RESEARCH ARTICLE

Predicting cost of inhalational anesthesia at low fresh gas flows: impact of a new generation carbon dioxide absorbent

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Abstract

It is well known that low fresh gas flows result in lower cost of inhalational agents. A new generation of carbon dioxide absorbents allows low flow anesthesia with all anesthetics but these new compounds are more expensive. This study examines the cost of inhalational anesthesia at different fresh gas flows combined with the cost of absorbent. The cost of sevoflurane and desflurane is lower at low fresh gas flows. Paradoxically the cost of isoflurane is cheaper at 2 L/min than at lower fresh gas flows due to increased cost of carbon dioxide absorbent. Therefore low fresh gas flows should be used when feasible with sevoflurane and desflurane, but higher fresh gas flows up to 2 L/min may be more economical with isoflurane during maintenance phase of anesthesia.

Key words: anesthetic cost; carbon dioxide absorbent; desflurane; inhalational anesthesia; isoflurane; maintenance phase; sevoflurane

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Introduction

The costs of healthcare are continuing to rise leading to increased attention on areas of practice where cost savings can be achieved. While low compared to the cost of running an operating room, the cost of anesthetic drugs can be substantial depending on choice of inhalational anesthetic agent and conditions in which it is administered. It is generally accepted that the cost of inhalational anesthesia is proportional to the fresh gas flow and therefore, low fresh gas flows have been encouraged as a mechanism to decrease the cost of inhalational anesthesia maintenance. Historically, low flow anesthesia has been limited with sevoflurane due to concerns of chemical reactions with the carbon dioxide absorbent, leading to the formation of Compound A. This substance was found to be nephrotoxic in rats,[1] but the clinical implications of this are not clear. Previous studies have suggested that there may be minor nephrotoxicity,[2] but results have been mixed. A recent meta-analysis concluded that in patients without renal disease sevoflurane did not lead to any significant nephrotoxicity.[3] In response to these issues new carbon dioxide absorbents have been introduced which decrease the possibility of accumulation of these toxic products.[4-6] One benefit of newer CO_2 absorbents is safety. New CO_2 absorbents, such as Amsorb, have been demonstrated to effectively completely eliminate the potential risk of compound A.[7] Otherwise the risks of CO_2 absorbents are relatively equal between different brands and recent generations. The cost of these new absorbents is higher than first generation agents and as such, may impact the cost saving of low flow anesthesia. This study quantitates the cost of a current carbon dioxide absorbent (Amsorb Plus™) in relation to fresh gas flow and provides a context for determining the costs of low flow inhalation anesthesia along with any potential cost savings.

Materials and Methods

Anesthetic potency as measured by the minimum alveolar concentration (MAC) was used in this study. Costs of inhalational anesthesia were calculated utilizing the universal gas law as described by a previous literature,[8] using the current prices of the agents at University of Nevada Reno (desflurane \$0.63/mL, sevoflurane \$0.34/mL, isoflurane \$0.10/mL). The cost is calculated by multiplying the fresh gas flow of the anesthetic agent by the potency of the inhalation agent in percent (%). This is to ensure that equipotent doses are compared. This number, now in mL/min (or converted to L/h), is used with the ideal gas law to yield moles. The molecular weight is then multiplied by the moles to yield grams of the anesthetic. The grams are then divided by the specific gravity of the inhalational agent yielding milliliters of the anesthetic. This value in milliliters can then be directly multiplied by the cost of the inhalational agents, as given above. This cost is then added to the cost of the carbon dioxide absorbent to yield the total cost per MAC hour of running each specific inhalational anesthetic agent. The cost of the carbon dioxide absorbent, Amsorb Plus™ (Armstrong Medical, Coleraine, UK) was based on \$17.68 per 1.2 L canister and was determined from calculation of the manufacturer's specifications which was in agreement with published studies.[9] The cost of Amsorb Plus™ was calculated to be \$1.62/h at 0.5 L/min flow, assuming an 80 kg person at 1 metabolic equivalent (3.5 mL O_2/kg/min). The costs of inhalational agents, desflurane, sevoflurane, and isoflurane, were calculated at fresh gas flows of 0.5, 1, 2, and 4 L/min.

