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CLINICAL RESEARCH

Measurement of anesthetic pollution in veterinary operating rooms for small animals
Isoflurane pollution in a university veterinary hospital

Drielle B.S. Figueiredo[a], Aline G. Aun[a], Juliana R. Lara[a], Natache A. Garofalo[b], Francisco José Teixeira-Neto[b], Leandro G. Braz[a], Mariana G. Braz[a,*]

[a] *Universidade Estadual Paulista (UNESP), Faculdade de Medicina, Departamento de Especialidades Cirúrgicas e Anestesiologia, Botucatu, SP, Brazil*
[b] *Universidade Estadual Paulista (UNESP), Faculdade de Medicina Veterinária e Zootecnia, Departamento de Cirurgia e Anestesiologia Veterinária, Botucatu, SP, Brazil*

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Abstract
Introduction: Inhaled anesthetics are used worldwide for anesthesia maintenance both in human and veterinary operating rooms. High concentrations of waste anesthetic gases can lead to health risks for the professionals exposed. Considering that anesthetic pollution in a veterinary surgical center in developing countries is unknown, this study aimed, for the first time, to measure the residual concentration of isoflurane in the air of operating rooms for small animals in a Brazilian university hospital.
Method: Residual isoflurane concentrations were measured by an infrared analyzer at the following sites: corner opposite to anesthesia machine; breathing zones of the surgeon, anesthesiologist, and patient (animal); and in front of the anesthesia machine at three time points, that is, 5, 30 and 120 minutes after anesthesia induction.
Results: Mean residual isoflurane concentrations gradually increased in the corner opposite to anesthesia machine and in the breathing zones of the surgeon and the anesthesiologist ($p < 0.05$). There was an increase at 30 minutes and 120 minutes when compared to the initial time points in the animal's breathing zone, and in the front of the anesthesia machine ($p < 0.05$). There was no significant difference at measurement sites regardless of the moment of assessment.
Conclusion: This study reported high residual isoflurane concentrations in veterinary operating rooms without an exhaust system, which exceeds the limit recommended by an international agency. Based on our findings, there is urgent need to implement exhaust systems to reduce anesthetic pollution and decrease occupational exposure.

* Corresponding author.
E-mails: mgbraz@hotmail.com, mariana.braz@unesp.br (M.G. Braz).

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Introduction

Halogenated inhalation anesthetics are widely used in the maintenance of human and veterinary general anesthesia, as they are inexpensive and do not require a venous infusion pump. In veterinary anesthesiology, the halogenated anesthetics mostly used are halothane, isoflurane, and sevoflurane, with isoflurane being the most used.[1]

Isoflurane (2-chloro-2- (difluoromethoxy) -1,1,1-trifluoro-ethane) has advantages over other halogenated anesthetics, including lower solubility than halothane, resulting in fast anesthesia recovery. In addition, isoflurane undergoes less hepatic biotransformation ($\leq$ 0.2%) than sevoflurane (3%) and halothane (20%).[2,3] Furthermore, isoflurane is less expensive than sevoflurane. Minimum Alveolar Concentration (MAC) refers to the potency of the anesthetic agent. In human adults, isoflurane has a MAC of 1.2%, approximately.[4] However, MAC varies among animals, including domestic animals (1.28% to 1.5% for dogs and 1.28% to 1.9% for cats).[5]

Improvement of health care of pets by their owners has been observed, contributing to a longer life expectancy of these animals and, consequently, to a greater likelihood of, at some point in their lives, being undergone surgery under anesthesia.[6] Thus, greater exposure to waste anesthetic gases is expected by professionals working in operating rooms. In the past few decades, health risks for professionals who are occupationally exposed to inhaled anesthetics have been discussed; the literature is more extensive dealing with professionals working in a human operating room[7–11] than in relation to professionals who work in a veterinary operating room.[12–14]

Thus, to minimize exposure to anesthetics, the National Institute of Occupational Safety and Health (NIOSH)[15] recommends a ceiling for halogenated anesthetic exposure (without the use of concomitant nitrous oxide) no greater than 2 parts per million (ppm) for a period not exceeding one hour. There are some articles in the scientific literature discussing anesthetic pollution in veterinary surgical centers, but all were performed in developed countries and with different objectives.[14,16–21]

