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EDITORIAL

Calcium hydroxide lime – a new carbon dioxide absorbent: a rationale for judicious use of different absorbents

All volatile inhalation anaesthetics react with desiccated carbon dioxide absorbents by absorption or degradation [1]. Those, which contain a difluoromethoxy moiety, can react with conventional CO_2 absorbents to generate carbon monoxide (CO) gas. The violence of this chemical reaction decreases considerably in the order desflurane > enflurane > isoflurane [2]. However, clinically significant generation of CO only occurs if the absorbent is absolutely dry. Even partial wetting significantly reduces the amount of CO generated: if soda lime contains only 4.8% water, or barium hydroxide lime contains only 9.5% water, absolutely no carbon monoxide is produced. Evidently desiccated barium hydroxide lime is more liable than soda lime to generate CO. In a large clinical trial no evidence of any increased risk of accidental CO intoxication was found, not even during low-flow anaesthesia of long duration, provided that proper maintenance of the absorbent was observed [3]. In single case reports accidental CO generation resulted in maximum carboxyhaemoglobin (CO-Hb) concentrations of 36% [4] which, according to the classification given by Pankow, is ranked as subacute CO intoxication [5].

Halothane, and much more vigorously, sevoflurane also react with desiccated CO_2 absorbents by absorption and degradation. Sevoflurane in particular was found to be degraded to a variety of reaction products [6]. Most of these substances – which included compounds A–C, methanol and formaldehyde – are not yet identified, but in individual clinical cases these gaseous breakdown products were observed to be harmful [7].

Thus, great care must be taken to avoid any accidental desiccation of the absorbent [8], for example: (a) consistent use of low-flow techniques, (b) a routine change of the absorbent at least weekly, (c). labelling the canisters with the filling date, (d) carefully closing all gas flow controls after each anaesthetic is complete, (e) avoiding drying out the breathing system or the anaesthetic ventilator overnight by leaving a continuous flow of gases which may pass through the canister, and (f) leaving the canister unfilled and relying on recharging at the point of use from a nearby supply of lime in its unopened original packaging. By such measures accidental CO intoxication and generation of harmful degradation products, resulting from chemical reactions of volatile anaesthetic agents with desiccated absorbents, can be safely avoided even in low-flow anaesthesia of long duration.

However, halothane and sevoflurane also react with CO_2 absorbents containing normal amounts of water, i.e. 14–16%, by generation of haloalkenes. The formation of compound A during sevoflurane anaesthesia is a matter of particular concern [9,10]. In recent years a vast number of scientific reports, clinical investigations and editorials on this topic have been published sometimes with quite contradictory results and conclusions such that even an expert could become confused. For instance, whereas one group of scientists reckoned that a compound A load of 150–240 ppmh was both nephrotoxic and neurotoxic in humans [11–13], another group failed to find any clinically significant nephro- or hepatotoxic effects, even after long lasting sevoflurane anaesthesia [14–16], and defined a compound A load of only 800 ppmh as harmful for humans [17]. The concentration of compound A in re-breathing systems increases with the sevoflurane concentration, the temperature within the absorbent, and with decreasing fresh gas flow (the latter resulting from increased

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CO_2 absorption, corresponding generation of heat in the canister and the decreased wash-out of trace gases). Again, barium hydroxide lime is more liable to generate compound A than soda lime. Peak compound A concentrations of up to 60 ppm were observed [18] when anaesthetic machines fitted with heated circle systems were used during minimal flow anaesthesia with a fresh gas flow as low as 0.5 L min^{-1}. In fact, a fresh gas flow of 1.0 L min^{-1} can be considered safe if a maximum load of 2 minimum alveolar concentration-hour sevoflurane is not exceeded [19,20].

In recently published investigations the admixture of strong alkali hydroxides, sodium and especially potassium hydroxide, was found to be mainly responsible for the decomposition of volatile anaesthetic agents in re-breathing systems [6,21]. Absorbents which are free from potassium hydroxide are significantly less liable to degrade volatile agents, not only when containing the normal amount of water but also if desiccated. Different brands of soda lime are available nowadays devoid of any admixture of potassium hydroxide: Drägersorb 800 plus™ (Dräger Medizintechnik, Lübeck, Germany), Sofnolime™ (Molecular Products, Thaxted, Essex, UK) and Spherasorb™ (Intersurgical Ltd, Wokingham, Berkshire, UK). In the summer of 1999, Murray and co-workers [22] introduced a new carbon dioxide absorbent with a completely alternative chemical composition, which is referred to as calcium hydroxide lime: Amsorb™ (Armstrong Medical Ltd, Coleraine, Northern Ireland). This product consists mainly of calcium hydroxide with small amounts of calcium chloride and calcium sulphate which are added to accelerate CO_2 absorption and to bind water. Murray and his colleagues' investigations proved this absorbent to be completely inert when brought into contact with desflurane or sevoflurane, not only in a desiccated condition but also when containing the normal amount of water. The absorption capacity is somewhat less if compared with conventional soda lime. However, further clinical investigation and trials are needed to verify the promising and convincing results of Murray's group. Amsorb™ has already been approved for clinical use in the countries of the European Union and became commercially available in the last few months of 1999. Lithium hydroxide, another alternative absorbent, also seems to be inert in relation to the degradation of volatile agents [23]. However, this compound is still subject to laboratory investigation, and – according to earlier findings – appears to be less promising than the new calcium hydroxide lime.

