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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 CO_2 absorbent and an absorbent free from strong alkali (Amsorb™). Although the times taken to breakthrough of CO_2 ($> 0.5\%$) within an *in vitro* low flow breathing systern 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 CO_2 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 CO_2, 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* CO_2 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 canIters 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 ThermH_2Osorb 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

Table 1 Canister dimensions: approximate cross-sectional area (cm), height (cm) and volume (ml).

Canister type	Approximate cross-sectional area	Height	Volume
ADU/2	110	6	660
ThermH$_2$Osorb	62	16	1000
Draeger Julian	95	260	1500
Ohmeda Jumbo	176	10	1768

'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_2O 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™ 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™ 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.

Table 2 Mean (SD) time (min) taken for CO_2 to exceed 0.5% in the inspiratory limb of a circle breathing system under *in vitro* conditions ($n = 3$ for each canister/absorbent system).

Canister type	Amsorb	Medisorb
ADU/2	80 (5)	111 (18)
Thern1H$_2$Osorb	280 (13)	370 (10)
Draeger Julian	358 (20)	550 (13)
Ohmeda Jumbo	763 (56)	1126 (48)

Table 3 Mean (SD) weight of absorbent (g) used within each design of canister ($n = 3$).

Canister type	Amsorb	Medisorb
ADU/2	468 (16)	558 (16)
ThermH$_2$Osorb	675 (9)	745 (14)
Draeger Julian	1000	1000

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™ is less dense than

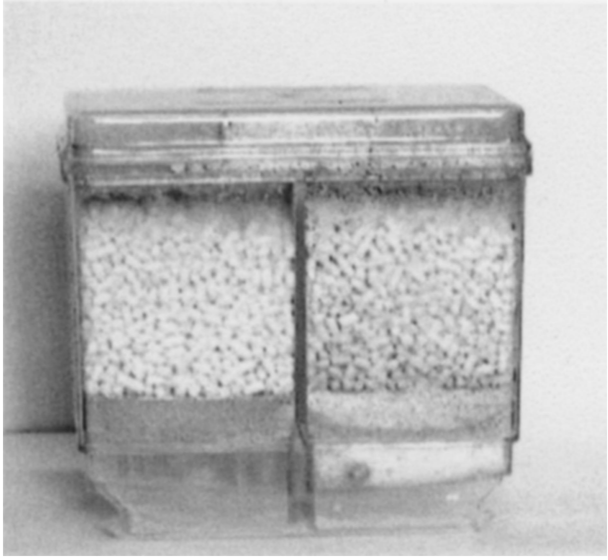

Figure 1 Canister A: ADU (Datex-Ohmeda, Helsinki, Finland).

Figure 2 Canister B: ThermH_2Osorb canister (Raincoat Corporation, Louisville, KY, USA).

Medisorb. Although the granules themselves contain air, this comprises a negligible portion of the total air space.

Optimum use of anabsorbent 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.

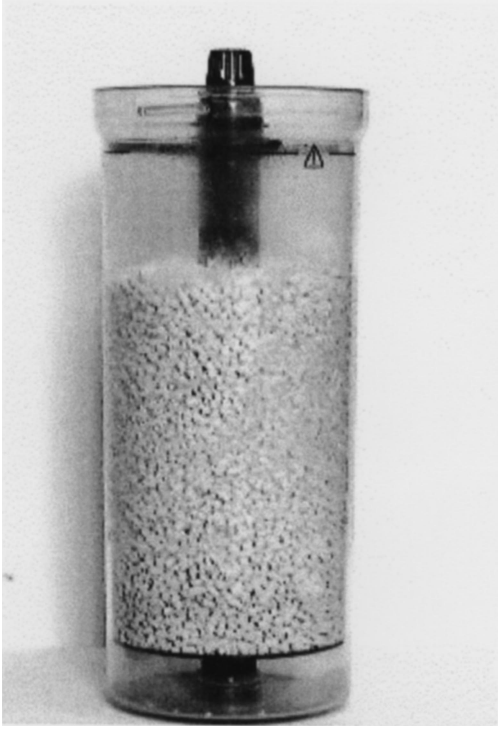

Figure 3 Canister C: the absorbent canister from a Draeger Julian anaesthetic machine (Draeger Medizintechnik GmbH, Germany).

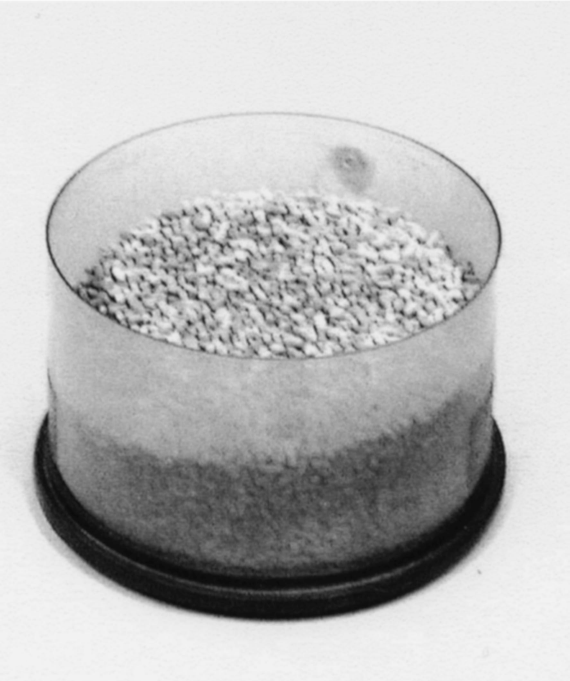

Figure 4 Canister D: canister from an Ohmeda Modulus anaesthetic machine (Datex-Ohmeda, Helsinki, Finland).

