Carbon monoxide production from desflurane and six types of carbon dioxide absorbents in a patient model

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Background: Desflurane is known to produce high concentrations of carbon monoxide (CO) in desiccated sodalime or Baralyme® (Allied Healthcare Products, St. Louis, MO). Desiccated absorbents without strong bases like potassium hydroxide or sodium hydroxide are reported to produce less or no CO at all. The purpose of this study is to compare the concentration of CO in an anesthesia circuit for desflurane with six different types of completely desiccated CO2 absorbents with less strong bases than sodalime.

Methods: A patient model was simulated using a circle anesthesia system connected to an artificial lung. Completely desiccated CO2 absorbent (950 g) was used in this system. A low flow anesthesia (500 ml min⁻¹) was maintained using desflurane. For immediate quantification of CO production a portable gas chromatograph was used.

Results: Peak concentrations of CO were very high in Medisorb® (Datex-Ohmeda, Hoevelaken, The Netherlands) and Spherasorb® (Intersurgical, Uden, The Netherlands) (13317 and 9045 p.p.m., respectively). It was lower with Loflosorb® (Intersurgical, Uden, The Netherlands) and Superia® (Datex-Ohmeda, Hoevelaken, The Netherlands) (524 and 31 p.p.m., respectively). Amsorb® (Armstrong, Coleraine, N. Ireland) and lithium hydroxide produced no CO at all.

Conclusion: Medisorb® and Spherasorb® are capable of producing large concentrations of CO when desiccated. Loflosorb® and Superia® produce far less CO under the same conditions. Amsorb® and lithium hydroxide should be considered safe when desiccated.

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line connected to the gas chromatograph. Sampled gas from the outlet of the infrared anesthetic vapor analyzer was returned to the circle anesthesia system.

Six types of carbon dioxide absorbents (Table 1) were used. The absorbents were purchased from their manufacturers. Each type of carbon dioxide absorbent was dried completely by using an oxygen flow of 151 min⁻¹ in glass containers until no more further weight reduction could be measured. The weight reduction was consistent with the producers specifications of water content of the absorbent.

**Experiments**

For each absorbent an experiment was performed in which 950 g of dry absorbent was used, the ventilator was set in IPPV mode with a tidal volume of 600 ml, with a frequency of 14 and 5 PEEP. After an equilibration with 40% oxygen and 60% nitrous oxide was established at a fresh gas flow of 51 min⁻¹, desflurane was introduced by a standard vaporizer. The dial was set at approximately 4% until the vapor analyzer showed approximately 3.0 vol% of desflurane in the anesthetic circuit. Then the fresh gas flow was reduced to 500 ml min⁻¹, maintaining an equilibrium of 3.0 vol% of desflurane in the anesthetic circuit during a 3-h experiment. The concentration of 3.0 vol% desflurane was derived from the textbook International Practice of Anesthesia (10), and used in our clinic with good results in combination with 60% nitrous oxide and fentanyl.

All experiments were performed in duplicate (12 experiments in total) in order to verify the reproducibility of the CO measurements. To verify that no CO was formed in normal circumstances, i.e. with fresh absorbents, these measurements were repeated with each of the absorbents in a fresh condition.

**Table 1**

<table>
<thead>
<tr>
<th>CO₂ absorbent</th>
<th>Ca(OH)₂ (%)</th>
<th>KOH (%)</th>
<th>NaOH (%)</th>
<th>LiOH (%)</th>
<th>H₂O (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medisorb®</td>
<td>81</td>
<td>0.003</td>
<td>1</td>
<td>–</td>
<td>18</td>
</tr>
<tr>
<td>Spherasorb®</td>
<td>84.5</td>
<td>0.003</td>
<td>1.5</td>
<td>–</td>
<td>14</td>
</tr>
<tr>
<td>Amsorb®</td>
<td>83.2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>14.4</td>
</tr>
<tr>
<td>LoFloSorb®</td>
<td>84</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>16</td>
</tr>
<tr>
<td>Superia®</td>
<td>79.5</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>17.5</td>
</tr>
<tr>
<td>Lithium hydroxide</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>99</td>
<td>1</td>
</tr>
</tbody>
</table>

Absorbents obtained from: Datex-Ohmeda (Medisorb®, Superia®), Intersurgical (Sperasorb®, LoFloSorb®), Armstrong (Amsorb®) and Chem2000 (lithium hydroxide). Amsorb® contains 2.4% other chemicals like polyvinylpyrrolidone, calcium chloride and calcium sulfate. Superia® contains 3% other chemicals like magnesiumchloride and aluminosilicate.

