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Amsorb Plus and Drägersorb Free, two new-generation carbon dioxide absorbents that produce a low compound A concentration while providing sufficient CO_2 absorption capacity in simulated sevoflurane anesthesia

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Abstract
Purpose. The properties of two new-generation CO_2 absorbents, Amsorb Plus (Armstrong Medical, Coleraine, UK) and Drägersorb Free (Dräger, Lübeck, Germany), were compared with those of Amsorb (Armstrong Medical) and Sodasorb II (W.R. Grace, Lexington, MA, USA).
Methods. The concentration of compound A produced by each absorbent was determined in a low-flow circuit containing sevoflurane, and the CO_2 absorption capacity of the absorbent was measured. The circuit contained 1000 g of each absorbent and had a fresh gas (O_2) flow rate of 1 l·min^{-1} containing 2% sevoflurane. CO_2 was delivered to the circuit at a flow rate of 200 ml·min^{-1}.
Results. The maximum concentrations of compound A were 2.2 ± 0.0, 2.3 ± 0.3, 2.2 ± 0.2, and 23.5 ± 1.5 ppm (mean ± SD) for Amsorb Plus, Drägersorb Free, Amsorb, and Sodasorb II, respectively. The maximum concentration of compound A for Sodasorb II was significantly higher than those for the other absorbents ($P < 0.01$). The CO_2 absorption capacities (time taken to reach an inspiratory CO_2 level of 2 mmHg) were 1023 ± 48, 1074 ± 36, 767 ± 41, and 1084 ± 54 min, respectively, and the capacity of Amsorb was significantly lower than that of the other absorbents ($P < 0.01$).
Conclusion. The new-generation carbon dioxide absorbents, Amsorb Plus and Drägersorb Free, produce a low concentration of compound A in the circuit while showing sufficient CO_2 absorption capacity.

Key words CO_2 absorbent · Compound A · CO_2 absorption capacity · Sevoflurane · Low-flow anesthesia

Introduction

Classical carbon dioxide (CO_2) absorbents degrade sevoflurane to 2-fluoromethyl-2-difluoro-1-(trifluoromethyl) vinyl ether (compound A) [1]. Although the toxicity of compound A is debatable [2–11], a CO_2 absorbent with reduced reactivity with sevoflurane is preferable for clinical use. In 1999, Amsorb (Armstrong Medical), the first absorbent to generate only small amounts of compound A, was released. However, in addition to this unique property, Amsorb has been reported to have a reduced capacity for CO_2 absorption, with a capacity of only 40% to 90% of that of standard sodalime [12–15]. Recently, two new-generation carbon dioxide absorbents, Amsorb Plus (Armstrong Medical) and Drägersorb Free (Dräger, Lübeck, Germany) have been released. Amsorb Plus is an advanced version of Amsorb. The manufacturers have announced that Amsorb Plus and Drägersorb Free generate small amounts of compound A from sevoflurane in a circle absorber and also have sufficient CO_2 absorption capacity. In the present study, we determined compound A concentrations in a low-flow circuit containing sevoflurane in the presence of each absorbent, and we simultaneously measured the CO_2 absorption capacity of the absorbent, in order to compare the properties of Amsorb Plus and Drägersorb Free with those of Amsorb and Sodasorb II.

Materials and methods

An Aestiva 3000 anesthesia system (Ohmeda, Madison, WI, USA) was used throughout this study. A 3-l latex bag connected to the Y-piece of the circuit acted as an artificial lung, and CO_2 was delivered at a flow rate of 200 ml·min^{-1} into the distal part of the bag. The artificial lung was ventilated 10 times·min^{-1} with a measured expired tidal volume of 500 ml. The anesthesia system was equilibrated on line for 30 min with a fresh gas (100% oxygen) flow rate of 6 l·min^{-1} in the absence of the CO_2 absorbent. After the preparation period, 1000 g of fresh absorbent (Amsorb Plus, Drägersorb Free, Amsorb, or

