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Cost Containment of Inhaled Anesthetic Agents in Pediatric Anesthesia: How Much Does Reducing the Fresh Gas Flow Matter?

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Abstract

Introduction: Techniques of cost containment remain important in the practice of medicine. One strategy to reduce the consumption of inhaled anesthetic agents is to use lower fresh gas flows (FGFs). The purpose of the current study is to evaluate various FGFs to determine the most effective means of conserving anesthetic agents and limiting costs.

Methods: Volatile anesthetic agent use and cost were determined using two different techniques. First by weighing the bottles containing the anesthetic agent before and after each case and secondly by measuring the amount of agent use based on Dion's equation. The latter is calculated as PFTMC/2412d using vaporizer concentration (P), fresh gas flow in liters per minute (F), time in minutes (T), molecular weight (M), cost in dollars/mL (C), and density in g/mL (d). Patients were divided into two groups. In the control group, patients were observed and data recorded without suggestions for FGF, gas percentage, and the specific gas used. In the intervention group, there was a specific protocol for FGF, gas percentage, and the gas used. Six cost quantitative variables and four patient quantitative variables were obtained.

Results and Discussion: The cohort for the study included 101 patients. There were 50 patients in the observational group and 51 in the intervention group. All cost measures were lower in the intervention (low flow) group than the control group. The average cost was 68.3-78.0% lower depending on the specific cost measure used.

Conclusion: There were cost savings in both measured and calculated gas use when implementing a protocol for low fresh gas flows with a cost reduction of 68.3-78.0%. The two most significant changes that can improve cost containment for volatile anesthetic agent use are decreasing FGF rates and switching to isoflurane after anesthetic induction.

Keywords: Inhaled anesthetics; Medical economics; Volatile anesthetic agent; Isoflurane; Sevoflurane

Introduction

Techniques of cost containment are important in medicine and anesthesia practice. Lack of understanding regarding the complexities of inhaled anesthetic agents and their use can lead to significant waste. With anesthetic medications accounting for 6% of total pharmacy costs in the United States and 20% of that being due to inhaled anesthetic agents, this may be one of the most feasible yet often overlooked areas for cost containment [1,2]. Inhaled anesthetic agents are used for the majority of anesthetics around the world. These medications are provided in liquid form and vaporized for delivery to the patient. This can lead to a situation where it may be difficult to accurately estimate the quantity of agent used and therefore, their cost may not be closely evaluated especially on a case by case basis [3]. The classical method of weighing the vaporizers is time consuming and logistically difficult. The latest generation of anesthetic machines can calculate the volume of gas consumption using copyrighted algorithms; however, the majority of anesthetic machines do not have this algorithm available.

At our hospital, which performed more than 31,000 anesthetics for pediatric patients last year, the cost of volatile anesthetic agents for one year was more than $300,000. More than 71% of this cost was for sevoflurane. Sevoflurane, which has replaced halothane, is used for inhalation induction in pediatric patients primarily due to its less pungent effects on the airway. During the induction phase of anesthesia, high fresh gas flows (FGFs) are often used which account for the higher volumes of volatile anesthetic agents that are consumed during this time. One strategy to reduce the consumption of inhaled anesthetic agents is to use lower FGFs. However, the FGF can change the physical characteristics of the anesthetic circuit.

The anesthetic circuit is often described as a semi-closed circle system. In the semi-closed system there is some rebreathing of exhaled gases with up to 90% loss of the gas to the environment. To conserve inhaled anesthetic agents, FGFs can be decreased to increase the percentage of rebreathing. By decreasing the FGF to the point where it equals physiological and equipment loss, the circuit becomes "closed" as only necessary FGF is provided. The patient then rebreathes approximately 100% of the inhaled anesthetic agent. This can generally be achieved by decreasing the FGF to 0.4-1 liters per minute. Oxygen consumption, carbon dioxide absorbed, inhaled anesthetic agent uptake, gas analyzer sampling and volume loss to the evacuation system all contribute to the necessary minimum FGF.

During the inhalation induction of anesthesia, FGFs greater than 6 liters per minute are often used in common clinical practice. At these high flows, the circuit becomes "open" with no rebreathing of the exhaled gas (Table 1). A rate above 50%-100% of the minute ventilation creates a situation where virtually all exhaled gas is lost to the evacuation system. An "open" system is the least cost efficient and has other disadvantages including deceased mucociliary function, loss of the patient's heat and water, ecological impacts of greenhouse gases, and occupational exposure. A lower FGF necessitates a good mask seal as leaks will be more obvious to the provider. The purpose of the current study was to evaluate various FGF rates in clinical anesthesia practice in an effort to determine the most effective means of conserving volatile anesthetic agents and limiting costs.

