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Economic considerations in the use of inhaled anesthetic agents

J. Golembiewski

Clinical Associate Professor, Colleges of Pharmacy and Medicine, University of Illinois, Chicago

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Autor para correspondencia: jgolemb@uic.edu

ABSTRACT

Purpose: To describe the components of and factors contributing to the costs of inhaled anesthesia, basis for quantifying and comparing these costs, and practical strategies for performing pharmacoeconomic analyses and reducing the costs of inhaled anesthetic agents.
Summary: Inhaled anesthesia can be costly, and some of the variable costs, including fresh gas flow rates and vaporizar settings, are potential targets for cost savings. The use of a low fresh gas flow rate maximizes rebreathing of exhaled anesthetic gas and is less costly than a high flow rate, but it provides less control of the level of anesthesia. The minimum alveolar concentration (MAC) hour is a measure that can be used to compare the cost of inhaled anesthetic agents at various fresh gas flow rates. Anesthesia records provide a sense of patterns of inhaled anesthetic agent use, but the amount of detail can be limited. Cost savings have resulted from efforts to reduce the direct costs of inhaled anesthetic agents, but reductions in indirect costs through shortened times to patient recovery and discharge following the judicious use of these agents are more difficult to demonstrate. The patient case mix, fresh gas flow rates typically used during inhaled anesthesia, availability and location of vaporizers, and anesthesia care provider preferences and practices should be taken into consideration in pharmacoeconomic evaluations and recommendations for controlling the costs of inhaled anesthesia.
Conclusion: Understanding factors that contribute to the costs of inhaled anesthesia and considering those factors in pharmacoeconomic analyses and recommendations for use of these agents can result in cost savings.

Key words: Cost, anesthesia, inhaled anesthesic agents, minimum alveolar concentration (MAC).

The cost of anesthesia care has three main components (1). Direct costs include the costs of anesthesia agents, other materials, and labor. Indirect costs include the costs related to the consequences of an event. These consequences may be intended or unintended (e.g., a prolongad stay in the operating room [OR] or postanesthesia care unit [PACU]). Intangible costs incluye the costs related to pain and suffering as a result of illness or treatment. Intangible costs, however, are difficult if not impossible to quantify.

The direct costs of anesthesia care may be divided into fixed costs and variable costs (1). Costs established in contract negotiations usually are fixed for the duration of the contract. Some variable costs hinge on decisions made by anesthesia care providers, and these variable costs are potential targets for cost savings. An example is the Choice of drugs used to provide general anesthesia in patients undergoing surgery or other invasive procedures.

Commonly, the intravenous (I.V.) anesthetics propofol and etomidate are used for induction (to render the patient unconscious). Often these induction agents are immediately followed by succinylcholine or a nondepolarizing neuromuscular blocking agent (e.g., rocuronium) to facilitate intubation. In children, instead of an i.v. agent such as propofol, sevoflurane is commonly used to induce general anesthesia. In both adults and children, inhaled anesthetic agents are the workhorses for maintaining anesthesia, although continuous i.v. infusion of propofol is an alternative to inhaled anesthetic agents. The recent propofol shortage has caused anesthesia care providers to examine their practices and consider alternatives such as the use of sevoflurane for induction of anesthesia in adults. A variety of other medications may be used intraoperatively to maintain paralysis, modulate blood pressure and heart rate, and provide other desired pharmacologic effects such as amnesia and analgesia. These medications may incluye nondepolarizing neuromuscular blocking agents (e.g., vecuronium, cisatracurium), reversal agents (e.g., neostigmine and glycopyrrolate), ephedrine, phenyle phrine, metoprolol, esmolol, labetalol, fentanyl, midazolam, ketamine, local anesthetics, and antiemetic agents.

COST OF INHALED ANESTHESIA

Inhaled anesthetic agents represent a major portion of anesthesia drug costs (2). Desflurane and sevoflurane are the most commonly used inhaled anesthetic agents, and they are costly.

Four factors contribute to the cost of inhaled anesthetic agents (3). These agents are commercially available as liquids, and the acquisition cost per milliliter is generally fixed, on the basis of a negotiated contract price. The second cost component is the volume of vapor produced per milliliter of liquid, which also is fixed and is based on the physical and Chemicals characteristics of the agent. The tirad cost component is the potency of the anesthetic agent, which varies from one agent to another but is a fixed physical property of the agent. The concentration of the agent required may vary depending on patient characteristics (e.g., age, concurrent medications, temperature) and the depth of anesthesia required for the invasiveness of the surgery being performed. The depth of anesthetic may be increased or decreased at various stages of the surgery, depending on the procedure. The fourth componentof the cost of inhaled anesthesia is the amount of anesthetic agent wasted.