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Sodasorb II) was placed into the upper canister, and glass balls were placed in the lower canister as filler. The anesthesia system was loaded for 5 min with 6 l·min^{-1} O_2 containing 2% sevoflurane. Subsequently the fresh gas flow rate was reduced to 1 l·min^{-1}, and the tidal volume setting was readjusted to maintain a volume of 500 ml. The concentrations of sevoflurane and CO_2 in the inspiratory limb were monitored using a gas analyzer (Capnomac Ultima; Datex, Helsinki, Finland). The sample gas was taken at a flow rate of 200 ml·min^{-1} and was not replaced into the circuit. The sevoflurane concentration in the circuit was maintained at 2%. The study was continued until the absorption capacity of the absorbent was exhausted, as defined by a CO_2 partial pressure of 2 mmHg in the inspiratory limb. The experiment was repeated three times with each absorbent, and the studies were conducted in a random order.

Gas samples for measurement of the concentration of compound A were collected from the inspiratory limb of the circuit just before the start of low-flow sevoflurane anesthesia and every hour for the following 5 h. A glass syringe (20 ml) was used, and silicon grease was applied in order to ensure an airtight seal. Each gas sample was analyzed immediately after collection.

The concentration of compound A was measured by a gas chromatograph (model GC-9A, Shimadzu, Kyoto, Japan) with a gas sampler (model MGS-5, Shimadzu). A glass column 5 m long and 3 mm in internal diameter filled with 20% DOP on Chromosorb WAW (Technolab, Osaka, Japan) 80/100 mesh was maintained at 100°C. The injection inlet temperature was 140°C. Nitrogen was used as the carrier gas at a flow rate of 50 ml·min^{-1}, fand a hydrogen flame ion detector was used. Standard calibration gas prepared from stock solutions of compound A (Maruishi Pharmaceutical, Osaka, Japan) was used to calibrate the chromatograph.

The measured values were expressed as means ± SD. The concentrations of compound A produced by the different absorbents were compared by a one-way analysis of variance (ANOVA) to evaluate statistical significance, followed by a Bonferroni multiple comparison test. The CO_2 absorption capacity was defined as the time (in minutes) taken to achieve inspiratory partial pressures of CO_2 of 2 mmHg. The CO_2 absorption capacity of the different absorbents was also compared by a one-way ANOVA, followed by a Bonferroni multiple comparison test. A P value <0.05 was considered statistically significant.

Results

The maximum concentrations of compound A generated in the circuit were 2.2 ± 0.0, 2.3 ± 0.3, 2.2 ± 0.2, and 23.5 ± 1.5 ppm for Amsorb Plus, Drägersorb Free, Amsorb, and Sodasorb II, respectively (Fig. 1). The maximum concentration of compound A with Sodasorb II was significantly higher than those with other absorbents ($P < 0.01$). The concentrations of compound A with Amsorb Plus, Drägersorb Free, and Amsorb remained at less than 3 ppm throughout the study period. The maximum concentration of compound A was observed 2 h after the start of the study with Sodasorb II, and the concentrations of compound A with Sodasorb II were also significantly higher than those with the other absorbents at each measurement point ($P < 0.01$). There were no significant differences in the concentrations of compound A with Amsorb Plus, Drägersorb Free, and Amsorb.

