



## RESEARCH ARTICLE

## Analyzing Volatile Anesthetic Consumption by Auditing Fresh Gas Flow: An Observational Study at an Academic Hospital

Luis Tollinche<sup>1</sup>, KaySee Tan<sup>2</sup>, Austin Han<sup>3</sup>, Leslie Ojea<sup>1</sup> and Cindy Yeoh<sup>1\*</sup>

<sup>1</sup>Department of Anesthesiology and Critical Care Medicine, Memorial Sloan Kettering Cancer Center, USA

<sup>2</sup>Department of Biostatistics, Memorial Sloan Kettering Cancer Center, USA

<sup>3</sup>Sophie Davis School of Biomedical Education, City University of New York (CUNY) School of Medicine, USA

\*Corresponding author: Cindy Yeoh, MD, Department of Anesthesiology and Critical Care Medicine, Memorial Sloan Kettering Cancer Center, USA, E-mail: yeohc@mskcc.org



### Abstract

**Background:** In a climate of cost containment, it is critical to analyze and optimize all perioperative variable costs. Fresh gas flow is one important variable that determines utilization of inhalational agents and can be tightly controlled by the anesthesia provider. Manufacturers of inhalational agents have recommendations for minimum gas flow for their respective agents. Any gas flow above these recommendations is considered misuse and leads to unnecessary expense. The purpose of this study was to characterize and quantify the excess use of inhalational agents by analyzing fresh gas flow rates for long duration cases.

**Methods:** Over a span of three months, operating room records were analyzed for all procedures lasting greater than 4 hours. End tidal inhalation agent percentage for Sevoflurane and Isoflurane and fresh gas flows were analyzed. 303 unique patients with at least 4 hours of anesthesia time were included. Analysis excluded the first and last 30 minutes of all anesthetics to account for need for higher gas flows during induction/emergence of anesthesia. 152 patients received sevoflurane alone. 33 patients received isoflurane alone. 107 patients received both isoflurane and sevoflurane and were included in sevoflurane group given the higher gas flow needs of sevoflurane. 11 patients received neither agent and were excluded from analysis. We proceed with n = 292 unique patients. (259 in Sevo, 33 in iso) We used the two-sided one sample t-test setting 2 ml/min as the null for sevo and 1 ml/min as the null for iso; we ran analysis using a nonparametric test that didn't require the fresh gas flow to be normally distributed - the two-sided one-sample Wilcoxon rank-sum test: p value = < 0.0001.

**Results:** The results of our study revealed a sevoflurane (n = 259) mean fresh gas flow (L/min) 2.55 (95% CI, 2.45-2.66) - significantly different from null of 2 ml/min (p < 0.0001). Isoflurane (n = 33) mean fresh gas flows (L/min) 2.33 (95% CI, 2.00-2.66) - significantly different from null of 1 l/min (p < 0.0001).

**Conclusion:** Manufacturer recommendation for sevoflurane is to maintain gas flows 1-2 l/min and Isoflurane at above 1 l/min. Given these recommendations, the anesthesia providers delivered fresh gas flows at least 28% higher than necessary for sevoflurane and at least 130% greater than necessary for isoflurane anesthetics that lasted greater than 4 hours. This is an area where cost reduction can be readily achieved. Future plans to realize a reduction in inhalational agent utilization include education of the benefits of fresh gas flow and instituting a low fresh gas flow policy.

### Introduction

Low flow anesthesia has been demonstrated to be a safe and reliable technique that offers a considerable reduction in volatile agent utilization [1-3]. In addition to cost savings, low flow anesthesia offers several advantages over "traditional" anesthesia delivery. Low flow anesthesia has been shown to reduce global and workplace pollution and to aid in temperature maintenance and humidity accumulation [4,5]. Every opportunity should be made to limit anesthesia medication waste while delivering safe and efficient care via low flow anesthesia.

### Cost

In a health care climate of cost containment, cost reduction measures have gained traction and become a major impetus for the revision of guidelines and recommendations. Anesthesia medications contribute a large portion of the expenses incurred in the operating room. Many anesthesiologists maintain a flow rate of 2-3 L/min during maintenance of anesthesia [1]. With

the advent of newer volatile agents with favorable pharmacodynamics and blood gas solubilities, the use of low flow anesthesia is a compelling technique with respect to cost reduction.

### Global pollution

In anesthesia delivery systems, waste gases that are no longer needed in the system are vented to the outside after extraction via the scavenging system. The total fresh gas flow used to administer anesthetic gases is proportional to the volume of gas that enters the scavenging system [4,6]. Ekbohm, et al. reported that the amount of sevoflurane, consumed, vaporized and released into the atmosphere at 1 MAC decreased from 0.66 (0.07) to 0.48 (0.05) g/min, a 27% reduction by halving fresh gas flow [7]. Accordingly, low gas flow techniques must be encouraged to limit the burden of greenhouse gases that stem from anesthesia delivery.

