







Elevated Waste Anaesthetic Gas Concentration in the Paediatric Post-Anaesthesia Care Unit

Pediyatrik Anestezi Sonrası Bakım Ünitesinde Atık Anestetik Gaz Konsantrasyonu Artışı

Timur Jan-Peter Özelsel¹ , Sam Kim¹ , Karen Buro² , Ban Tsui³ 

¹Department of Anaesthesia and Pain Medicine, University of Alberta, Edmonton, Canada

²Department of Mathematics and Statistics, Macewan University, Edmonton, Canada

³Department of Anaesthesiology, Perioperative and Pain Medicine, Stanford University, Palo Alto, USA

Cite this article as: Özelsel TJP, Kim S, Buro K, Tsui B. Elevated Waste Anaesthetic Gas Concentration in the Paediatric Post-Anaesthesia Care Unit. Turk J Anaesthesiol Reanim 2018; 46(5): 362-6

ORCID IDs of the authors: T.J.P.Ö. 0000-0002-1780-0632; S.K. 0000-0002-1734-1771; K.B. 0000-0002-3041-9836; B.T. 0000-0003-2889-0730.

Objective: Exposure to waste anaesthetic gas (WAG) is a recognised occupational hazard for health care professionals (HCP). In recovery rooms, scavenging and ventilation systems differ from those in the operating room, raising the question as to how efficient they are. This study aims to measure the levels of ambient sevoflurane over the course of consecutive workdays in the paediatric recovery room of a tertiary academic centre.

Methods: The following is a descriptive-analytic study of ambient air sevoflurane levels measured using a MIRAN® 205B Series SapphIRE portable ambient air analyser. Samples were obtained between 7:30 am and 6:30 pm for two non-consecutive weeks on consecutive weekdays in our paediatric recovery room area.

Results: The ambient air levels of sevoflurane exceeded the ceiling concentration of 0.5 ppm recommended by the National Institute for Occupational Safety and Health on all days of measurement. The concentration of sevoflurane in ambient air correlates directly with the number of patients present.

Conclusion: Even in a modern recovery room constructed according to current building standard and code, ambient air levels of WAG exceed the recommendations. Future research and practice standards are needed to reduce this occupational exposure. Disregarding whether chronic exposure to WAG is harmful, we have shown that HCP working in recovery rooms are chronically exposed to concentrations which exceed recommended levels. Strategies are needed to reduce ambient levels of WAG in post-anaesthesia care units.

Keywords: Inhalational anaesthesia, occupational exposure, recovery room, paediatric anaesthesia, sevoflurane, volatile anaesthetics

Amaç: Atık anestetik gaz (AAG) maruziyeti sağlık çalışanları için tanımlanmış mesleki bir tehlikedir. Uyanma odalarında, anestetik gaz temizleme ve ventilasyon sistemleri ameliyathanedekilerden farklıdır ve bu da ne kadar etkili olduklarına dair bir soru oluşturmaktadır. Bu çalışma üçüncü basamak bir akademik merkezdeki pediyatrik uyanma odasında, ardışık çalışma günlerinde, ortamdaki sevofluran düzeylerini ölçmeyi amaçlamaktadır.

Yöntemler: Bu tanımlayıcı analitik çalışmada oda havasındaki sevofluran düzeyleri, MIRAN® 205B Series SapphIRE taşınabilir ortam havası analizörü kullanılarak ölçüldü. Numuneler ardışık olmayan 2 haftada, ardışık işgünlerinde saat 07.30 ile 18.30 arası pediyatrik uyanma odasında alındı.

Bulgular: Ortam havasındaki sevofluran seviyeleri, tüm ölçüm günlerinde, Ulusal Mesleki Güvenlik ve Sağlık Enstitüsü tarafından 0,5 ppm olarak önerilen üst sınırı aşmıştır. Ortam havasındaki sevofluran seviyesi mevcut bulunan hasta sayısı ile doğrudan ilişkilidir.

Sonuç: Günümüz standartlarına ve koduna göre inşa edilen modern bir uyanma odasında bile, ortam havasındaki AAG düzeyleri önerilen değerleri aşmaktadır. Bu mesleki maruziyeti azaltmak için başka araştırma ve uygulama standartlarına ihtiyaç vardır. Kronik AAG maruziyetinin zararlı olup olmadığını dikkate almaksızın, uyanma odalarında çalışan sağlık çalışanlarının sürekli olarak, önerilen seviyeleri aşan seviyelere maruz kaldıklarını ortaya koyduk. Anestezi sonrası bakım ünitelerinde ortamdaki AAG seviyelerini azaltmak için stratejilere gereksinim vardır.

