detection for the device include a hemoglobin oxygen saturation of \(< 15\%\) or \(> 95\%\) and a cortical tissue depth of \(> 2\) cm.\(^8\) The output shows the percentage saturation by measuring oxyhemoglobin (O-Hb) and deoxyhemoglobin. The percentage saturation is not the sum of O-Hb and COHb.

ScO\(_2\) values in healthy individuals range from 55 to 75. If ScO\(_2\) values decrease by more than 25% from baseline during monitoring with NIRS in cardiovascular operations, cerebral ischemia is suspected and appropriate measures are taken.\(^9\)

Although cerebral oximetry has been used in various previous clinical studies,\(^10-13\) to the best of our knowledge, there are no studies evaluating its clinical usefulness in CO intoxication. The purpose of this study was to evaluate the usefulness of cerebral oximetry in acute CO intoxication.

### Materials and Methods

#### Study design and setting

This study was performed in the Emergency Medicine Department of the RTE University Teaching and Research Hospital, Turkey, between October and December 2013. The protocol was approved by the local ethical committee. Written informed consent was obtained from all study participants.

#### Participants

During the study period, 32 patients with a history of exposure to CO gas and symptoms of CO intoxication were admitted to our ED. All patients had headache, nausea, and elevated COHb levels. The duration of exposure to CO gas was unknown. Patients who were smokers and those with anemia, hyper/hypotension, and chronic diseases that could affect and distort the cerebral oximetry measurements were excluded. Finally, 18 eligible patients were included in this study. The poisoning occurred as a result of the use of coal-burning stoves for home heating. The patients were all in groups of 3 and at most 5 members of a family sharing a single room. CO poisoning was diagnosed by the medical history of the patient and levels of COHb \(> 5\%) in the peripheral blood.

#### Treatment protocol

One hundred percent oxygen therapy by face mask at \(8–10\) l/min was started the moment patients reached the ED. At the same time, arterial blood was collected for blood gas analysis. Oxygen therapy was administered for \(2\) h at this level and then at \(4\) l/min. None of our patients had clinical symptoms requiring them to receive hyperbaric oxygen therapy. All patient symptoms resolved within \(3\) h. Blood COHb levels were analyzed \(12\) h after admission, when patients had no symptoms. Patients were informed about the chronic effects of CO intoxication. All patients had normal blood COHb levels \(12\) h after admission and were discharged in a healthy condition.

#### Cerebral oximetry measurements

Age, gender, and additional diseases at the time of admission were recorded for patients agreeing to participate. COHb was measured in arterial blood using a Cobas b 221 Blood Gas System (Roche Diagnostics, Indianapolis, IN, USA). Cerebral saturation levels were measured by NIRS using an INVOS 5100c device (Somanetics, Troy, MI, USA). Cerebral oximetry probes were attached to the right and left frontal regions of patients with suspected CO intoxication symptoms, and measurements were then...
started. At this point, arterial blood was collected and sent to the laboratory for blood gas analysis. Subsequently, 100% oxygen therapy was started via a face mask at a high flow of 8–10 l/min for the first 2 h, and 4 l/min thereafter. NIRS measurements were taken over 10 min at the initial presentation, and the highest and lowest values were recorded. Oxygen therapy was started subsequently. Before being discharged, the cerebral saturation levels of patients who had received oxygen therapy were measured in normal room air using NIRS for 10 min, as was done at initial presentation. It should be born in mind that the “cerebral hemoglobin saturation” values in this study depended on the concentrations of R-state hemoglobin, i.e., O-Hb and COHb, and T-state hemoglobin, i.e., deoxyhemoglobin. Therefore, the method used in this study did not allow discrimination of O-Hb and COHb concentrations in the brain.

**Statistical analysis**

Patients’ pre- and post-treatment ScO2 values were compared using the Mann-Whitney test and the Wilcoxon test. Pearson’s correlation test was used in the analysis of correlations between measurements. Data are presented as the arithmetic mean ± SD unless indicated otherwise. Significance was set at $P < 0.05$.

**Results**

The study flow chart is depicted in Fig. 1, inclusive of patient numbers. The mean patient age was 33.3 ± 18.0 (11–58 years). Eleven (61.1%) patients were female and 7 (38.9%) were male. No loss of consciousness occurred. Glasgow Coma Scale scores on admission were 15, and no patient had indications of ischemia in their electrocardiograms. Blood COHb levels were elevated on admission to the ED (mean 29.3% ± 6.7%). Arterial pH at the time of admission was 7.37 ± 0.03, pCO2 was 43.1 ± 6.1, and pO2 was 66.4 ± 2.6 (Table 1). Mean ScO2 values at the time of admission were 59.0 ± 4.0 (range 51.5–65.0) in the right frontal region and 60.9 ± 5.1 (range 53.0–68.5) in the left frontal region. After receiving oxygen therapy in the ED, patients were again assessed using cerebral oximetry before being discharged. Mean post-treatment ScO2 values were 75.0 (range 65.5–90.5) in the right frontal region and 73.5 (range 62.0–90.0) in the left frontal region (Table 2).

Cerebral saturation values following oxygen therapy were statistically significantly higher in both lobes than when patients were under the influence of CO gas at the time of admission ($P = 0.005$ for both lobes).

There was a negative correlation between right frontal ScO2 levels and blood COHb levels at the time of presentation ($r = -0.63$, $P = 0.005$). There was also a negative correlation between left frontal ScO2 levels and blood COHb levels at the time of presentation ($r = -0.53$, $P = 0.005$).

A negative correlation also existed between right frontal ScO2 levels and blood COHb levels measured at the time of discharge ($r = -0.62$, $P = 0.005$). A statistically significant, moderate, negative correlation was also determined between the left frontal ScO2 levels and blood COHb levels at discharge ($r = -0.56$, $P = 0.005$).