The absence of an adequate gas exhaustion system in operating rooms is one of the most relevant factors contributing to high residual anesthetic concentrations.[22] According to a study published in the early 1990s in the UK, ventilation and scavenging conditions in veterinary operating rooms were already reported as precarious, and generally worse than those found in operating room for humans.[16] In fact, exposure to residues of anesthetic gases is a relevant risk factor for preterm delivery female veterinarians working in rooms without scavenging.[23]

It should be noted that, in addition to internal pollution in operating rooms, the residues of anesthetic gases are also eliminated outdoors, which can cause environmental impact. It should be noted that inhaled anesthetics contain halogenated compounds that resemble chlorofluorocarbons and, therefore, can have deleterious effects on the ozone layer. Based on measurements performed in several environments, including urban areas and even remote Antarctica, rapid accumulation, and increased presence of residues from the most modern halogenated anesthetics in the global atmosphere have been detected over the past decades.[24]

In view of the above and due to the lack of data from developing countries, this first-time study aimed to measure the residual concentration of isoflurane in the air of the operating room setting for performing anesthesia in small animals at a university veterinary hospital in Brazil.

Methods

The study was previously approved by the local Ethics Committee (report: 2.422.128) and carried out in a veterinary surgical block without a gas exhaustion system. The study was carried out throughout the day (one surgery in the morning and one in the afternoon, when available), for 2 months, in the four operating rooms (48 to 70 m^3) to perform procedures with a minimum duration of 2 hours in small animals. Anesthesia induction of animals was performed using an intravenous agent and maintenance with isoflurane after orotracheal intubation using a cuff, according to the routine procedures performed at the operating room.

The anesthesia equipment available in the operating rooms were: Conquest 5000 and Conquest 3000 Slim, both from HB Hospitalar, Fuji 2604 from Takaoka, and Fabius Plus from Dräger (equipped with the most modern vaporizer). For the Conquest and Fuji models, the open system (or breathing circuit without valve) was used in patients weighing less than 7 kg, and the semi closed system (or circle circuit with valve) was used in animals weighing over 7 kg. As for the Dräger equipment, only the semi closed system was used.

To measure residual concentrations of isoflurane in the operating rooms, we used the portable gas analyzer InfraRan 2 Four Gas Anesthetic Specific Vapor Analyzer (Wilks – A Spectro Scientific Co., Inc., Norwalk, CT). The analyzer detects anesthetic concentrations by infrared in real time. The recommended measurement range for isoflurane is 0 to 50 ppm and we reset the equipment (with a carbon filter) before starting each measurement, following the instructions manual.

Air samples were collected at five sites: corner opposite to anesthesia machine; in the breathing zones of the surgeon, anesthesiologist, and patient (animal); and in front of the anesthesia machine (Figure 1), at three time points, that is 5, 30 and 120 minutes after anesthesia induction. Thus, the mean residual concentrations of the anesthetic were calculated for all moments and sites.

Statistical analysis

The Shapiro-Wilk test was applied for checking data distribution. As data were parametric, we performed the analysis of repeated measures to compare mean values at the study time points for each site of measurement. The Levene test was used for assessing equality of error variances, the Mauchly test for the sphericity of means, and the Bonferroni test to preform multiple comparisons. Analysis of variance was used to compare sites at each time point. Levels below 5% were considered significant.

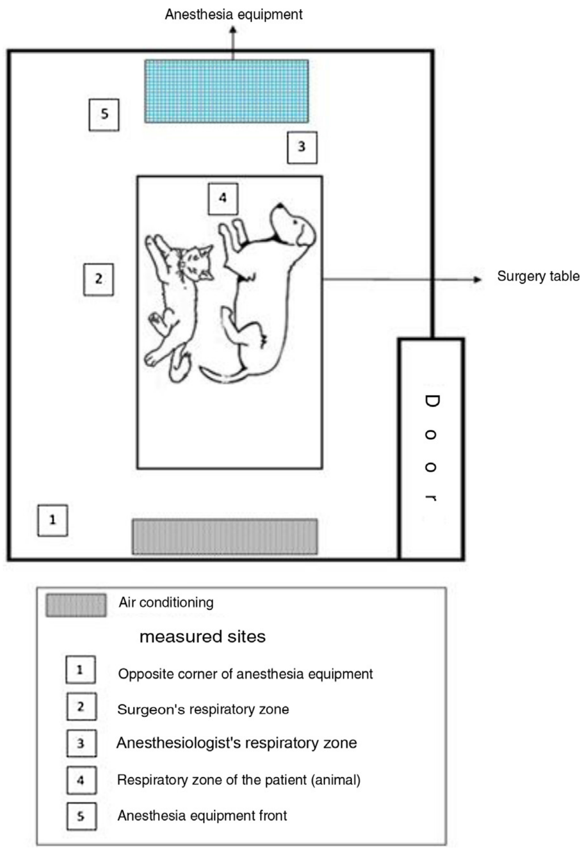

Figure 1 Diagram of veterinary operating rooms depicting the sites where isoflurane residues were measured.