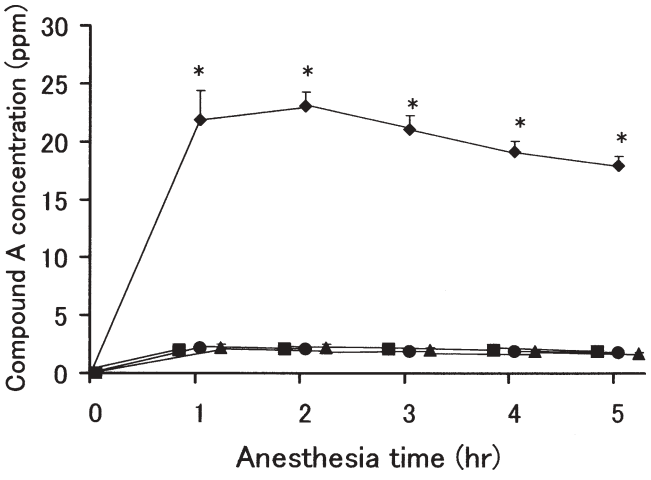

Fig. 1. Comparison of concentrations of compound A in anesthesia circuit with Amsorb Plus (●), Drägersorb Free (▲), Amsorb (■), and Sodasorb II (◆). *$P < 0.01$ vs. Amsorb Plus, Drägersorb Free, and Amsorb. Values are means ± SD

The CO_2 absorption capacities of the four absorbents are shown in Fig. 2. The CO_2 absorption capacity of Amsorb was significantly lower (by approximately 70%) than those of the other absorbents ($P < 0.01$). There were no significant differences in the CO_2 absorption capacities of Amsorb Plus, Drägersorb Free, and Sodasorb II.

Discussion

Our results showed that not only Amsorb, but also Amsorb Plus and Drägersorb Free, are less reactive with sevoflurane than Sodasorb II. Although several previous studies have reported that sevoflurane is most reactive with the KOH alkaline component of CO_2 absorbents [16–18], sevoflurane reacts with both KOH and NaOH [19,20]. For instance, Drägersorb 800 Plus, which contains NaOH but little KOH, was devel-

Table 1. Chemical composition of carbon dioxide absorbents (weight%)[a]

CO_2 absorbent	$Ca(OH)_2$	KOH	NaOH	$CaCl_2$	H_2O	PVP	$CaSO_4$
Drägersorb Free	74–82	0	<2	3–5	14–18	—	—
Amsorb Plus	>75	0	0	0.7	14.5	0.7	0.7
Amsorb	>75	0	0	0.7	14.5	0.7	0.7
Sodasorb II	76.5	2.25	2.25	0	18.9	—	—

PVP, polyvinylpyrrolidine
[a]Values were provided by the manufacturers

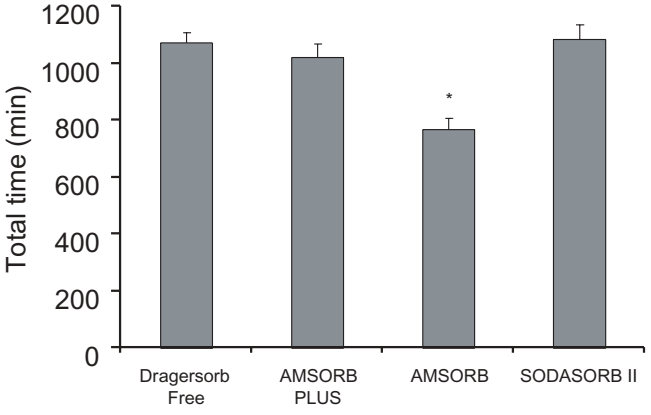

Fig. 2. Total times (minutes) until each absorbent reached end points (2 mmHg CO_2 breakthrough) expressed as means (SD). $*P < 0.01$ vs. Amsorb Plus, Drägersorb Free, and Sodasorb II

oped to decrease the production of compound A, but Drägersorb 800 Plus still produces a large amount of compound A [20]. Furthermore, Stabernack et al. [19] reported that a CO_2 absorbent containing only calcium hydroxide [$Ca(OH)_2$] also generates compound A. Drägersorb Free consists of $Ca(OH)_2$ with NaOH and calcium chloride ($CaCl_2$) but does not contain KOH (Table 1). Amsorb Plus and Amsorb contain $Ca(OH)_2$ mixed with $CaCl_2$ and calcium sulfate ($CaSO_4$) but contain neither KOH nor NaOH. The $CaCl_2$ and $CaSO_4$ are added to accelerate CO_2 absorption and to bind water, which is an essential first step of CO_2 removal [21]. The presence of $CaCl_2$ in Amsorb Plus, Drägersorb Free, and Amsorb may contribute to a decrease in compound A generation or may act to eliminate compound A.

