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, but the clinical implications of this are not clear. Previous studies have suggested that there may be minor nephrotoxicity, but results have been mixed. A recent meta-analysis concluded that in patients without renal disease sevoflurane did not lead to any significant nephrotoxicity. In response to these issues new carbon dioxide absorbents have been introduced which decrease the possibility of accumulation of these toxic products.4 One benefit of newer CO2 absorbents is safety. New CO2 absorbents, such as Amsorb, have been demonstrated to effectively completely eliminate the potential risk of compound A.7 Otherwise the risks of CO2 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 PlusTM) 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, 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 PlusTM (Armstrong Medical, Cotheraine, 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. The cost of Amsorb PlusTM 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 O2/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

| Inhalational agent cost | CO₂ absorbent cost | Total cost |
|-------------------------|--------------------|------------|
| Desflurane              | Sevoflurane        | Isoflurane |
| 0.5 L/min               |                    |            |
| Inhalational agent cost | 5.16               | 1.07       | 0.16       |
| CO₂ 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       |
| CO₂ 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       |
| CO₂ 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       |
| CO₂ 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 fresh 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.4 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 CO₂ 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 CO₂ 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 CO₂ 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

Intravenous agents are added in practice to lower the MAC by 10%.16 It is important to note that 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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**Author contributions**

Study design, implementation, and manuscript writing: AEM, BDB. CEM; data analysis: AEM, BDB. All authors approved the final version of the manuscript.

**Conflicts of interest**

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