APPARATUS

The in vitro performance of carbon dioxide absorbents with and without strong alkali

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Summary

We report the in vitro longevity of a conventional soda lime CO2 absorbent and an absorbent free from strong alkali (Amsorb™). Although the times taken to breakthrough of CO2 (> 0.5%) within an in vitro low flow breathing system were shorter with the alkali-free absorbent, we found that the size and shape of the absorbent container was the major factor in determining the efficiency of the CO2 absorbents.

Keywords Equipment: carbon dioxide absorbents; canister; soda lime. Anaesthesia: low flow.

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Traditional soda lime relies on the presence of a strong alkali, either sodium or potassium hydroxide (or both), to catalyse the absorption of carbon dioxide by calcium hydroxide. The use of a strong alkali facilitates the absorption of CO2, but there is increasing evidence that these strong bases degrade volatile agents to toxic compounds not only in vitro but also in clinical practice [1, 2]. The breakdown of volatile anaesthetics by conventional soda lime, with the subsequent production of compound A, carbon monoxide and formaldehyde, has been reported [3–7]. Removing sodium and potassium hydroxide from the absorbent will prevent the production of such compounds [8] but may decrease the absorptive capacity of a lime. It is known that the efficiency of any carbon dioxide absorbent also depends on the canister size and shape [9], although the relative importance of these factors is unknown.

The aim of this study was to determine the in vitro CO2 absorptive capacity of both a commercially available soda lime (Medisorb) and a commercially available carbon dioxide absorbent Amsorb™ (which contains neither KOH nor NaOH) within four different designs of absorbent canister.

Methods

Four commercially available carbon dioxide absorbent canisters were tested. An ADU/2 compact patient-circuit absorbent canister (canister A) from a Datex-Ohmeda ADU (Datex-Ohmeda, Helsinki, Finland, Fig. 1) and a ThermH2O sorb canister (Raincoat Corporation, Louisville KY, USA – canister B –Fig. 2) were filled with either Medisorb or Amsorb™. The weight of each absorbent used to fill the canister was determined. The absorbent canister from a Draeger Julian anaesthetic machine (canister C – Draeger Medizintechnik GmbH, Germany –Fig. 3) and one half of a Jumbo Canister from an Ohmeda Modulus anaesthetic machine (canister D – Datex-Ohmeda –Fig. 4), were alternately filled with 1000 g of Medisorb or Amsorb™. The height, cross-sectional area and volume of each canister are shown in Table 1. The cross-sectional area and volumes of canisters A, B and C are approximate as these are not hollow containers, but consist of baffles and gas conduits within the canister. The dimensions are given only as a guide to the overall size and shape of the container. The canisters were positioned within the expiratory limb of a circle breathing system. An artificial lung was attached to the
‘patient’ end of the breathing system and ventilated with a tidal volume of 500 ml, a respiratory rate of 10 breaths.min\(^{-1}\) and an I:E ratio of 1:2. A fresh gas flow of 500 ml O\(_2\) and 500 ml N\(_2\)O was delivered to the inspiratory limb of the circuit and 200 ml.min\(^{-1}\) of CO\(_2\) delivered to the artificial lung through a calibrated rotameter. A Capnomac (Datex-Ohmeda, Sweden) measured CO\(_2\) concentrations within the inspiratory limb of the circle and recorded the data at 5-min intervals. The time taken for the Cl concentration within the inspired limb to exceed 0.5% was recorded. Each experiment was repeated three times.

**Results**

The times taken to breakthrough of CO\(_2\) in the inspiratory limb of the breathing system with Amsorb\(^{TM}\) and Medisorb for each canister are shown in Table 2. The weight of absorbent used in each canister is shown in Table 3. The volume of carbon dioxide absorbed per 100 g of each absorbent within the different canister systems is shown in Fig. 5. Canister D improved the efficiency of Medisorb by 563% and Amsorb\(^{TM}\) by 446% when compared with the least efficient canister – canister A.

**Discussion**

The fundamental reason for the use of low fresh gas flows in anaesthesia is economy. Further benefits include a reduction in pollution and the humidification of inspired gases. These advantages must be achieved without adverse effect to the patient.