The maximum compound A concentrations for Amsorb Plus, Drägersorb Free, and Amsorb in the present study were 2.2 ± 0.0, 2.3 ± 0.3, and 2.2 ± 0.2 ppm, similar to those obtained for soda lime using a protocol for high-flow (6 l·min^{-1}) sevoflurane anesthesia [22]. US Food and Drug Administration (FDA) guidelines suggest that fresh gas flows of less than 1 l·min^{-1} in a circle absorber are not appropriate and that sevoflurane exposure should not exceed 2 MAC-hours at flow rates of 1 to < 2 l·min^{-1}. The toxicity of compound A remains controversial. Data from animal studies regarding the safety of compound A during low-flow sevoflurane anesthesia are insufficient to prove safety, or the lack thereof, in patients. However, sevoflurane anesthesia at a flow rate of greater than 2 l·min^{-1} in patients has been approved by the FDA. Because the concentration of compound A generated in the circuit using low-flow sevoflurane anaesthesia at 1 l·min^{-1} with Amsorb Plus, Drägersorb Free, and Amsorb is comparable to that in sevoflurane anaesthesia at 6 l·min^{-1} with soda lime, we conclude that low-flow sevoflurane anesthesia at a flow rate of 1 l·min^{-1} with Amsorb Plus, Drägersorb Free, or Amsorb is also safe.

Carbon monoxide (CO) is produced by a reaction between CO_2 absorbents and the inhaled anesthetic agent [23]. Factors accelerating CO generation are similar to those that accelerate compound A generation [24]. It has previously been reported that minimal CO is produced by Amsorb [11], and we speculate that CO production by Drägersorb Free may also be minimal.

The CO_2 absorption capacities of Amsorb Plus and Drägersorb Free were greater than that of Amsorb and approximately the same as that of Sodasorb II in our study. Stabernack et al. have reported that CO_2 absorbents that contain small amounts of NaOH (3.2%) have a greater CO_2 absorption capacity than absorbents that do not contain NaOH [19]. Drägersorb Free contains small amounts of NaOH, in contrast to Amsorb Plus (Table 1), and this may be a reason for its high capacity. On the other hand, the product information for Amsorb Plus states that the chemical composition remains unaltered from Amsorb and that the material gives optimum bed packing as a result of the range of granule sizes, whereby the intergranular spaces between the larger granules are filled by smaller granules. This leads to reduced channeling of anesthetic gas, which results in better carbon dioxide absorption. Figure 3 shows the granules of the absorbents. The granules of Amsorb Plus seem to be a little bit smaller than those of Amsorb, but the reported granule size distributions of both absorbents are the same (2.5–5.0 mm; 4–8 US mesh).