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 CO_2 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 CO_2 absorbent. This study highlights the potential inefficient use of all absorbents due to shortcomings in canister design.

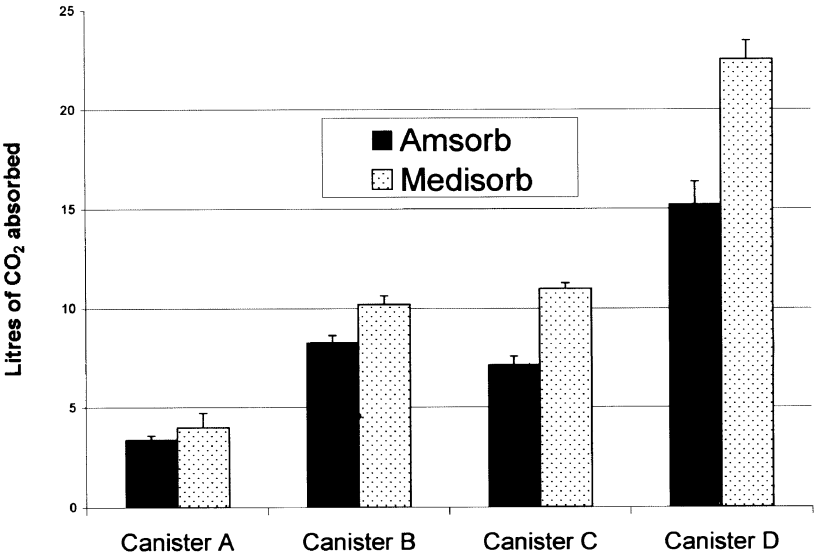

Figure 5 The amount of CO_2 absorbed (litres) per 100g absorbent within each different canister system ($n = 3$), before CO_2 levels exceeded 0.5% in the 'inspiratory' limb of the *in vitro* breathing circuit. Bars (error bars) are mean (SD).

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 CO_2 absorbents, regardless of the presence of strong alkali.

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References

1 Murray JM, Renfrew CW, Bedi A, McCrystal CB, Jones DS, Fe. JPH. Amsorb: a new carbon dioxide absorbent for use in anesthetic breathing systems. *Anesthesiology* 1999; **91**: 1342–8.
2 United States Pharmacopeia XXII. *National Formulary Requirements. Carbon Dioxide Absorbents: Soda Lime.*
3 Cunningham DD, Huang S, Webster J, Mayoral J, Grabenkort WV. Sevoflurane degradation to compound A in anaesthesia breathing systems. *British Journal of Anaesthesia* 1996; **77**: 537–43. Q1
4 Munday IT, Ward PM, Foden ND, Jones RM, Van Pelt FN, Kenna JG. Sevoflurane degradation by soda lime in a circle breathing system. *Anaesthesia* 1996; **51**: 622–6.
5 Baxter PJ, Garton K, Kharasch ED. Mechanistic aspects of carbo i monoxide formation from volatile anesthetics. *Anesthesiology* 1998; **89**: 929–41.
6 Woeffick HJ, Dunning M, Connolly LA. Reduction in the incidence of carbon monoxide exposures in humans undergoing general anesthesia. *Anesthesiology* 1997; **87**: 228–34.
7 Funk W, Gruber M, Wild K, Hobblialin J. Dry soda lime markedly degrades sevoflurane during simulated inhalation induction. *British Journal of Anaesthesia* 1999; **82**: 193–8.

8 Neumann MA, Laster MJ, Weiskopf RB, *et al.* The elimination of sodium and potassium hydroxides from desiccated soda lime diminishes degradation of desflurane to carbon monoxide and sevoflurane to compound A but does not compromise carbon dioxide absorption. *Anesthesia and Analgesia* 1999; **89**: 768–73.

9 Elam JO. The design of circle absorbers. *Anesthesiology* 1958; **19**: 99.

10 Adriani J, Rovenstine EA. Experimental studies on carbon dioxide absorbers for anesthesia. *Anesthesiology* 1941; **2**: 1–19.

11 Adriani J, Byrd ML. A study of carbon dioxide absorption appliances for anesthesia: the canister. *Anesthesiology* 1941; **2**: 450–55.

12 Brown ES. Voids pores and total air space of carbon dioxide abs orbents. *Anesthesiology* 1958; **19**: 1–6.

13 Brown ES. The activity and surface area of fresh soda lime. *Anesthesiology* 1958; **19**: 208–12.

14 Eger El II, Koblin DD, Bowland T, *et al.* Nephrotoxicity of sevoflurane versus desflurane anesthesia in volunteers. *Anesthesia and Analgesia* 1997; **84**: 160–8.

15 Ebert TJ, Frink EJ, Kharasch ED. Absence of biochemical evidence for renal and hepatic dysfunction after 8 hours of 1.25 minimum alveolar concenitation sevoflurane anesthesia in volunteers. *Anesthesiology* 1998; **88**: 601–10.

16 Frink EJ Jr, Nogami WM, Morgan SE, Salmon RC. High carboxyhemoglobin concentrations occur in swine during desflurane anesthesia in the presence of partially dried carbon dioxide absorbents. *Anesthesiology* 1997; **87**: 308–16.

17 Berry PD, Sessler DI, Larson MD. Severe carbon monoxide poisoning during desflurane anesthesia. *Anesthesiology* 1999; **90**: 613–6.

18 Lentz RECO. Poisoning during anesthesia poses puzzles: new agent used in Florida case. *Anesthesia Patient Safety Foundation Newsletter* 1994; **9**: 13–24.

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