### Homeostasis

Low flow anesthesia has the benefit of maintaining homeostasis in several parameters including temperature regulation and humidity control. Kleeman showed that low gas flow techniques (defined as less than 0.5 liters/min) improved humidification and temperature regulation [8]. Bengtson demonstrated that a low flow circle system yielded higher inspiratory humidity and temperature compared with high flow anesthesia [9,10].

### Operating room contamination

Recent emphasis has been placed on the potential negative health effects from work place exposure to trace concentrations of volatile anesthetics [5,11]. Restrictions have been placed on both types of gases and maximum exposure during a workday. High ambient air concentrations of anesthetic gases have been linked to the practice of maintaining unnecessarily high gas flows during general anesthesia [12]. It is incumbent on the clinician delivering volatile anesthetics that all machines operate securely and with safeguards to reduce the occurrence of entrained air into the operating room. Equally important, however, for the improvement of workflow air quality is the reduction of fresh gas flow during volatile anesthetic delivery [4,5].

In spite of robust notification systems and the well described benefits of low flow anesthesia [13], it is theorized that most clinicians do not follow recommendations and continue to deliver high flow during the maintenance phase of anesthesia. We conducted an observational study to investigate the fresh gas flow rates delivered during general anesthesia at a major academic institution. This institution provides fresh gas flow education and offers ventilators with notification systems to help limit fresh gas flow. Despite these robust systems, the investigators hypothesized that most clinicians were not practicing low flow anesthesia.

## Methodology

### IRB approval

IRB exemption was approved by MSKCC under the criteria of low protocol risk level. Approval number: IRB X15-027. IRB Approval Date: June 3, 2015. contact information: Dr. Roger Wilson, Chairman, IRB, Memorial Sloan Kettering Cancer Center 1275 York Avenue, NY 10065.

The electronic records of all patients undergoing surgery were evaluated for the volatile agent use and fresh gas flow rate. Data were collected from the anesthesia ventilator and fed directly to the electronic record (EPIC Systems Co). The data were captured continuously from the anesthesia delivery unit. The various components of the data were subdivided and categorized: flow rate of oxygen, nitrous oxide, air, concentration inspired volatile agent, concentration expired volatile agent, and total fresh gas flow. Data recording took place at Memorial Sloan Kettering Cancer Center (MSKCC), New York, NY (USA). MSKCC is a cancer treatment and research institution that employs over 1000 physicians and treats more than 600,000 patients with approximately 400 types of cancer annually. MSKCC has 473 inpatient beds and 72000 square foot surgical center. The anesthesia care team includes attending anesthesiologists, residents, CRNAs and CRNA students. All operating rooms use the same Apollo (DRAGER) Anesthesia machine which has "optimal" fresh gas flow notification. Vaporizers for Isoflurane and Sevoflurane were available in all rooms. The data were collected for a period of six months between January and June 2016. Inclusion criteria included all patients who received general anesthesia with a volatile anesthetic during the time period. All procedures selected lasted greater than 4 hours of anesthesia time. Anesthesia time was defined as time from "induction of anesthesia" to "emergence from anesthesia". 4 hours was selected as a time cutoff to ensure that all surgical procedures had arrived at a stable maintenance of anesthesia phase. The 4 hour time allowed for achievement of steady state levels of volatile anesthetic and eliminated the possibility that anesthesiologists were aggressively titrating anesthesia levels. Both elective and emergent procedures were included. There were no restrictions on type of surgery and all surgery types were included. Exclusions included anesthesia time less than 4 hours and general anesthetics that did not involve volatile anesthetics.

All procedures lasting greater than 4 hours of anesthesia time were included. The primary outcome was average gas flow during the procedure, quantified and analyzed separately by two groups: Patients who received sevoflurane versus isoflurane. Gas flow rates were assessed and recorded every 30-minutes. Analyses excluded the gas flow rate recorded during the first and last 30 minutes of the procedure to account for the need for higher gas flows during induction and emer-

gence of anesthesia. Patients who received isoflurane for the entire procedure were categorized under the isoflurane group; patients who received sevoflurane-alone or both isoflurane and sevoflurane formed the sevoflurane group. The average gas flow rate for the procedure (less the first and last 30 minutes) was calculated at the patient-level. Gas flow rates are presented as median (25<sup>th</sup>, 75<sup>th</sup> percentile) within each group.