**Table 1 Blood gas values (mean ±SD) before and after oxygen therapy for CO intoxication**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-treatment (before O2 treatment)</th>
<th>Post-treatment (at time of discharge)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial pH</td>
<td>7.37 ± 0.03</td>
<td>7.33 ± 0.02</td>
</tr>
<tr>
<td>Arterial pCO2 (%)</td>
<td>43.1 ± 6.1</td>
<td>25.3 ± 3.7</td>
</tr>
<tr>
<td>Arterial pO2 (%)</td>
<td>66.4 ± 2.6</td>
<td>94.6 ± 2.2</td>
</tr>
<tr>
<td>COHb (%)</td>
<td>29.29 ± 6.7</td>
<td>1.5 ± 0.6</td>
</tr>
</tbody>
</table>

COHb levels at the time of presentation ($r = -0.53$, $P = 0.005$).

A negative correlation also existed between right frontal ScO2 levels and blood COHb levels measured at the time of discharge ($r = -0.62$, $P = 0.005$). A statistically significant, moderate, negative correlation was also determined between the left frontal ScO2 levels and blood COHb levels at discharge ($r = -0.56$, $P = 0.005$).
Patients were discharged as completely healthy with normal hemoglobin, leukocyte count, kidney and liver function, and serum electrolyte levels and with blood COHb levels below 3%.

**Discussion**

Cerebral saturation levels were lower in the acute period, when all patients were exposed to CO gas, than after oxygen therapy. In addition, there was a negative correlation between blood COHb levels and cerebral saturations while patients were under the effect of CO gas. In other words, the higher the COHb levels, the lower the cerebral saturations. The NIRS method used in this study did not allow discrimination of O-Hb and COHb concentrations in the brain. However, NIRS measures oxy- and deoxy-hemoglobin in venous and arterial blood at a 70:30 ratio in the microvasculature. Therefore, unlike pO2, ScO2 values can reflect hypoxia at the cellular level and theoretically can be used as an indicator of cerebral hypoxia. The cause of cerebral hypoxia in CO intoxication is that the affinity of CO for hemoglobin is 200 times greater than that of O2. CO produces hypoxia in cells by suppressing the respiratory chain.14 The low ScO2 values found in our study resulted from hypoxia developing in cells. In an experimental study, Tichauer et al. measured cerebral O2 saturation after inducing hypoxia in newborn baby pigs and assessed cerebral saturation using NIRS.15 They determined that NIRS measurements decreased as hypoxia increased. Their study, performed to assess cerebral saturation in the case of hypoxia, suggested that the use of NIRS can be beneficial, particularly in neonatal departments.

If a 25% decrease from ScO2 values measured at the start of surgery occurs during cardiovascular operations, this is considered to indicate cerebral hypoxia.16 NIRS is gradually starting to be used to assess cerebral oxygenation in other diseases. Frish et al. used NIRS to assess the effectiveness of resuscitation in five patients on whom they performed cardiopulmonary resuscitation and reported that NIRS can be beneficial in evaluating cerebral circulation.17 On the basis of our findings, we consider that NIRS will be useful in assessing cerebral oxygenation in acute CO intoxication.

In addition, the acute symptoms of CO intoxication are associated with COHb levels in the blood. However, blood COHb levels may sometimes be normal on admission if patients are given oxygen en route to hospital. Unconscious patients are given oxygen when brought to hospital by emergency ambulance, so it may be difficult to diagnose these patients using blood COHb levels.18 Hawkins et al. reported that blood COHb levels in patients they admitted to intensive care as a result of CO intoxication were not high enough to account for the patients’ clinical conditions and suggested that COHb level is not a good marker to indicate hyperbaric oxygen therapy.5 All the patients included in the current study were conscious and none were pregnant. Consequently, in the absence of any electrocardiographic or myocardial ischemia findings, there was no need for any patient to receive hyperbaric oxygen therapy.

In our opinion, assessment of cerebral saturation with NIRS could prove useful in predicting potential neurological complications. We also suggest that studies comparing measurements performed with NIRS before and after hyperbaric oxygen therapy may be helpful in showing cerebral hypoxia in acute CO intoxication.

**Study limitations**

The most significant limitation of this study is the low number of subjects. Another is that our patients were free of the effects of CO and had access to fresh air while traveling to the hospital; because no patients were brought in by ambulance, our measurements could not be performed at the scene of the incident. We suspect that greater differences between pre- and post-oxygen therapy ScO2 measurements may be determined in future experimental studies.

Cerebral injury in CO intoxication is known to occur mainly in the basal ganglia. These lesions can be detected using computerized tomography of the brain and cerebral magnetic resonance imaging. While some studies report that NIRS measurements involve the cerebral frontal region, and particularly the cortex, this measurement in the cerebral cortex is known to reflect global oxygenation of brain tissue as a whole.19 Therefore, the low ScO2 measurements in cases of CO poisoning-related cerebral intoxication in this study reflect global ischemia of brain tissue. Further studies are now needed to compare NIRS measurements and brain diffusion MRI to detect injury developing in the basal ganglia.
Conclusion

In conclusion, cerebral oximetry may be an effective technique for assessing cerebral oxygenation in acute CO intoxication. This noninvasive technique can also be used during follow-up. Wide-ranging studies comparing blood COHb levels, cerebral oxygen saturation, and clinical findings are needed to establish the role and benefits of cerebral oximetry in CO intoxication.

Conflict of Interest

The authors declare no conflict of interest.

Financial Disclosure

The authors declare that this study has received no financial support.

References