Results

Data were collected during 21 surgeries, each of them at the three time points and at the five sites. Most of the isoflurane residue measurements were performed with the operating room doors open (73%). The general data are shown in Table 1. The patients anesthetized were pets, mostly dogs. We used roughly 1.5 MAC (average of 2.3%), low Fresh Gas Flow (FGF) and, in most of the cases, the semi closed breathing circuit and Dräger equipment.

Table 2 shows the mean values of residual isoflurane concentrations measured in the operating rooms. Over time, the values showed gradual increase in the site opposite to the anesthesia machine, and in the breathing zones of the surgeon and the anesthesiologist ($p < 0.05$). At the site opposite to the anesthesia machine, there was a 3-fold and 5.5-fold increase in the values measured at 30 and 120 minutes, respectively, when compared with the start of anesthesia induction. Similarly, we observed 3.2-fold and 3.3-fold increase at the breathing zones of surgeons and anesthesiologists, respectively, at 30 minutes; and 6-fold and 5.5-fold increase in the measurements performed at the breathing zones of surgeons and anesthesiologists, respectively, 120 minutes after anesthesia induction.

In relation to the other two measurement sites, there was also a significant increase at 30 minutes and 120 minutes when compared with the initial moments ($p < 0.05$). At the breathing zone of the animal, there was 3.5-fold and 4.9-fold increase at 30 minutes and 120 minutes, respectively,

Table 1 General data from measurements performed at operating rooms.

Operating rooms assessed	Minimal alveolar concentration (%)	Fresh gas flow (L. min^{-1})	Anesthesia machine			Type of respiratory circuit		Animals		
			Fabius plus (%)	Conquest (%)	Fuji (%)	Semi-closed (%)	Open (%)	Dogs (%)	Cats (%)	Weight (Kg)
4	2.3 ± 0.5	1.1 ± 0.4	44	40	16	90	10	90	10	14 ± 9

Data presented as absolute number or mean ± standard deviation.

Table 2 Isoflurane residue concentrations in ppm (mean ± standard deviation) measured at different times and sites in veterinary operating rooms used for small animals.

Time	Measurement sites					*p*- value
	Corner opposite to anesthesia machine	Surgeon breathing zone	Anesthesiologist breathing zone	Patient breathing zone	Front of anesthesia machine	
5 min	2.7 ± 2.3^a	2.5 ± 2.2^a	2.6 ± 2.1^a	3.0 ± 2.4^a	4.4 ± 5.2^a	0.38
30 min	8.2 ± 6.1^b	8.1 ± 4.9^b	8.6 ± 5.0^b	10.4 ± 6.3^b	13.2 ± 16.8^b	0.57
120 min	13.9 ± 7.3^c	15.1 ± 7.2^c	14.2 ± 7.7^c	15.7 ± 7.8^b	23.1 ± 17.5^b	0.41
p-value	< 0.001	< 0.001	< 0.001	< 0.001	0.006	

The letters indicate the comparison of concentration means at each time and site; different letters show statistically significant difference.

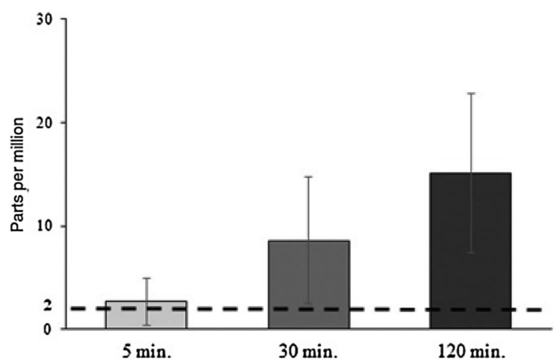

Figure 2 Comparison of overall isoflurane concentration residues mean values (mean ± standard deviation) measured at the 5 sites and at the three study time points. The dashed horizontal line shows the limit value recommended by the National Institute of Occupational Safety and Health (NIOSH).

when compared with the anesthesia induction. Close to the anesthesia machine, there was a 3-fold and 5.3-fold increase at 30 minutes and 120 minutes, respectively, when compared with anesthesia induction.