To estimate whether the observed gas flow rate is significantly different from the manufacturer recommendations, we compared the gas flow rate within each group to the minimum gas flow recommended (the null): 2 ml/min for sevoflurane group and 1 ml/min for isoflurane group. Comparisons are conducted using the one-sample Wilcoxon rank-test. The one-sample Wilcoxon rank sum test is a non-parametric alternative to the one-sample t-test when the data may not be normally-distributed. All analyses were conducted in R 3.1.1 (R Development Core Team, Vienna, Austria). All statistical tests are two-sided.

## Results

The original data set included 338 unique patients who had general anesthetics lasting greater than 4 hours of anesthesia time. Only 303 unique patients with at least 4 hours of anesthesia time were identified. The total number of patients who received neither sevoflurane nor isoflurane was 11 and these patients were excluded. The number of patients who received only sevoflurane (and no isoflurane at any time) was 152. The number of patients with only isoflurane and no sevoflurane at any time was 33. The number of patients who received both sevoflurane and isoflurane was 107. These patients were considered and analyzed in the sevoflurane group. Given that manufacturer suggestions for sevoflurane are higher than isoflurane, any patient who was exposed to sevoflurane was analyzed in the sevoflurane group.

We proceeded with N = 202 unique patients (259 in SEVO, 33 in ISO). There were 129 female patients and 174 male patients. The following analysis excluded the first and last 30 minutes of anesthesia time.

- 129 Female, 174 Male.

	Isoflurane	Sevoflurane
<b>Female</b>	13	112
<b>Male</b>	20	147

- Median age (25<sup>th</sup>, 75<sup>th</sup> percentile): 62 years (51, 69); mean age: 59.1 years.

	Median Age (25 <sup>th</sup> , 75 <sup>th</sup> )	Mean Age
<b>Sevoflurane</b>	62 (51, 69)	58.6
<b>Isoflurane</b>	66 (55, 74)	63.2

- Median (25<sup>th</sup>, 75<sup>th</sup>) number of 30-min increments: 12 (10, 16)

## Major outcomes

SEVO (N = 259 unique patients),

Mean fresh gas volume in ml/min: 2.55 (95% CI, 2.45 - 2.66),

Significantly different from null of 2 ml/min ( $p < 0.0001$ ) using the two-sided one sample t-test setting 2 ml/min as the null.

The more appropriate method is to use a nonparametric test that doesn't require the fresh gas volume to be normally distributed: Two-sided one-sample Wilcoxon rank-sum test setting 2 ml/min as the null:  $p$ -value  $< 0.0001$ , and present the median (25<sup>th</sup>, 75<sup>th</sup> percentile): 2.10 (1.8, 2.75) fresh gas volume ml/min in the SEVO group.

ISO (n = 33 unique patients not overlapping with SEVO),

Mean fresh gas volume in ml/min: 2.33 (95% CI, 2.00 - 2.66),

Significantly different from null of 1 ml/min ( $p < 0.0001$ ) using the two-sided one sample t-test setting 1 ml/min as the null.

The more appropriate method is to use a nonparametric test that doesn't require the fresh gas volume to be normally distributed: Two-sided one-sample Wilcoxon rank-sum test setting 2 ml/min as the null:  $p$ -value  $< 0.0001$ , and present the median (25<sup>th</sup>, 75<sup>th</sup> percentile): 2.00 (1.4, 2.6) fresh gas volume ml/min in the SEVO group.

## Discussion

The manufacturer of sevoflurane recommends that fresh gas flows be maintained between 1 and 2 L/min during the maintenance phase of anesthesia [14]. Our study revealed a fresh gas flow rate of 2.55 L/min for patients in the sevoflurane arm of the study. This reflects an almost 30% greater fresh gas flow utilized over the span of our study than what is recommended by the manufacturer. We found a mean fresh gas flow rate of 2.33 L/min for patients in the isoflurane arm. A conservative lower limit of fresh gas flow of 1 L/min was utilized for the study. In this group, the fresh gas flow rates were 133% greater than recommended.

Our study is superior to previous similar investigations for two important reasons. First, in our study we exclude the first and last 30 minutes of anesthesia time during analysis. The first and last 30 minutes reflect the time period of induction and emergence of anesthesia respectively. These 30 minutes are felt to require higher gas flows to quickly titrate volatile anesthesia levels and to vary concentrations [15]. Other studies have included this time period during their analysis and artificially "penalize" the clinician for higher than recommended gas flows [2,13,16-18]. Secondly, our study separated the two volatile anesthetics sevoflurane and isoflurane into two unique groups during data analysis. Because fresh gas flow rate requirements are different for these

two agents, it is imperative that the fresh gas flow rates be compared to their respective fresh gas flow rate requirement. In other studies, the fresh gas flow rate requirements are the same for both sevoflurane and isoflurane [2,3,16-19]. It is more appropriate to analyze the excess fresh gas flows delivered for sevoflurane and isoflurane arms separately.