Results

The costs of the inhalation agents alone per MAC hour at 0.5 L/min fresh gas flow are desflurane $5.16, sevoflurane $1.07, and isoflurane $0.16. Thus, the total cost of the anesthetic plus carbon dioxide absorbent under these conditions are: $6.78, $2.69 and $1.78 respectively (**Table 1**). At a fresh gas flow of 1 L/min (assuming a doubling of anesthetic cost and a halving of absorbent usage), the combined costs are: $11.13, $2.95 and $1.13 respectively. At a fresh gas flow of 2 L/min, the combined costs are: $21.05, $4.69 and $1.05 respectively. This fresh gas flow of 2 L/min was the least expensive for isoflurane when compared to fresh gas flows of 0.5, 1, and 4 L/min. At a fresh gas flow of 4 L/min, the combined costs are: $41.48 for desflurane, $8.76 for sevoflurane and $1.48 isoflurane.

Table 1: Cost in US dollars of desflurane, sevoflurane, and isoflurane at different fresh gas flows per minimum alveolar concentration hour

	Desflurane	Sevoflurane	Isoflurane
0.5 L/min			
Inhalational agent cost	5.16	1.07	0.16
CO_2 absorbent cost	1.62	1.62	1.62
Total cost	6.78	2.69	1.78
1 L/min			
Inhalational agent cost	10.32	2.14	0.32
CO_2 absorbent cost	0.81	0.81	0.81
Total cost	11.13	2.95	1.13
2 L/min			
Inhalational agent cost	20.64	4.28	0.64
CO_2 absorbent cost	0.41	0.41	0.41
Total cost	21.05	4.69	1.05
4 L/min			
Inhalational agent cost	41.28	8.56	1.28
CO_2 absorbent cost	0.2	0.2	0.2
Total cost	41.48	8.76	1.48

Discussion

These data allow comparison of anesthetic costs at various gas flows. The results demonstrate that desflurane and sevoflurane support the conventional view that low fresh gas flows result in lower costs. This is in agreement with the traditional view that lower gas flows are more cost effective. In addition, other published literature has shown that when utilizing sevoflurane with new generation carbon dioxide absorbents lower fresh gas flows were allowed.[8] Paradoxically, isoflurane costs are higher at lower fresh gas flows as the cost per hour of the Amsorb Plus™ is greater than the agent cost. Under these conditions, the least expensive flow rate for isoflurane is approximately 2 L/min where the cost is $1.05 per MAC hour. Isoflurane with its high potency and low starting cost per ml is much more influenced by CO_2 absorbent costs at low flows. At 0.5 L/min isoflurane costs $0.16 per MAC hour while the soda lime costs $1.62 that represents 91% of the total cost. Conversely, the cost of desflurane per mL at our institution is approximately six times higher than that of isoflurane. When this cost is coupled with the decreased potency of desflurane compared to isoflurane it leads to an inhalational agent that is much more expensive to use. This expense means that the contribution in cost from the CO_2 absorbent is much less significant in the calculation of the overall cost.

Another factor to consider during maintenance anesthesia is choice of inhalational agent. Among inhalational anesthetic gases the largest difference is in their pharmacokinetics with onset/offset of the gases being the largest difference. These issues do not differ to a clinically significant degree during maintenance phase of anesthesia nor with different CO_2 absorbents.

Some institutions have actually stopped providing desflurane due to its high cost and detrimental effects as a greenhouse gas, which is 15–20 times worse than other inhalational agents.[10]

The major determinant of inhalational anesthetic requirements is dosages of concurrent medications as MAC values are additive in nature. The use of other sedating medications will lower the MAC requirement for any given individual. One of the main determinants of inhalational agent dose is age, which peaks at 6 months for most agents and is commonly reported to decrease by 6% for every decade of life.[11-15]

Interindividual variability during maintenance phase of anesthesia with inhalational agents is overall small. However there are some factors that significantly influence MAC. Aside from age, a possible significant difference in the general population is red hair, which is caused by a mutation in the melanocortin-1 receptor. In one study anesthetic potency was noted to be decreased by 19%.[16] However larger more recent studies have found no difference.[17,18] This is in contrast to maintenance with intravenous agents such as propofol, which can have large interindividual variability. Other patient conditions and metabolic abnormalities, such as hypoxia and hypotension, have been shown to decrease MAC.[19,20]

The implications of these findings on the cost of inhalational anesthesia in the maintenance phase are straightforward. As age increases and MAC decreases the subsequent cost of anesthesia at maintenance phase will decrease, as less anesthetic will be used. The anesthetic dose should be titrated to individual requirements which will compensate for the conditions noted above.