**Carbon monoxide measurements**

Gas was automatically sampled every 5 min from the anesthetic circuit at a rate of 100 ml min⁻¹ during 10 s until 180 min for measuring the concentrations of carbon monoxide with a portable gas chromatograph (Varian Chrompack CP 2003P, Varian Analytical Instruments, Bergen op Zoom, The Netherlands) with a high-sensitivity thermal conductivity detector (TCD) and a Molsieve 5 A column (Varian Analytical Instruments, Bergen op Zoom, The Netherlands). Reliable measurement range of this setup is 1 p.p.m. to 1*10⁶ p.p.m. with a margin of error of 10%. The GC was calibrated with two calibration mixtures of 210 and 981 parts per million (p.p.m.) CO in nitrogen (Hoekloos specialty gasses, Dieren, The Netherlands). The calibration with 981 p.p.m. Carbon monoxide confirmed the linearity of the TCD. The GC was connected to a desktop PC for control of the GC and data recording, analysis and storage.

**Analysis of data**

Analyses were performed with SPSS 11.0 (SPSS, Gorinchem, The Netherlands). The Mann–Whitney U test was used to assess the reproducibility of CO measurements, expressed as lack of significant differences between the 36 CO concentrations of consecutive measurements. The Kruskal–Wallis was used for comparison between median CO concentrations of all absorbents. Data were presented as peak and median concentrations. For all analyzes the significance level was set at 5%.

**Results**

**Carbon monoxide measurements**

Since there were no differences in the carbon monoxide tensions in the two consecutive measurements for each absorbent (Mann–Whitney U test: P > 0.05), the mean of the two values were used for depiction of the experiments with Medisorb® (Datex-Ohmeda, Hoevelaken, The Netherlands), Spherasorb® and LoFloSorb® (Intersurgical, Uden, The Netherlands) (Fig. 1), and comparison among the six absorbents.

Carbon monoxide concentrations with the absorbents are shown in Fig. 1. It was not detected with normally hydrated conditions. Both peak and median values of carbon monoxide concentration were highest with Medisorb® and Spherasorb® and it was very low or not detected for LoFloSorb®, Superia®, Amsorb® and lithium hydroxide (P < 0.001, Table 2). Highest concentrations of CO were detected after
15–20 min (third or fourth sample) for all absorbents except Amsorb\textsuperscript{RI} and lithium hydroxide.

Interestingly, during the experiments with Medisorb\textsuperscript{RE} and Spherasorb\textsuperscript{RE} the anesthetic vapor infrared analyzer reported a concentration of enflurane up to 1.2 vol%, which correlated significantly with the measured CO concentration (Spearman’s \( r \) test: 0.98 for Medisorb\textsuperscript{RE} and 0.90 for Spherasorb\textsuperscript{RE}, both with \( P < 0.001 \)).

### Discussion

Our study provides the maximum concentrations of CO for each desiccated CO\textsubscript{2} absorbent when using 3.0 vol% desflurane with a oxygen/nitrous oxide mixture. Regarding the toxicity of CO, the Henderson and Haggard’s Index of Toxic effect (6) indicates that 1 h of exposure of greater than 1500 p.p.m. of CO is dangerous to life. Therefore our findings show that in these extreme conditions lethal CO concentrations can be reached for Medisorb\textsuperscript{RE} and Spherasorb\textsuperscript{RE}.