Open	Greater than 6 liters per minute or ≥ 50-100% of the minute ventilation
Semi-open	3-6 liters per minute
Semi-closed	1-3 liters per minute
Closed	Less than 1 liter per minute

Table 1: Definitions of circuits used during anesthetic care and estimated FGF.

Patients and Methods

This study was considered exempt by the IRB review board of Nationwide Children's Hospital (Columbus, Ohio) as it entailed a quality improvement project.

Anesthetic gas usage has been measured in many different ways. Weighing the gas vaporizer prior to use and then after use can be used to give a weight in grams of the volatile anesthetic agent that is used. This weight can then be converted into volume if the density of the liquid is known. Volatile anesthetic agents all have densities greater than water so that a milliliter of the agent weighs more than one gram. Once the volume of gas that has been used is calculated, the cost per milliliter can be used to further define the cost. The removal and weighing of the vaporizers is time consuming and logistically complicated in modern day operating rooms with quick turn-over times between cases. Therefore, for the purpose of the current study, volatile anesthetic agent use and hence cost was determined by weighing the anesthetic gas fill bottles before and after each case. The vaporizer was filled to the fill line prior to starting the case and the bottle weighed. At the conclusion of the case, the vaporizer was refilled to the fill line and the bottle was weighed again. The difference in weight was then used as the weight of the gas used during the previous case.

The second method of measuring gas usage was based on Dion's equation which provides a calculation of cost in dollars equal to PFTMC/2412d [4]. This equation has been shown to have a strong correlation to the actual gas used and to the protocol used by the Draeger Anesthesia Machine (Draeger Medical Inc, Telford, PA 18969) for measuring gas use [5]. The formula uses the variables of vaporizer concentration (P), fresh gas flow in liters per minute (F), and time in minutes (T). The constants are molecular weight (M), cost in dollars/mL (C), and density in g/mL (d). The factor of 2412 assumes that the volatile anesthetic agent follows ideal gas laws and has a known constant atmospheric density at 21°Centigrade.

A data entry spread sheet was created on which the FGF rate, vaporizer settings, and time were recorded during each case. This was then entered into an excel spread sheet to calculate cost. The cost per bottle of volatile anesthetic agent and the chemical properties of the gases are listed in Tables 2 and 3.

Gas	Cost per bottle	Volume of bottle in milliliters	Cost per milliliter
Sevoflurane	$78	250	$0.312
Isoflurane	$47	250	$0.188
Desflurane	$146	240	$0.61

Table 2: Estimated cost of volatile anesthetic agents.

Gas	Molecular weight (g/mole)	Density (g/mL)
Sevoflurane	200.055	1.52
Isoflurane	184.5	1.87
Desflurane	168	1.465

Table 3: Chemical properties of volatile anesthetic agents.

These variables were used to simplify the Dion's equation creating a constant for each gas. The (molecular weight) (cost)/ (2412) (density) for each gas was calculated (Table 4). With these numbers we were able to simplify the equation for each gas:

Sevoflurane cost =(inspired percentage)(flow)(minute)/59.13

Isoflurane cost =(inspired percentage)(flow)(minute)/105.69

Desflurane cost =(inspired percentage)(flow)(min)/34.38

For example, 10 minutes of 2% sevoflurane with a FGF rate of 4 liters per minute would cost: (2) (4) (10)/59.13 or 80/59.13=$1.35. These formulas can also be used to create another efficiency measure of cost per minute of anesthesia. In the above example, the cost per minute of anesthesia would be $0.135. These measures can also be used to compare anesthetic techniques for cost efficiency in the same way the term, miles per gallon, is used to compare automobile efficiency.

Gas	Constant
Sevoflurane	59.13
Isoflurane	105.69
Desflurane	34.38

Table 4: Dion's constants.

In the control group, patients were observed and data recorded without suggestions for the anesthesia provider on FGF, volatile anesthetic agent inspired percentage, and the specific volatile anesthetic agent used. At the completion of the case, the weight of the volatile anesthetic agent used from the bottles was determined and cost calculated by the Dion's equation. In the intervention group, patients used a specific protocol on FGF rate, inspired agent percentage, and specific volatile anesthetic agent to be used (Figure 1). The control group's data were recorded without explanation to the anesthesia providers so as to not lead to bias of the observed control group.

