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The Calculated Economic Cost of Inhalator Volatile Anesthetics in Low Flow Anesthesia

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Abstract

Taking into consideration the leading role of doctors in hospitals, saving costs on the health budget has become one of the main concerns during their everyday work. Low minimal and closed-circuit flow anesthesia has been applied since the beginning of the anesthesia history. Many reasons force the modern anesthesiologist to reconsider the role of low flow anesthesia and especially for the saving costs. One of the economical advantages of low flow anesthesia is the reduction up to 75% of the costs of the inhalation agents and this depends on the duration of anaesthesia, prices of the inhalation agents and the level of flow reduction. The entry into the market of low solubility agents such as Desflurane and Sevoflurane has initiated a new era in the usage of low flow anesthesia in order to maintain the cost associated with the adaptation of the fresh gas flow to the base of patient requirements. The Low-flow anesthesia is approved in many studies and the usage of this technique can bring up to the salvage of anesthetic substances without reducing the patient's comfort. Thanks to current technological and pharmacological possibilities, low flow anesthesia or closed circuit anesthesia are performed by anesthesiologists with a vast amount of interest in this technique and in regards to the economic savings it is quite important for this type of anesthesia to become a chosen technique amongst all anesthesiologists.

Keywords: Cost analysis, low flow anesthesia, inhalator anesthetics.

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INTRODUCTION

Anesthesia's evolution throughout the years depicts a clear image that over the last three decades, anesthetic machines have become one of the most important facilities in the operating rooms. Gas flows are measured exactly before a fixed amount is dispensed through a calibrated vaporizer. Gases and vaporizer mixes enter a circuit in which they are moistened, heated and then inhaled by the patient. Ventilators allow mechanical control of the respiration. This occurrence is due to the development of modern anesthetic machines, vaporizer and gas compression monitors. For many clinicians the choice of a cool gas flow higher than 3-5L / min was widely accepted as a daily routine of anesthetic technique. For many decades it has been limited to devoting enthusiasm to low-flow closed-circuit anesthesia and the anesthetists were very responsive to the kinetics of gases. Clinical, cultural, environmental, pharmacological, technological and economic reasons forced modern anesthetists to re-evaluate the role of low flow and closed-circuit inhaler anesthesia in clinical practice. The release of new volatile agents as well as advanced anesthetic machines associated with a high reliability monitoring system make low-flow or closed-loop anesthesia feasible in everyday practice. The two newest and more expensive agents, Sevoflurane and Desflurane, have many benefits including induction, maintains, outgoing and emergence of anesthesia (1).

Healthcare reforms lead to increasing pressure on anesthetists to consider the costs of current anesthesia strategies. Many health-care institutions are emphasizing cost reduction plans as a primary tool for managing the hospital, although the costs of drugs used for anesthesia constitute less than 6% of the total costs of per operative care (2, 3). In per operative cost analysis, anesthesia is estimated at 10-15% of the total cost of inpatient stay, and the exact value depends on the type of surgical operation performed. In the cost analysis only for the intraoperative period, the cost of anesthesia operation contributes around 20%, for the cost of anesthetic materials spent up to 10% of the total cost, while the inhaler agent accounts for less than 1%. By collecting the cost of inhalation agents, about 5% of the total anesthetic budget in its service is recorded by voluntary agents, and this contribute 20% to the cost of all anesthetic medication rates in the anesthetic service (4, 5). Low flow anesthesia has been pursued since the beginning of the anesthesia history. For many decades this form of anesthesia has been embraced by devoted, enthusiasts and those very fond of gas kinetics (5). For most anesthesiologist selecting a fresh gas flow higher than 3-5 L/min was widely accepted as a routine technique.The introduction of new volatile agents and advanced anesthesia machines accompanied by highly reliable monitoring systems, made low flow anesthesia feasible on a daily basis (6). Over 80% of anesthetic gases are wasted when flows of 5 L/min are used. Several studies also prove that the use of low and minimal flow anesthesia techniques can dramatically reduce the costs of volatile anesthetics (5, 6). Typically the reduction of FGF from 3 to 1L/min results in savings of about 50% of the total consumption of any volatile agent. Anesthetic drugs constitute only a small proportion 3-4% of the total cost of a surgical procedure; VAAs (Volatile anesthetic agents) may account for up to 20% of total anesthesia costs (7). The cost of inhaler agents is related: with the amount used of it, depends on the purchase price on the market, by their relative potency, from the amount of vaporizer released per ml of liquid and finally (but not least) the amount of fresh stream of gases dispersed in the vaporizer that is the most important factor determining the cost of anesthesia (8).The cost of anesthetic techniques is scarcely transparent through anesthetic protocol. Calculating VAA drugs' cost is hidden by the delivery method. VAAs are purchased in liquid form and administered through a vaporizer, making it difficult for a direct measure of how much VAA is used per case without the aid of a vapor analyzer. Differing delivery concentrations and delivery techniques may change total consumption of VAAs and change its costs significantly. A difficult challenge for institutions is calculating VAA costs. As method of cost analysis were discovered seven formulas: Dion's formula, Loke's formula, A volume percent equation, A four compartment model, Weight measurement, Volume measurement and MAC comparison (7, 9). We are going to explain each formula below.