Literature strongly supports the use of low flow anesthetic techniques over “traditional” anesthesia gas delivery because of advantages ranging from cost savings to reduction in global pollution [13]. While there are potential risks associated with low-flow anesthesia, modern anesthesia machines meet all the technical requirements for the safe use of low flow techniques if they are used in conjunction with equipment for monitoring inhaled and exhaled gas concentrations [19].

Tight control of inhalational agents with low-flow techniques could ultimately translate into significant cost savings, decreased global pollution and improved homeostasis.

## Conclusion

Our study reintroduces and highlights the importance of low-flow anesthesia delivery techniques. While low-flow anesthesia is considered sound and recommended practice, our study demonstrates the fact that clinicians, while armed with the knowledge, may still fail to follow low-flow anesthesia recommendations. It is of essence, given the multitude of benefits stemming from a simple change, that anesthesia departments evaluate and analyze their current practice of gas flow delivery and effect appropriate change as needed so as to reduce the negative effects of “traditional” anesthesia gas delivery.

## Acknowledgments

The authors’ work was supported and funded in part by NIH/NCI Cancer Center Support Grant P30 CA008748.

## References

- Ryu HG, Lee JH, Lee KK, Nam Su Gil, Chong Soo Kim, et al. (2011) The effect of low fresh gas flow rate on sevoflurane consumption. *Korean J Anesthesiol* 60: 75-77.
- Dexter F, Maguire D, Epstein R (2011) Observational study of anaesthetists’ fresh gas flow rates during anaesthesia with desflurane, isoflurane and sevoflurane. *Anaesth Intensive Care* 39: 460-464.
- Body SC, Fanikos J, DePeiro D, Philip JH, Segal SB (1999) Individualized feedback of volatile agent use reduces fresh gas flow rate, but fails to favorably affect agent choice. *Anesthesiology* 90: 1171-1175.
- Feldman JM (2012) Managing fresh gas flow to reduce environmental contamination. *Anesth Analg* 114: 1093-1101.
- Brattwall M, Warrén-Stomberg M, Hesselvik F, Jakobsson J (2012) Brief review: Theory and practice of minimal fresh gas flow anesthesia. *Can J Anaesth* 59: 785-797.
- Mapleson W (1998) The theoretical ideal fresh-gas flow sequence at the start of low-flow anaesthesia. *Anaesthesia* 53: 264-272.
- Ekbom K, Assareh H, Anderson R, Jakobsson J (2007) The effects of fresh gas flow on the amount of sevoflurane vaporized during 1 minimum alveolar concentration anaesthesia for day surgery: A clinical study. *Acta Anaesthesiol Scand* 51: 290-293.
- Kleemann P (1990) The climatization of anesthetic gases under conditions of high flow to low flow. *Acta Anaesthesiol Belg* 41: 189-200.
- Bengtson J, Sonander H, Stenqvist O (1987) Preservation of humidity and heat of respiratory gases during anaesthesia—a laboratory investigation. *Acta Anaesthesiol Scand* 31: 127-131.
- Bengtson J, Bengtson A, Stenqvist O (1989) The circle system as a humidifier. *British Journal of Anaesthesia* 63: 453-457.
- Guirguis S, Pelmeur P, Roy M, Wong L (1990) Health effects associated with exposure to anaesthetic gases in Ontario hospital personnel. *Br J Ind Med* 47: 490-497.
- McGregor DG (2000) Occupational exposure to trace concentrations of waste anesthetic gases. *Mayo Clin Proc* 75: 273-277.
- Nair BG, Peterson GN, Neradilek MB, Newman SF, Huang EY, et al. (2013) Reducing wastage of inhalation anesthetics using real-time decision support to notify of excessive fresh gas flow. *Anesthesiology* 118: 874-884.
- Inhalation Anesthesia Agent Ultane (package insert). AbbVie Inc, North Chicago.
- Baum JA (1999) Low-flow anesthesia: theory, practice, technical preconditions, advantages, and foreign gas accumulation. *J Anesth* 13: 166-174.
- Kennedy R, French R (2003) An audit of anaesthetic fresh-gas flow rates and volatile anaesthetic use in a teaching hospital. *N Z Med J* 16: 116.
- Kennedy RR, French RA (2008) Changing patterns in anesthetic fresh gas flow rates over 5 years in a teaching hospital. *Anesth Analg* 106: 1487-1490.
- Hanci V, Yurtlu S, Ayoğlu H, Okyay RD, Erdoğan G, et al. (2010) Effect of low-flow anesthesia education on knowledge, attitude and behavior of the anesthesia team. *Kaohsiung J Med Sci* 26: 415-421.
- Baum JA, Aitkenhead A (1995) Low-flow anaesthesia. *Anaesthesia* 50: 37-44.