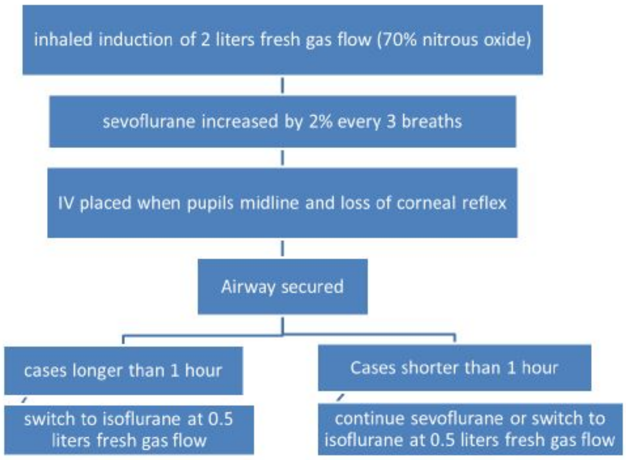

Figure 1: Low-flow Intervention protocol.

Six cost quantitative variables and 5 patient quantitative variables were obtained. The 6 patient qualitative variables included weighed cost per minute (cpm), calculated cpm, calculated induction cpm, weighed cost, calculated cost, and calculated induction cost. Weighed cost per minute was calculated by using weight in grams of liquid used divided by density to gain the volume of gas used.

The calculated cost per minute used the Dion's equation to determine volume. To evaluate the statistical significance of whether the cost of the volatile anesthetic agents was different between the groups, a non-parametric Wilcoxon rank sum test was used. The patient variables included age, weight, gender, presence of a leak around the airway device, and obesity. These were analyzed using the Wilcoxon rank sum tests, chi-squared tests, or the Fisher's exact test. Additionally, the time to ready for placement of an intravenous cannula and total anesthetic induction time were noted and analyzed using a non-parametric Wilcoxon rank sum test. Finally, in order to assess the impact of each variable while controlling for important covariates, a multiple logistic regression using the dichotomized cost measures was performed.

Results

The cohort for the study included 101 patients. There were 50 patients in the observational group and 51 who followed the suggested interventions to decrease volatile anesthetic use. No patient was withdrawn from the study due to intraoperative concerns or adverse effects. The demographic data are listed in Table 5.

	Female	Male	Age (years)	ETT	LMA or mask	BMI>30
Observed flow group (control)	34%	66%	5.8 ± 4.7	72%	28%	2%
Low-flow group (intervention)	43%	57%	6.4 ± 5.5 y	73%	27%	4%
ETT=Endotracheal tube; LMA=Laryngeal mask airway; BMI=Body mass index						

Table 5: Demographic data of the two study groups.

The summary cost data for each group separately are shown in Table 6. All cost measures were significantly lower in the intervention (low flow) group than the control group (p<0.0001).

Gas flow	Variable	N	Median	Mean	SD	Minimum	Maximum
Observed flow (control group)	weighed cpm	50	0.1900	0.2920	0.2227	0.0400	1.0900
	calculated cpm	50	0.2050	0.2528	0.1716	0.0200	0.7700
	weighed cost	50	9.8500	13.4120	13.8677	1.6400	84.2500
	calculated cost	50	9.3050	12.0878	10.4808	2.1600	59.6300
	calculated induction cost	41	5.1600	6.1517	4.0459	0.8800	20.9600
	calculated induction cpm	41	0.8100	0.7746	0.2471	0.1700	1.3200
Low flow protocol (intervention group)	weighed cpm	51	0.0600	0.0794	0.0641	0.0100	0.3600
	calculated cpm	51	0.0500	0.0567	0.0372	0.0100	0.2300
	weighed cost	51	3.1600	3.4655	1.6162	1.0100	7.1900
	calculated cost	51	2.7000	2.6578	1.1473	0.7400	5.9900
	calculated induction cost	44	1.7250	1.9500	0.8204	0.6800	3.9900
	calculated induction cpm	44	0.2300	0.2214	0.0504	0.1000	0.3200
CPM=Cost per minute in dollars; All cost measures were significantly lower in the intervention (low flow) group than the control group (p<0.0001)							

Table 6: Cost per minute calculations.

Across the cost measures, the mean cost was lower by 68.3-78.0% (Table 7). Using logistic regression analysis to determine predictors of a "high cost" anesthetic defined as a cost above the median for each measure, the variable of low flow was found to be significant in reducing the chance of a "high cost" in all the measured categories ($p<0.0001$). Other variables including gender, weight, age and time to IV did not significantly reduce the risk of a "high cost". The time until the patients were ready for placement of an intravenous cannula was longer in the observed (control) group than the intervention (low flow) group (3.20 ± 1.54 minutes for the observed group and 2.52 ± 1.23 minutes for the low flow group, $p=0.0372$).

Cost Measure	% Difference
weighed cost per minute	-72.8042
calculated cost per minute	-77.5844
weighed cost	-74.1613
calculated cost	-78.0122
calculated induction cost	-68.3015
calculated induction cost per minute	-71.4235

Table 7: Percent decrease in mean cost by using low gas flow.