Although we observed mean measurement values slightly higher at all moments at the front part of the anesthesia machine compared with the other sites, there was no significant difference ($p > 0.05$) among sites, regardless of the time of measurement.

Figure 2 depicts the measurement means at the five sites at the three time points evaluated and the reference value of 2-ppm, which is the ceiling value recommended by NIOSH.

Discussion

The present study revealed that the mean residual concentration of isoflurane clearly over exceeded the values of 2-ppm at all time points and sites of measurement, and a progressive increase in concentrations over time, especially at the breathing zones of the professionals.

Monitoring residual anesthetic concentrations is essential to determine anesthetic air pollution in the operating room. It is noteworthy that even after 5 minutes of anesthetic induction, mean values were already just above 2-ppm (reference value) in all measured sites, and the values more than quadrupled after 30 minutes of anesthesia, reaching values 7 to 12-fold higher than the reference value after 120 minutes of anesthesia. The limit recommended by NIOSH[15] had already been exceeded in the initial 5 minutes of anesthesia and was largely exceeded at subsequent times, as regrettably there is no Brazilian recommendation concerning the limits of exposure to anesthetics nor guidelines for installation of scavenging/ventilation systems in the operating room. Thus, these data reveal, for the first time, high anesthetic pollution of isoflurane found in veterinary operating rooms used for anesthesia in pets (canines and felines) in a developing country, which may be representative of many veterinary surgical centers around the world that have the same scenario. Thus, contamination of work environment by the use of inhaled anesthetics should be kept to a minimum to mitigate occupational exposure.[18]

Even with the use of a semi-closed breathing system in most surgeries, as well as an open system (Mapleson/Baraka), there was leak/release of residues of anesthetic gas contributing to the anesthetic contamination of ambient air, which promptly dissipated in operating rooms that were small in volume, fully polluting them, regardless of measurement sites. Thus, all professionals working in those rooms were occupationally exposed to relevant anesthetic pollution, irrespective of their location. Indeed, the highest residual concentrations of isoflurane were registered close to the anesthesia machine, in which the Active Gas Scavenging (AGS) exhaustion system exits from the front part of the anesthesia machine. We must also remember that older anesthesia machines are more likely to present leakage due to the absence of tests performed before anesthetic procedures. Other causes of contamination of operating rooms include leakage of inhalation anesthetic during filling of vaporizers, orotracheal tube with no cuff, high FGF ($\geq 3\,L.min^{-1}$), and particularly lack of exhaustion and ventilation system.[25,26]

It should be emphasized that measurements were made in a surgical block without gas exhaustion/ventilation system. Considering the study[22] performed in a surgical block for human patients at a university hospital, in operating rooms without a gas exhaustion system, which also revealed which residual isoflurane concentrations far exceeded the recommended international limit (NIOSH), and that anesthetic pollution increased as anesthesia time increased, it is evident that there is accumulation of anesthetic pollution both in human and veterinary operating rooms when a gas exhaustion system is lacking. Interestingly, when comparing our results to that study, which evaluated three measurement sites similar to ours and at 30 and 120 minutes of anesthesia, all mean values of isoflurane residues found in our study were higher than those reported by Braz et al. in 2017,[22] showing the high contamination of anesthetic in a veterinary surgical block when no exhaustion system is set. The same authors evaluated residual isoflurane concentrations in operating rooms with a gas exhaust system performing 7 air changes per hour and observed that the mean values of concentrations of the anesthetic were closer to the 2-ppm limit. Thus, the requirement of an efficient exhaustion system to reduce anesthetic pollution and, consequently, reduce exposure to exposed professionals is evident.