These results support the notion that a full understanding of costs is important for rational practice choices.

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References

1. Jin L, Baillie TA, Davis MR, Kharasch ED. Nephrotoxicity of sevoflurane compound A [fluoromethyl-2,2-difluoro-1-(trifluoromethyl)vinyl ether] in rats: evidence for glutathione and cysteine conjugate formation and the role of renal cysteine conjugate beta-lyase. *Biochem Biophys Res Commun*. 1995;210:498-506.
2. Eger EI 2nd, Koblin DD, Bowland T, et al. Nephrotoxicity of sevoflurane versus desflurane anesthesia in volunteers. *Anesth Analg*. 1997;84:160-168.
3. Kharasch ED, Frink EJ Jr, Zager R, Bowdle TA, Artru A, Nogami WM. Assessment of low-flow sevoflurane and isoflurane effects on renal function using sensitive markers of tubular toxicity. *Anesthesiology*. 1997;86:1238-1253.
4. Kobayashi S, Bito H, Morita K, Katoh T, Sato S. 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. *J Anesth*. 2004;18:277-281.
5. Levy RJ. Anesthesia-related carbon monoxide exposure: toxicity and potential therapy. *Anesth Analg*. 2016;123:670-681.
6. Feldman JM, Lo C, Hendrickx J. Estimating the impact of carbon dioxide absorbent performance differences on absorbent cost during low-flow anesthesia. *Anesth Analg*. 2020;130:374-381.
7. Versichelen LF, Bouche MP, Rolly G, et al. Only carbon dioxide absorbents free of both NaOH and KOH do not generate compound A during in vitro closed-system sevoflurane: evaluation of five absorbents. *Anesthesiology*. 2001;95:750-755.
8. Loke J, Shearer WA. Cost of anaesthesia. *Can J Anaesth*. 1993;40:472-474.
9. Epstein RH, Dexter F, Maguire DP, Agarwalla NK, Gratch DM. Economic and environmental considerations during low fresh gas flow volatile agent administration after change to a nonreactive carbon dioxide absorbent. *Anesth Analg*. 2016;122:996-1006.
10. Sherman J, Le C, Lamers V, Eckelman M. Life cycle greenhouse gas emissions of anesthetic drugs. *Anesth Analg*. 2012;114:1086-1090.
11. Lerman J, Sikich N, Kleinman S, Yentis S. The pharmacology of sevoflurane in infants and children. *Anesthesiology*. 1994;80:814-824.
12. Lerman J, Robinson S, Willis MM, Gregory GA. Anesthetic requirements for halothane in young children 0-1 month and 1-6 months of age. *Anesthesiology*. 1983;59:421-424.
13. Eger EI 2nd. Age, minimum alveolar anesthetic concentration, and minimum alveolar anesthetic concentration-awake. *Anesth Analg*. 2001;93:947-953.
14. Mapleson WW. Effect of age on MAC in humans: a meta-analysis. *Br J Anaesth*. 1996;76:179-185.
15. Nickalls RW, Mapleson WW. Age-related iso-MAC charts for isoflurane, sevoflurane and desflurane in man. *Br J Anaesth*. 2003;91:170-174.
16. Liem EB, Lin CM, Suleman MI, et al. Anesthetic requirement is increased in redheads. *Anesthesiology*. 2004;101:279-283.
17. Doufas AG, Orhan-Sungur M, Komatsu R, et al. Bispectral index dynamics during propofol hypnosis is similar in red-haired and dark-haired subjects. *Anesth Analg*. 2013;116:319-326.
18. Gradwohl SC, Aranake A, Abdallah AB, et al. Intraoperative awareness risk, anesthetic sensitivity, and anesthetic management for patients with natural red hair: a matched cohort study. *Can J Anaesth*. 2015;62:345-355.
19. Kurita T, Takata K, Uraoka M, et al. The influence of hemorrhagic shock on the minimum alveolar anesthetic concentration of isoflurane in a swine model. *Anesth Analg*. 2007;105:1639-1643, table of contents.
20. Cullen DJ, Eger EI 2nd. The effects of hypoxia and isovolemic anemia on the halothane requirement (MAC) of dogs. I. The effect of hypoxia. *Anesthesiology*. 1970;32:28-34.

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