1. Dion's Formula

The cost of inhaled agents was determined by using the formula quoted by Dion in the Canadian Journal of Anesthesia in 1992; incorporating the ideal gas law (10). The cost of an anesthetic agent can be calculated from the concentration (%)-P of gas delivered, FGF (L/min)- F duration of inhaled anesthetic delivery (min)-T, molecular weight (MW in g)-M, cost per ml (in dollars)-C, a conversion factor, 2412,to account for the molar volume of a gas at 21ºC (24.12 L), and density (d in g/ml)-d. The formula is the following:

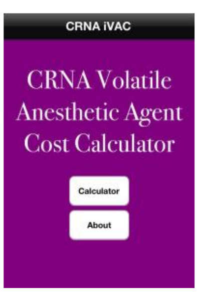
Cost = PxFxTxMxC/2114xd

The vaporizer setting, FGF and duration of operations are variables that depend upon the protocol of the anesthesia service. The molecular weight, cost and density are specific for different agents (as shown in Table Nr1).

Table 1. Molecular weight, cost and density are specific for different agents.

	Halothane	Enflurane	Isoflurane	Sevoflurane	Desflurane
Molecular Weight (g) M	197.4	184.4	184.4	200	168.04
Cost($-ml-¹)C	0.069	0.5	0.86	0.65	0.27
Density (g.ml-¹)d	1.87	1.52	1.50	1.517	1.465

Dion's formula incorporates the ideal gas law in order to convert ml VAA vapor into ml of VAA liquid, which is used to determine its cost. According to the ideal gas law that is PV=nRT where: P=absolute pressure, V=volume, n=amount of the substance of gas, R=the ideal gas constant and T= the absolute temperature of the gas. In order to convert volume of vapor into a ml of VAA, the density and molecular weights are used to convert the VAA vapor into moles, moles are converted into ml of liquid VAA using a conversion factor of 2412.According to the universal gas law equation, one mole of an ideal gas at one atmospheric pressure and corresponding to 21^{o} C will liberate 24.12 liters of vapor and this explains the factor of 2412 in the formula. At 0 ^{o} C, the factor of 2240 would be used, corresponding to the molar volume of a gas of 22.4L.Dion's Formula was determined to be easily reproducible and is the most referenced method for calculating cost in the literature (9, 10). This method is a simple tool in the discipline of Pharmaco-economics that can be used by every anesthetist as Weinberg et al stated. Subsequently Dion's Formula was utilized in the creation of a resourceful iApp tool. This iApp may prove the cost savings advantages of using low flow anesthesia (9).



2. Loke's Formula

Loke and Shearer, in a letter to the editor in 1993, questioned the use of Dion's formula with contemporary volatile agents (11). They used Dion's original formula and incorporated the ideal gas law directly into the formula rather than using a conversion factor of 2412 for 24.12 Liters, which represents molar volume of gas at atmospheric pressure at 21ºC.

3. A volume percent equation

Puckett and Andrews in 1997 calculated the cost of inhalator anesthetics using the vaporizer dialed percent setting, the volume percent equation, the ml of vapor per ml liquid calculation, and the cost per ml of liquid VAA. The volume percent equation was used to calculate at 1 MAC and a FGF = 2 L/min. The vapor produced by one ml of VAA was calculated using the ml of vapor per ml liquid equation Volume % = [Vapor Flow Rate/(FGF + Vapor Flow Rate)] x 100 (12).

4. A four compartment model

Lockwood and White (9,13) in 2001 attached the Weiskopf and Eger four compartment model to create a computer model for comparing the cost of Isoflurane, Desflurane, and Sevoflurane in open and closed systems. The four-compartment computer model takes into consideration the pharmacokinetic and pharmacodinamic properties of different inhalation anesthetic agent in the body.

5. Weight measurement

Boldt et al (14) realized a randomized control trial (RCT) in 1998 comparing standard and new anesthetic techniques with economic cost. Volatile anesthetic consumption was measured by weighing vaporizers after each case using a precision weighing machine. Each agent was measured to the nearest 0.1 g and subsequently converted to ml (sevoflurane1.52g/ml, desflurane 1.465g/ml). According to the authors, the use of precise weighing machines allows for precise measurement of consumed liquid quantities. The reduction of FGF, regardless of VAA delivered, results in considerable VAA cost savings (15).

6. Volume measurement

Cobos et al (16) in 2007 used a computer to log FGF and inhaled concentrations of anesthetics. The authors proposed that reducing FGF by half may theoretically decrease the cost of all VAAs by half.