The concentration of inhaled anesthetic necessary to provide general anesthesia is quantified by using the concept of minimum alveolar concentration (MAC), which is defined as the alveolar concentration of the inhaled anesthetic agent at 1 atmosphere of pressure that prevents movement in response to a surgical stimulus in 50% of patients. The MAC reflects the dosage of an anesthetic agent required to produce the desired depth of anesthesia. The MAC required varies according to the desired response. For example, an alveolar concentration of 1.2–1.3 MAC is required to consistently prevent patient movement during surgical stimuli (e.g., incision), whereas an alveolar concentration below 0.4–0.5 MAC allows patients to open their eyes on command at the end of surgery (4). MAC values can be compared among inhaled anesthesia agents; the MAC values for desflurane, sevoflurane, and isoflurane are 6.0%, 2.05%, and 1.15%, respectively (4).

The amount of inhaled anesthetic agent wasted is directly correlated to the fresh gas flow rate (5). The use of a high flow rate increases the amount of inhaled anesthetic agent vaporizad and decreases rebreathing of exhaled anesthetic gas (6). This approach provides greater control of the level of anesthesia, but it has a higher cost (3). The amount of anesthetic gas vaporizad exceeds what partitions from the gas phase into the lung and brain tissues, resulting in waste. Excess anesthetic gas ends up being vented into the atmosphere.

In contrast, using a low fresh gas flow rate maximizes rebreathing of exhaled anesthetic gas, minimizes the amount of anesthetic gas vented into the atmosphere, and is less costil than a high flow rate. However, this approach provides less control of the level of anesthesia. A low gas flow rate also may conserve the patient's expired heat and humidity.

COMPARING COSTS

The costs of an inhaled anesthetic agent can be estimated by calculating the cost per MAC hour, defined as administration of the inhaled anesthetic agent at 1 MAC for one hour. The cost per MAC hour of the agent can be calculated from the concentration (%) of gas delivered (i.e., the vaporizer setting), fresh gas flow rate (FGF in L/min), duration of inhaled anesthetic delivery (60 min), molecular weight (MW in g), cost per mL (in dollars), a factor to account for the molar volume of a gas at 21 °C (2412), and density (D in g/mL). The formula is as follows (7):

Cost per MAC hour ($) = [(Concentration) (FGF) (duration) (MW) (cost/mL)] / [(2412) (D)]

For example, the cost per MAC hour of isoflurane at a fresh gas flow rate of 2 L/min is $1.04 based on a concentration of 1.15% for 1 MAC, duration of 60 minutes, MW of 184.5 g, average wholesale cost per mL of $0.15, and density of 1.496 g/mL. Most of the components in the formula used to calculate cost per MAC hour are fixed, except for fresh gas flow rate. The two most commonly used inhaled anesthetic agents, desflurane and sevoflurane, are substantially more expensive than isoflurane at fresh gas flow rates ranging from 1 L/min to 3 L/min (Table 1). The cost per MAC hour of these agents hinges on the fresh gas flow rate; for example, when using average wholesale cost, the cost per MAC hour for desflurane at a typical flow rate of 1 L/min is similar to that of sevoflurane at a typical flow rate of 2 L/min. When institucional acquisition cost is considered, the cost per MAC hour may be higher or lower than when average Wholesale cost is used.

PRACTICAL EXPERIENCE

The potential cost savings from analyzing and modifying the use of inhaled anesthetic agents are illustrated by experiences in several health systems. A collaborative effort involving the pharmacy and anesthesiology departments to reduce the use of desflurane and increase the use of sevoflurane at Montefiore Medical Center in the Bronx, New York, suggested a potential cost savings of more than $100,000 between March 2007 and April 2008 (8). Isoflurane was the workhorse anesthetic agent at Montefiore, but desflurane and sevoflurane also were used at the medical center. Sevoflurane was more expensive than desflurane when the acquisition costs of the same volume of liquid were compared.

In evaluating the possibility of similar potential savings at one's own institution, a closer look is warranted. As previously discussed, the cost of an inhaled anesthetic agent is not based solely on acquisition cost. Fresh gas flow rates must be taken into consideration, and these rates often vary considerably according to the inhaled anesthetic agent being administered, current intraoperative conditions, and the anesthesia care provider.

A second consideration is that anesthesia machines vary in terms of the number of vaporizers on the machine. A different vaporizer is required for each inhaled anesthetic agent. Older anesthesia machines may have three vaporizers, but most newer anesthesia machines have two vaporizers (accommodating two agents), and compact anesthesia machines have only one vaporizar (accommodating one agent). Great care and effort are required in switching vaporizers if a patient requires an agent that is not already set up on the machine. Newer anesthesia machines are designed with connectors to prevent errors involving filling the vaporizer with the wrong agent, and the position of the vaporizar is critical during placement, removal, and storage. Spills in the OR and inadvertent exposure of OR personnel to the anesthetic agent also are a concern. To minimize the need to switch vaporizers in anesthesia machines that have two vaporizers, the two most appropriate vaporizers should be placed in the machine. For example, an isoflurane vaporizer may be kept in OR rooms where Langer surgeries are performed, a sevoflurane vaporizer kept in OR rooms where children are anesthetized, and vaporizers for sevoflurane and desflurane kept in OR rooms where short surgeries are performed. The choice of vaporizers can therefore vary from one anesthetizing location to another within the institution as well as between institutions.