Discussion

Anesthetic gas cost is a variable direct cost in that it is a price paid for the irreversible use of a resource dealing with materials that are dependent on the volume of work. Unlike other medications, the cost of these medications can be modified by decreasing fresh gas flow thereby decreasing cost without decreasing potency. Other factors that may add to total institutional cost when comparing volatile anesthetic agents that were not considered in the current study include recovery time, adverse effects (risk of delirium, postoperative nausea and vomiting, heat loss, and loss of mucocilliary function). Additionally, other indirect costs of the volatile anesthetic agents such as environmental impact of the release of greenhouse gases and occupational exposure were not measured. The costs discussed in this paper are purely the volume of gas used at current market values. The current study demonstrated a significant cost savings in both measured and calculated gas use when implementing a protocol for the use of low fresh gas flows with a reduction of between 68.3-78.0% depending on the cost measure used. For our institution this correlates with a savings of more than $200,000 per year.

When first released, there were concerns expressed with the potential for the accumulation of compound A when lowering the FGF to less than 1 liter per minute while using sevoflurane. According to the United States Food & Drug Administration, FGFs less than 1 liter per minute are never recommended with sevoflurane and FGFs less than 2 liters per minute for greater than two MAC hours are not recommended [6]. However, there are no data to suggest that these degradation products cause harm to humans in amounts that can be produced during low flow anesthesia [7]. The toxic levels vary considerably based on the animal species, being 300 ppm/hour in rats, 612 ppm/hour in pigs, and 600-800 ppm/hour in monkeys [8-10]. During human trails, exposures as high as 300 ppm/hour have no clinical effect on renal function [11].

During low flow anesthesia, compound A concentrations averaged 8-24 ppm/hour with soda lime and 20-32 ppm with Baralyme® [12]. This fact was reviewed by our institutional review board and found not to be significant if the use of low flow sevoflurane was limited to less than 1 MAC-hour. This allowed the algorithm for the current study to include the use of sevoflurane at 1 MAC for cases less than 1 hour. Alternatively, given that the use of sevoflurane provides significant clinical advantages only during anesthetic induction given its favorable hemodynamic profile and limited irritant effects on the airway, it is feasible and cost effective, as noted in our current study, to switch to isoflurane following anesthetic induction. This practice would then eliminate any theoretical concerns regarding the accumulation of toxic metabolites during the use of sevoflurane with low FGFs. It is commonly taught that higher FGFs will provide a more rapid induction of anesthesia. This premise was not supported by the findings of our study as we noted that induction time (time until the patient was ready for placement of an intravenous cannula) was significantly less in the intervention group (low FGF). It may be that this finding was unrelated to the FGF rate and rather the use of a protocol as it also guided the rate at which the concentration of the inhaled anesthetic agent was increased thereby limiting practitioner variability.

The cost measures of dollars per minute of gas used are important in that one can measure at any point in the anesthetic management how efficiently the anesthesia provider is delivering anesthetic gas. In a previous study, the cost per minute of sevoflurane in the induction protocol using 6 liters per minute and maintenance of 2 liters per minute was 13.23 rupees, which corresponds to approximately $0.22 per minute [13]. This cost is similar to the mean calculated cost of $0.25 per minute in our control group. However, when the low flow protocol was followed, this cost decreased to $0.05 per minute. Just like driving a car with a constant readout of miles per gallon that is known instantaneously to the driver, a real time feedback measure of efficiency during anesthetic care would allow for changes in behavior at any point during the anesthetic care. Such measures been incorporated into the newest generation of anesthesia machines as they provide volatile anesthetic agent use in milliliters at the end of each case. With that information, the cost of the anesthetic agent can be determined if the cost per volume is known. However, it does not take into account the length of the case and therefore is not a measure of efficiency. Alternatively, Dion's equation could become part of the electronic medical record in the near future and provide the feedback to allow providers to assess their efficiency.

Conclusion

According to our study, the two most important changes that can improve cost containment for inhaled anesthetic agents are decreasing the FGF especially during anesthetic induction and switching to isoflurane. Although these are obvious when one understands the factors that regulate anesthetic agent consumption, they are often ignored in common clinical practice especially in a training environment or when there is limited impact related to the direct costs of anesthetic care. A secondary impact on cost was the more rapid induction of anesthesia with the use of the protocol for the low FGF technique which resulted in the more rapid induction of anesthesia. Given the cost of time in the operating room, even minor differences must be considered when evaluating changes in practice and their effect on cost. Ongoing education and quality improvement maneuvers to monitor FGF rates and choice of agent during maintenance anesthesia may result in significant cost savings during anesthetic care by decreasing the total cost of volatile anesthetic agents.

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