Regarding scientific literature, there are limited data available measuring isoflurane residues while it is used for anesthesia maintenance of small/domestic animals. According to a study from Portugal using a gas chromatography method, the authors reported mean residual isoflurane concentrations below 2-ppm in operating rooms with gas exhaustion system, whereas in its absence, mean concentrations increased to 5.8-ppm during anesthesia in dogs.[14] A study carried out in the 1990s in Canada showed isoflurane concentration higher than 4.5-ppm when small animals were intubated with a cuff and anesthetized with isoflurane using both open and semi-closed respiratory systems.[17]

In a study conducted on experimental animals (rodents) anesthetized with isoflurane in a research laboratory, low residual anesthetic concentrations were observed, since the operating room was complying to Australian regulations, with appropriate ventilation and an effective gas exhaustion system and modern model of anesthesia machine, resulting in minimal exposure to anesthetics.[20] In a recent publication, research reports were reviewed retrospectively to evaluate isoflurane exposure in rooms used to perform surgical procedures in animals (primate, swine, and rodent) and in operating rooms where humans underwent surgery at the US National Institutes of Health.[21] Measurements were performed in operating rooms with a laminar flow system that produced 17 air changes per hour without recirculation and whose anesthesia machine also had a scavenging system connected to the central system of exhaustion of the hospital, with suctioning flow of 45 $L.min^{-1}$. All concentrations measured by infrared spectroscopy were below 2-ppm.

Thus, the installation and proper functioning of an exhaust system in operating rooms, modern anesthesia machines with scavenging system, and personnel training for correct anesthesia machine handling are relevant measures to reduce the levels of exposure both in veterinary and human anesthesiology. Hence, efforts are clearly required to effectively reduce anesthetic contamination of the air in operating rooms.

Considering our findings and data in the literature, it is urgent and necessary to improve the conditions of operating rooms in which several professionals work. The Brazilian Society of Anesthesiology and the Brazilian College of Veterinary Anesthesiology, among other similar entities in developing countries, have a relevant role in improving the quality standards in the area. Thus, we suggest that the entities also promote the awareness of professionals exposed to occupational harm and, especially, of managers to improve the work environment to minimize exposure to anesthetics, through the implementation of regulations and political measures aiming to create specific laws/norms, like those designed many decades ago in developed countries. Reducing anesthetic pollution and preventing potential unhealthy health risks for professionals working in operating rooms is a public health issue, and it is the responsibility of operating room managers to promote a safe environment for their professionals, which includes biosafety.

Regarding the possible limitations of the present study, we can mention the fact that residual anesthetic measurements were performed throughout the day (without previous definition of standardization, such as the first surgery of the day), which may have influenced the pollution of the second surgery of the day in the same room. However, it should be underlined that there was always a 3-hour interval between surgeries, which may have reduced the bias concerning accumulation of anesthetic contamination. In addition, because in most cases operating room doors remained open, there was a certain amount of air circulation; if the doors were closed, the level of anesthetic contamination would certainly be much higher.

It should be underscored that inhaled anesthetics vaporize into the atmosphere and there is much debate about their greenhouse potentials and contributions to the destruction of the ozone layer contributing to climate change, the greatest human public health threat. Environmental damage from waste anesthetic gases depends on their molecular weight, half-life in the atmosphere and the potential for global warming.[27] The atmospheric half-life of isoflurane is the lowest among halogenated anesthetics, which is 3.2 years, but this anesthetic has a higher global warming potential than sevoflurane.[28] A study showed that the average climate impact per anesthetic procedure at the University of Michigan, in the USA, is comparable to the emission of 22 kg of Carbon Dioxide (CO_2) and estimated annual emissions of waste anesthetic gases are equivalent to the CO_2 emissions of a coal plant.

In fact, the impact of inhaled anesthetics is small compared to other polluters; even so, it has great relevance if we consider the large number of operating rooms worldwide. A multicenter study involving university hospitals in the USA, Canada and the UK, using isoflurane, sevoflurane, and desflurane reported that operating rooms are an important source of greenhouse gas emissions, with estimated emissions in these three countries of 9.7 million tons of CO_2 per year, equivalent to 2 million passenger vehicles.[29] Recently, due to the impact of global warming, British authors have emphasized the opportunity for professionals in the field to contribute to environmental sustainability in veterinary anesthesiology.[30] It is important to state that having an ecologically balanced environment is a constitutional right, and public authorities must defend and preserve it for present and future generations.

In conclusion, the present study revealed, in a Brazilian public university veterinary hospital, high residual concentrations of isoflurane in operating rooms lacking exhaust systems and used for small animals, and which exceeded the limits recommended by an international agency. The results are relevant and possibly represent most veterinary surgical centers around the globe, especially in developing countries, which do not have gas exhaust/ventilation systems. Thus, there is an urgent need to raise awareness and correct the issue and to improve working conditions in surgical blocks to reduce occupational exposure to health professionals to a minimum, as well as to mitigate greenhouse gas emissions.

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Conflicts of interest

The authors declare no conflicts of interest.

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