7. MAC comparison

This method estimates the costs of each VAA based only on MAC values. The measurement of MAC to unit cost calculation ignores other variables involved in true cost calculations including the physics of vaporization, anesthetic delivery techniques and FGF rates. Total consumption of a VAA determines costs not at an assumed potency to potency comparison (15). Minimal alveolar concentration is analogous to the computerised values of ED50 according to the respective curve of the pharmacological dose. In this way the potency of different inhalation agents can be compared (16). Although the use of MAC in comparing the potency of various anaesthetics has been criticised, it is nowadays widely used (17).

Cost saving

Cost saving is one of the major leading concerns of health system nowadays. The benefit on health budgets due to low-flow anesthesia are shown and approved in many studies. LFA is a simple method but much more effective in minimizing costs of Sevoflurane anesthesia for operations lasting 2 hours or more (18, 19). The table below presents the calculations.

According to table Nr 2, using Isoflurane anesthesia with FGF =4 l/min for a period of one year results in 13678 dollars spent, while on the other hand using Isoflurane anesthesia with FGF =1 l/min for the same period results in about 4789 dollars spent and the savings reach approximately 8889 dollars when using LFA.

Table 2. Isoflurane anesthesia

Substance	Price US $/l	Consumption High flow	Costs per day (8 h)	Costs per year (220 days)	Consumption Low flow	Costs per day (8 h)	Costs per year (220 days)
O2	0,0011	1,3	0,69	151	0,5	0,26	58
N2O	0,0088	2,7	11,40	2509	0,5	2,11	465
Soda Lime	4,44	0	0,00	0	0,0031	6,61	1453
Isoflurane	222	0,00047	50,08	11018	0,00012	12,79	2813
Sums		**4 l/min**	**62,17**	**13678**	**1 l/min**	**21,77**	**4789**

Table 3. Sevoflurane anesthesia

Substance	Price US $/l	Consumption High flow	Costs per day (8 h)	Costs per year (220 days)	Consumption Low flow	Costs per day (8 h)	Costs per year (220 days)
O2	0,0011	1,3	0,69	151	0,5	0,26	58
N2O	0,0088	2,7	11,40	2509	0,5	2,11	465
Soda Lime	4,44	0	0,00	0	0,0031	6,61	1453
Sevoflurane	530	0,00047	119,57	26305	0,00012	30,53	6716
Sums		**4 l/min**	**131,66**	**28965**	**1 l/min**	**39,51**	**8692**

Table 4. The cost of anesthetic substances in $ according to flow that change in progressive scale.

Volatile Agents	Halothane	Isoflurane	Sevoflurane	Desflurane
FGF 1 l/min	6.9	8.5	10.0	11.5
FGF 2 l/min	13.9	16.9	20.0	23.0
FGF 3 l/min	20.8	25.4	30.0	34.6
FGF 4 l/min	27.7	33.8	40.0	46.1
FGF 5 l/min	34.7	42.3	50.0	57.6
FGF 6 l/min	41.6	50.8	60.0	69.1
FGF 7 l/min	48.5	59.2	69.9	80.7

While according to table Nr 3 using Sevoflurane anesthesia with FGF =4 l/min for a period of one year about 28965 dollars are spent, while using Sevoflurane anesthesia with FGF =1 l/min for the same period about 8692 dollars are spent. Using LFA with Sevoflurane almost 20273 dollars are accumulated as savings. These calculations are made with iApp employing Dion's Formula.

In Table Nr 4 is shown the cost of anesthetic substances according to flow that change in progressive scale.

A review publication by John K. Varkey (9) supports the fact that inhalation anesthesia with Sevoflurane is the most cost effective in low flow rates (Table 5).

CONCLUSIONS

This work is a guide for anesthetists to calculate the economic costs of volatile anesthetic agents correctly and in a more rapid way. Choosing the anesthetic agent, the calculation of right doses on time and the safety of the patient is a challenge encountered throughout everyday clinical practice. The cost of anesthesia depends on 3 major factors: 1. The price of volatile agents used for volatile anesthesia.

Table 5. Cost effectiveness of most used agents.

Author	Year	Level of Evidence	VAA	Cost/mL	FGF (L/m)	Cost	Method	Region
Chernin 19	2004	VII	Desflurane	$0.41	1	$6.99/hr	Dion	US
					2	$13.96/hr		
					3	$20.97/hr		
			Sevoflurane	$0.83	1	$5.48/hr		
					2	$10.95/hr		
					3	$16.43/hr		
Goiembiewski1	2010	VII	Desflurane	$0.96	1	$12.96	Dion	US
					2	$25.93		
					3	$38.88		
			Sevoflurane	$0.9	1	$6.05		
					2	$12.10		
					3	$18.10		

2.The quantity of volatile agents that's dependent fully on the fresh flow anesthesia used in delivery technique, that is easily adjusted in the flow meter. 3. The duration of inhalator anesthesia.

Dion's formula is the most straightforward and more practical tool used nowadays and CRNA Volatile Anesthetic Agent cost calculator application determines the real cost of volatile anesthetic agents. The majority of evidence reported in literature emphasizes the fact that inhalation anesthesia with Sevoflurane is the most cost effective agent when compared with the other agents used for similar flow rates.

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