The potential increase in safety afforded by removing the strong bases from a CO\(_2\) absorbent is at the expense of carbon dioxide absorptive capacity of that absorbent. Removing NaOH and KOH from soda lime allows breakthrough of CO\(_2\) to occur more quickly than normal. The absolute absorptive capacity of calcium hydroxide for CO\(_2\) remains unchanged. This study demonstrates that breakthrough of CO\(_2\) occurs more quickly in a lime without strong bases; however, the chief determinant of longevity in this study was the canister design. The effects of tidal volume, canister volume and canister shapes have been well researched and reported in the literature [10, 11]. To permit effective absorption of CO\(_2\) with any agent, there must be a minimum resident time of the gas over the absorbent surface and this varies widely between absorbent canisters. The void space or air space in any canister determines this residence time and this in turn depends chiefly upon the size and shape of the canister [12]. Only a small contribution is made by the size and shape of the granules themselves and this ‘space’ also depends upon how tightly the granules are packed together and in this regard Amsorb\(^{TM}\) is less dense than

<table>
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<tr>
<th><strong>Canister type</strong></th>
<th>Amsorb (\bar{x}) (SD)</th>
<th>Medisorb (\bar{x}) (SD)</th>
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<tbody>
<tr>
<td>ADU/2</td>
<td>468 (16)</td>
<td>558 (16)</td>
</tr>
<tr>
<td>ThermH(_2)Osorb</td>
<td>675 (9)</td>
<td>745 (14)</td>
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<tr>
<td>Draeger Julian</td>
<td>1000</td>
<td>1000</td>
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<tr>
<th><strong>Table 1</strong> Canister dimensions: approximate cross-sectional area (cm), height (cm) and volume (ml).</th>
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<th><strong>Table 2</strong> Mean (SD) time (min) taken for CO(_2) to exceed 0.5% in the inspiratory limb of a circle breathing system under <em>in vitro</em> conditions ((n = 3) for each canister/absorbent system).</th>
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**Figure 1** Canister A: ADU (Datex-Ohmeda, Helsinki, Finland).
Medisorb. Although the granules themselves contain air, this comprises a negligible portion of the total air space.

Optimum use of an absorbent is made when the tidal volume is equal to the void space within the canister [12] and for conventional soda lime, the void space constitutes between 45 and 47% of the total canister volume [12]. Given these ratios, canisters with a total volume of less than a litre would be unsuitable for adult clinical practice and ideally a canister volume of 2 litres is the minimum that will allow for tidal volumes encountered clinically.

For 8- to 16-mesh soda lime, it has been calculated that only about 30% of the surface area of the absorbent is active in CO₂ absorption [13] and the surface area is further reduced by channelling of gas through paths of least resistance within the canister. Provided that the air space in the canister is greater than or equal to the tidal volume, then it is by channelling of gas that the shape of the canister has its greatest influence on absorption. Channelling of gas may be seen in anaesthetic practice as a ‘footprint’ left as the pH of a lime changes and a pH-sensitive dye incorporated in all commercially available limes changes colour. In the absence of strong base, this colour change is not reversible and can provide the clinician with not only a reliable indication of exhaustion of the absorbent, but also with a visible record of flow through and absorbent utilisation within the canister. From this study, it appears that the convenience of a small size canister is a trade-off against efficient use of a CO₂ absorbent. This study highlights the potential inefficient use of all absorbents due to shortcomings in canister design.

Figure 2 Canister B: ThermH₂Osorb canister (Raincoat Corporation, Louisville, KY, USA).

Figure 3 Canister C: the absorbent canister from a Draeger Julian anaesthetic machine (Draeger Medizintechnik GmbH, Germany).

Figure 4 Canister D: canister from an Ohmeda Modulus anaesthetic machine (Datex-Ohmeda, Helsinki, Finland).
In clinical practice, however, there are other considerations which affect longevity when absorbents containing strong bases are used. For example, the economic benefits of low flow anaesthesia are seldom fully realised when sevoflurane is used. A restriction on fresh gas flow rates still exists in Australia, Canada, Greece, Norway, New Zealand, Switzerland and the USA where there is ongoing concern about the presence of compound A in closed and low flow breathing systems. Compound A is nephrotoxic in rats but it is debatable as to whether his compound is harmful in humans [14, 15]. Unfortunately carbon dioxide absorbents containing strong bases can also degrade desflurane, enflurane and isoflurane to carbon monoxide (CO). Although concerns about CO poisoning were first raised in an animal model [16], severe CO poisoning has subsequently been reported in clinical practice [17]. The hydration of both baralyme and soda lime has been identified as an important factor in the production of carbon monoxide by volatile anaesthetics in circle systems at both high and low fresh gas flows [14] and due to concerns over potential harm to patients the United States FDA Center for Disease Control have recommended that: 'All soda lime that has been dormant in the anesthesia machine for more than 24 hours should be changed, and dated' [18]. This again effectively reduces the in vivo longevity of soda lime.

In conclusion, the size and shape of an absorbent canister has a major effect on absorptive capacity of all CO₂ absorbents, regardless of the presence of strong alkali.

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