Our study confirms the results from other studies (4, 5) that less KOH and, to a lesser extent, NaOH in the carbon dioxide absorbent results in less CO production. However, these studies used 30-ml vials, 21 g of dry absorbent and 4, 3–4, 5 vol% desflurane without nitrous oxide, therefore providing a desflurane concentration below 1 MAC. Our study used a complete circle system with a complete canister of absorbent and 1 MAC desflurane in nitrous oxide, and therefore the results are more easily translated to a clinical situation. Another advantage of our study lies in the gas chromatograph we used. This gas chromatograph sampled automatically and online during each experiment, therefore avoiding possible manual sampling and injecting errors. To our knowledge this is the first time this kind of setup has been used.

The absorbents used in our study contain no KOH or trace amounts of KOH. The absorbents containing NaOH are responsible for the highest concentrations of CO. However this is not related to the amount of NaOH in the absorbent because Spherasorb\textsuperscript{RE} contains more NaOH than Medisorb\textsuperscript{RE} and produces less CO. The absorbents completely free of NaOH and KOH produced the smallest amounts of CO where Loflosorb\textsuperscript{RE} is still capable of producing more than 200 p.p.m. of CO. Superia\textsuperscript{RE} generates small but insignificant concentrations of CO and Amsorb\textsuperscript{RE} and lithium hydroxide do not produce CO. Possible explanation for the CO production of Loflosorb\textsuperscript{RE} could be the lack of extra ingredients like polyvinylpyrrolidone, calcium chloride and calcium sulfate used in Amsorb\textsuperscript{RE} and magnesiumchloride and alumino silicate used in Superia\textsuperscript{RE}.

Naturally when using classic sodalime (11) or Baralyme\textsuperscript{RE} (5), it would generate higher amounts of CO. Also higher amounts of desflurane (as used in an oxygen/air mixture) would give higher CO concentrations (12). Less desiccation will result in lower concentrations of CO, as published by Frink et al. (13) in a \textit{in vivo} study with swine. Other parameters like carbon dioxide absorption, fresh gas flow and minute volume have small effects on CO production, as shown by Woehlk et al. (14). Because of the relatively small effect of carbon dioxide absorption on CO production we did not add carbon dioxide to our model.

The reported enflurane concentration is probably attributable to the production of trifluoromethane that is simultaneously produced with CO (15) and is known to be detected as enflurane by this vapor
The analyzer (16). The enflurane detection disappears below a CO concentration of approximately 1800 p.p.m.; this explains why no ‘enflurane’ was detected in the other experiments. In case of a ‘mixed gas’ warning or an unexpected ‘enflurane’ detection using desflurane and one of these absorbents, one should consider the possibility of a (high) CO production.

The highest risk for CO formation occurs when fresh gas flow is maintained in an anesthesia system during a few days, because after 41 h of a 71 min⁻¹ fresh gas flow the soda lime will become critically dry (17). So, if one would like to avoid this potential lethal CO production from desflurane with the carbon dioxide absorbent one should consider using absorbents like Amsorb(®), lithium hydroxide or Superia(®). Also desiccated Loflosorb(®) is not dangerous to life but could generate a mild CO intoxication after three or more hours.

When considering changing the type of absorbent, one should also consider the cost factor, because most newer types of absorbents are more expensive and have a lower CO₂ absorbing capacity. As Stabernack et al. (5) demonstrated, the latter is not the case for lithium hydroxide, which has a higher carbon dioxide absorbing capacity but is much more corrosive than the absorbents based on calciumhydroxide and is therefore not available for use in clinical practice. Instead of changing the absorbent, one could also implement a safety protocol to maintain a proper humidity level inside the carbon dioxide absorbent (18), thus preventing the formation of CO.

Conclusions

In this simulated patient model we demonstrated the possible production of high concentrations of CO in the more classic absorbents Medisorb(®) and Spherasorb(®). Loflosorb(®) generates only small amounts of CO. The products Superia(®), Amsorb(®) and Lithium hydroxide should be considered safe to use in combination with desflurane. Because lithium hydroxide is not available for clinical use, only Superia(®) and Amsorb(®) are commercially available for anesthesia systems. A report from the vapor analyzer that a mixed gas or a certain amount of enflurane is present when using desflurane suggests that greater than 1800 p.p.m. Carbon monoxide is already present in the anesthesia circle system.

References


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