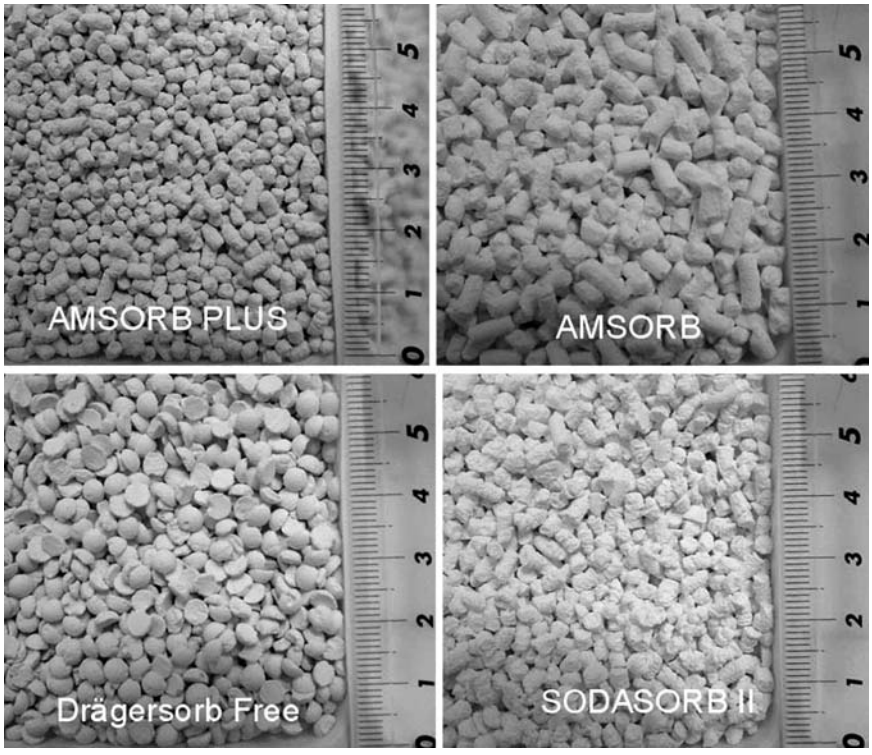

Fig. 3. Granules of Amsorb Plus, Amsorb, Drägersorb Free, and Sodasorb II

All absorbents that we used had a color indicator change of white to violet. The violet color of exhausted Amsorb Plus did not disappear, because Amsorb Plus contains no strong alkali. On the other hand, the violet color of exhausted Drägersorb Free was removed by NaOH.

The regular prices of 5-l units (4.5 kg) of Amsorb Plus and Drägersorb Free in Japan are 9500 and 8800 yen, respectively. However, because the actual selling prices of both absorbents are much different from the regular prices, an economic comparison is difficult. We conclude that there is little to choose between Amsorb Plus and Drägersorb Free from an economic perspective.

In summary, our results show that two new absorbents, Amsorb Plus and Drägersorb Free, produce a low concentration of compound A in the circuit, and that each has a CO_2 absorption capacity similar to that of Sodasorb II and greater than that of Amsorb. We conclude that low-flow sevoflurane anaesthesia at a flow rate of 1 l·min^{-1} is safe with use of Amsorb Plus, Drägersorb Free, or Amsorb.

References

1. Morio M, Fujii K, Satoh N, Imai M, Kawakami U, Mizuno T, Kawai Y, Ogasawara Y, Tamura T, Negishi A, Kumagai Y, Kawai T (1992) Reaction of sevoflurane and its degradation products with soda lime: toxicity of the byproducts. Anesthesiology 77:1155–1164
2. Gonsowski CT, Laster MJ, Eger EI II, Ferrell LD, Kerschmann RL (1994) Toxicity of compound A in rats: effect of a 3-hour administration. Anesthesiology 80:556–565
3. Gonsowski CT, Laster MJ, Eger EI II, Ferrell LD, Kerschmann RL (1994) Toxicity of compound A in rats: effect of increasing duration of administration. Anesthesiology 80:566–573
4. Kharasch ED, Thorning D, Garton K, Hankins DC, Kilty CG (1997) Role of renal cysteine conjugate β-lyase in the mechanism of compound A nephrotoxicity in rats. Anesthesiology 86:160–171
5. Kharasch ED, Hoffman GM, Thorning D, Hankins DC, Kilty CG (1998) Role of the renal cysteine conjugate β-lyase pathway in inhaled compound A nephrotoxicity in rats. Anesthesiology 88:1624–1633
6. Mazze RI, Jamison RL (1997) Low-flow (1 l/min) sevoflurane: Is it safe? Anesthesiology 86:1225–1227
7. Eger EI II, Koblin DD, Bowland T, Ionescu P, Laster MJ, Fang Z, Gong D, Sonner J, Weiskopf RB (1997) Nephrotoxicity of sevoflurane versus desflurane anesthesia in volunteers. Anesth Analg 84:160–168
8. Ebert TJ, Frink EJ, Kharasch ED (1998) Absence of biochemical evidence for renal and hepatic dysfunction after 8 hours of 1.25 minimum alveolar concentration sevoflurane anesthesia in volunteers. Anesthesiology 88:601–610
9. Higuchi H, Sumita S, Wada H, Ura T, Ikemoto T, Nakai T, Kanno M, Satoh T (1998) Effects of sevoflurane and isoflurane on renal function and on possible markers of nephrotoxicity. Anesthesiology 89:307–322
10. Obata R, Bito H, Ohmura M, Moriwaki G, Ikeuchi Y, Katoh T, Sato S (2000) The effects of prolonged low-flow sevoflurane anesthesia on renal and hepatic function. Anesth Analg 91:1262–1268
11. Kharasch ED, Powers KM, Artru AA (2002) Comparison of Amsorb, Sodalime, and Baralyme degradation of volatile anes-