TABLE I

ESTIMADE COST PER MAC HOUR ($) OF INHALED ANESTHETIC AGENTS[* a b c]

Fresh Gas Flow Rate (L/min)	Isoflurane[a]	Desflurane[b]	Sevoflurane[c]
1	0.52	12.96	6.05
2	1.04	25.93	12.10
3	1.56	38.88	18.15

[*] MAC = minimum alveolar concentration.

[*] All estimated costs per MAC hour are based on a duration of 60 minutes and the following formula: Cost per MAC hour ($) = [(Concentration)(FGF)(duration)(MW)(cost/mL)]/[(2412)(D)] where FGF is fresh gas flow rate in L/min, MW = molecular weight in g, cost per mL is in dollars based on average wholesale price, and D = density in g/mL.

[a] Isoflurane calculations are based on a concentration of 1.15%, molecular weight (MW) of 184.5 g, cost per mL of $0.15, and density of 1.496 g/mL.

[b] Desflurane calculations are based on a concentration of 6%, MW of 168g, cost per mL of $0.96, and density of 1.45 g/mL.

[c] Sevoflurane calculations are based on a concentration of 2.05%, MW of 201g, cost per mL of $0.90, and density of 1.51 g/mL.

At Montefiore Medical Center, it appears that sevoflurane and isoflurane vaporizers were selected as the two vaporizers on the anesthesia machine, making the use of desflurane available only on request. At many institutions, however, that may not be appropriate for the type of patients and the surgical procederes performed. Close collaboration between the anesthesia and pharmacy departments is necessary to determine the most appropriate location and choice of vaporizer for each anesthesia machine and anesthetizing location in the institution.

The potential for cost savings from reducing the fresh gas flow rate used for inhaled anesthesia was demonstrated at another institution. At the University of Nebraska Medical Center, the combined costs of desflurane and sevoflurane amounted to $477,000 in fiscal year 2005–2006 (9).

The purchase price of the two inhaled anesthetic agents was similar, but the cost per minute was significantly higher for sevoflurane ($0.79) than desflurane ($0.56, $p = 0.022$), largely because of a higher average fresh gas flow rate and MAC equivalent Turing induction and maintenance of anesthesia. A potential annual cost savings of $238,500 from reducing the fresh gas flow rate by 50% was projected.

ANALYZING COSTS

Anesthesia records are maintained on paper in most health systems, although automated record Keeling systems are available in many institutions. It usually is difficult to ascertain from anesthesia records the precise duration of delivery of a particular concentration of an inhaled anesthetic agent. Titration to a desired level of anesthesia typically requires frequent changes in vaporizer settings, and the amount of detail in paper-based anesthesia records is limited. Nevertheless, anesthesia records can be used to obtain a sense of patterns of use (e.g., Choice and concentration of agent, rough estimation of MAC hours of use) and fresh gas flow rates. These variables can substantially contribute to the direct costs of anesthesia.

The indirect costs of anesthesia are much more difficult to quantify than the direct costs. In theory, the lower solubility of desflurane and sevoflurane in blood and tissues compared with isoflurane may confer a more rapid emergence from anesthesia and discharge from the PACU, offsetting the higher cost of these agents compared with isoflurane (10,11). However, it has been difficult to demonstrate a reduction in the time to PACU discharge from the use of sevoflurane instead of isoflurane after short surgical procedures (12). In one study, a shorter time to orientation was observed with the use of sevoflurane instead of isoflurane primarily in long (more than three hours) surgical cases (13). However, the isoflurane had not been titrated downward Howard the end of surgery, as is the custom in clinical practice to promote a shorter time to emergence from anesthesia following completion of the surgical procedure. There was no difference in the time to eligibility for discharge between sevoflurane and isoflurane despite failure to titrate isoflurane at the end of surgery in this study.

Several factors should be taken into consideration in pharmacoeconomic evaluations and recommendations for controlling the cost of inhaled anesthetic agents. The surgical case mix (e.g., number of inpatient procederes versus outpatient procedures, children versus adults, normal weight versus morbidly obese patients) and fresh gas flow rates typically used during inhaled anesthesia are hmong these factors. The role of isoflurane in the institution depends on anesthesiology care provider practices and surgical case mix. The availability and the locations of isoflurane vaporizers also are considerations.

The impact of efforts to promote the cost-effective use of inhaled anesthetic agents can be evaluated by using purchasing records for these agents, which provide a rough measure of usage and cost. Changes in patient case mix or anesthesia care providers' practices could have an impact on fresh gas flow rates and choice of agent and thus on inhaled anesthetic costs. Auditing anesthesia records is time consuming, especially if records are available Orly on paper, but it can provide valuable insight into usage patterns and the impact of cost-saving measures for inhaled anesthetic agents.

CONCLUSION

Inhaled anesthetic costs can be substantial. Careful consideration and management of factors that affect the direct and indirect costs of inhaled anesthesia can provide economic benefits.

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