Calcium hydroxide lime was first used during clinical observations in our hospital in Damme where consistently fresh gas flows as low as 0.5–0.25 L min^{-1} are used in routine clinical practice [24]. As the useful life of CO_2 absorbents depends mainly on the load of exhaled CO_2, i.e. on the amount of re-breathing, clinically relevant utilization times of absorbents can be determined in this way [25]. Over several measurement cycles, in which the respective percentage of time was exactly measured when a flow rate between 0.5 and 0.25 L min^{-1} (Minimal Flow Time = MFT) was used, the following mean utilization times (UT) were determined for different brands of absorbents: Amsorb™ UT 19.6 h, MFT 73.5%; Drägersorb 800 plus™ UT 33.1 h, MFT 81.3%; Sofnolime™ UT 29.2 h, MFT 83%; Spherasorb™ UT 33.4 h, MFT 76%. All measurements were conducted using a Dräger Cicero anaesthetic machine, equipped with a Jumbo-CO_2 absorber containing 1.5 L of absorbent. The utilization time was taken to be the period of time from the filling of the canister to the exhaustion of the absorbent, marked by the inspired CO_2 concentration reaching 1.0 vol%. That meets quite well the results of previous investigations – under the same preconditions – in which, using conventional soda lime Atemkalk™ (ICI, Planckstadt, Germany), a mean utilization time of 51.2 h, MFT 52.9%, was found [26].

Thus the utilization time, or life, of calcium hydroxide lime under comparable clinical conditions was found to be about two-thirds of the utilization time of potassium-free soda lime. The actual prices in Germany for 1.5 L of the different brands of absorbents are: Amsorb™ 9.05 Euro, Drägersorb 800 plus™ 9.13 Euro, Sofnolime™ 3.82 Euro and Spherasorb™ 4.80 Euro. If the respective absorbent is used until exhaustion its consumption (consistent use of extremely low fresh gas flow rates assumed) results in the following costs per 1 h of anaesthesia: Amsorb™ 0.46 Euro, Drägersorb 800 plus™ 0.28 Euro, Sofnolime™ 0.13 Euro, Spherasorb™ 0.14 Euro. From clinical experience the scavenging capacity of 1.5 L of absorbent contained in a Jumbo-canister is sufficient to absorb CO_2 safely over a period of a whole week; likewise for all four absorbents. The use of absorbents over a period of 1

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week, of course, demands continuous monitoring of the respired CO_2 concentration [8]. Accordingly if the absorbent is routinely changed once a week, unless it has been previously exhausted, the use of calcium hydroxide lime will increase the cost of absorbent by not more than about 5 Euro $week^{-1}$, i.e. 0.71 Euro day^{-1}. Alternatively, if the absorbent is used until it is completely exhausted the use of calcium hydroxide lime (again consistent use of extremely low fresh gas flow rates is assumed) will increase the cost by at most 0.33 Euro h^{-1}. Of course, routine use of higher gas flow rates will decrease the costs per hour for absorbents, although the knock-on added costs of volatile agents will exceed these savings considerably. Thus, the additional cost resulting from the use of calcium hydroxide lime is really quite low when related to the potential improvement in patient safety, which may be gained by the use of an absorbent being completely inert with respect to all volatile agents.

The following rationale for the judicious use of the different absorbents seems to be justified: to reduce the possibility of degradation of anaesthetic agents at least potassium-free soda lime should be used consistently. The use of barium hydroxide lime should be abandoned. If sevoflurane is only used intermittently in indicated cases, and low-flow anaesthetic techniques with this agent are only performed in cases not exceeding 2–3 h, the use of potassium-free soda lime is safe. This CO_2 absorbent can be used safely together with the all the other inhalation anaesthetics without any reservations, even in low-flow anaesthesia of long duration. However, this statement is only true when proper maintenance of the absorbent is observed, which includes all measures taken to avoid any liability to dehydrate the absorbent. However, if sevoflurane is the preferred volatile agent, even in longer lasting cases and with low-flow anaesthetic techniques, the use of calcium hydroxide lime should be obligatory. The recommendations for proper maintenance of the absorbent, nevertheless, must be carefully followed.

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