thetics and formation of carbon monoxide and compound A in swine in vivo. Anesthesiology 96:173–182
12. Murray JM, Renfrew CW, Bedi A, McCrystal CB, Jones DS, Fee JPH (1999) Amsorb: a new carbon dioxide absorbent for use in anesthetic breathing systems. Anesthesiology 91:1342–1348
13. Mchaourab A, Arain SR, Ebert TJ (2001) Lack of degradation of sevoflurane by a new carbon dioxide absorbent in humans. Anesthesiology 94:1007–1009
14. Higuchi H, Adachi Y, Arisuma S, Kanno M, Satoh T (2001) The carbon dioxide absorption capacity of Amsorb is half that of soda lime. Anesth Analg 93:221–225
15. Ueyama H, Takashina M, Suzuki T, Sriranganathan V, Mashimo T (2000) Warning: carbon dioxide absorption capacity of Amsorb was unexpectedly low in low-flow anesthesia. Anesthesiology 93:1560–1561
16. Yasumi Y, Bito H, Sato S (1999) Effects of basic components and water content of CO_2 absorbent on compound A production in vitro. Anesthesiology 91: A400
17. Cunningham DD, Huang S, Webster J, Mayoral J, Grabenkort RW (1996) Sevoflurane degradation to compound A in anaesthesia breathing systems. Br J Anaesth 77:537–543
18. Ikeuchi Y, Bito H, Katoh T, Sato S (2000) Quantification of the degradation products of sevoflurane using four brands of CO_2 absorbent in a standard anesthetic circuit. J Anesth 14:143–146
19. Stabernack CR, Brown R, Laster MJ, Dudziak R, Eger EI II (2000) Absorbents differ enormously in their capacity to produce compound A and carbon monoxide. Anesth Analg 90:1428–1435
20. Higuchi H, Adachi Y, Arimura S, Kanno M, Satoh T (2000) Compound A concentrations during low-flow sevoflurane anesthesia correlate directly with the concentration of monovalent bases in carbon dioxide absorbents. Anesth Analg 91:434–439
21. Mchaourab A, Arain SR, Ebert TJ (2001) Lack of degradation of sevoflurane by a new carbon dioxide absorbent in humans. Anesthesiology 94:1007–1009
22. Bito H, Ikeda K (1995) Effect of total flow on the concentration of degradation products generated by reaction between sevoflurane and soda lime. Br J Anaesth 74:667–669
23. Fang ZX, Eger EI II, Laster MJ, Chortkoff BS, Kandel L, Ionescu P (1995) Carbon monoxide production from degradation of desflurane, enflurane, isoflurane, halothane, and sevoflurane by soda lime and Baralyme. Anesth Analg 80:1187–1193