Anahtar Kelimeler: İnhalasyon anestezisi, mesleki maruziyet, uyanma odası, pediyatrik anestezi, sevofluran, volatil anestetikler

Introduction

Waste anaesthetic gas (WAG) is defined as an anaesthetic gas that is released or leaks during medical procedures (1). Ever since Vaisman reported a link between the exposure to WAG and adverse health outcomes in 1967 (2), the topic has been of interest to all those exposed on a regular basis. Early research into the topic consisted mainly of questionnaires, distributed among exposed workers of institutions or members of professional societies (3-5). The American Society of Anesthesiologists (ASA) conducted one study in 1974 (6), which linked a long-term exposure to WAG to spon-

taneous abortion, congenital abnormalities, infertility, premature births, cancer and renal and hepatic disease. In light of this, the National Institute for Occupational Safety and Health (NIOSH) published recommendations in 1977 (7), setting a Recommended Exposure Limit (REL) for anaesthetic gas. While no major health care system has binding guidelines for occupational exposure limits to WAG, recommendations exist to reduce the health care workers' exposure to WAG as much as possible. The REL set by NIOSH remains the standard from which recommendations around the world have been derived. Specifically, NIOSH recommends that in a period of 8 hours, the concentration for nitrous oxide not exceed 50 ppm and the halogenated ethers sevoflurane, desflurane and isoflurane not exceed 2 ppm. When nitrous oxide is used in combination with a halogenated ether, these limits are reduced to 25 ppm for nitrous oxide and to 0.5 ppm for halogenated ethers.

The scientific foundation of the REL by NIOSH has been subject to criticism. The studies employed were questionnaires, which suffered from the two main known limitations of questionnaires, that is, leading questions and insufficient response rates. The previously mentioned study by ASA had around 75,000 responses-which was still less than 50% of the people the survey was sent to. Furthermore, the three volatile anaesthetics most frequently used today-sevoflurane, desflurane and isoflurane-were not available when the studies leading to the creation of the REL were conducted. Nevertheless, the increased awareness of WAG led to many improvements in the operating room (OR) ventilation systems: for example, scavenging of anaesthetic gas from the patient and workstation, positive pressure gradient from the OR to surrounding rooms, standards for the air exchange rates in an OR, and a laminar flow pattern of ventilation in the work zone of an OR. Measurements taken at the author's institution show the OR environment to be essentially uncontaminated by WAG.

Research within the last decade has focused mainly around the WAG genotoxicity. One study demonstrated that recovery room nurses have detectable amounts of isoflurane in their breath even after 2 days away from hospital (8). In another study, increased genotoxicity in anaesthesiologists was reversed after a 2-month vacation (9), whereas the reversal only took 5 days for a patient who had undergone surgery under general anaesthesia (10). Because of the long elimination half-life of volatile anaesthetics in the peripheral fat compartment (11), bioaccumulation most notably occurs in HCP who are repeatedly exposed.

Waste anaesthetic gas in post-anaesthesia care units (PACU) is generated by patients exhaling gases and vapours they have received during surgery. PACU units in hospitals in North America are built differently from ORs with regard to ventilation standards. We report results of the daily measurement of WAG in a paediatric PACU over 2 non-consecutive weeks separated by 4 months. This is an expansion of preliminary data previously reported (12).

As a general disclaimer, the authors are well aware of the inaccuracy of the term WAG. Nitrous oxide is the only gas in the group, and sevoflurane, desflurane and isoflurane are all halogenated ethers. For simplicity purposes and in keeping with the term being used widely in scientific nomenclature, we will include all of the inhalational anaesthetics under the blanket term of WAG.

Methods

Description of locations

Ambient air concentrations of sevoflurane were measured on 5 consecutive workdays (Monday through Friday) in the PACU of a paediatric operating room. Measurements were performed in 2 different time periods-1 week in July 2014 and 1 week in October 2014. These two time periods also reflect two different workloads and thus patient loads in PACU, with the July week representing a period of reduced OR activity and the October week representing a period of regular OR activity.

The PACU is designed to accommodate up to six paediatric patients at a time. Total air exchanges per hour are 9.5 of which 6 (minimum) are fresh gas air exchanges. There is a positive pressure gradient relative to adjacent areas, the temperature is kept within a range of 18 to 26°C, and relative humidity between 20% and 60%.

Measurement

A MIRAN[®] 205B Series SapphIRe portable ambient air analyser (Thermo Electron Corporation, Waltham, MA) was used to measure the concentration of sevoflurane. This device can measure a wide range of chemical substances, including anaesthetic gases using infrared spectroscopy. As per the manufacturer, it has an accuracy of $\pm 10\%$ and a detection limit of 0.04 ppm for the main volatile anaesthetics. We calibrated the analyser outside the OR suite each day prior to measurement. The analyser was set up beside the nursing desk, which is the central location of PACU, that is, not in the patient zones. Measurements were taken between 7:30 am and 6:30 pm for all days of the study period. The MIRAN can be used in a multi-gas or a single-gas application mode. It is more accurate when used in single-gas mode (factor of 10). Nitrous oxide was often used as part of mask induction and was demonstrable on a test measurement in PACU. With sevoflurane being the volatile anaesthetic administered in the majority of cases, we decided to measure ambient air levels of sevoflurane as a single agent with higher accuracy vs. doing a multi-gas analysis with desflurane and nitrous oxide. Measurements were taken every 3 minutes throughout the day. Fresh gas flows in between 0.5 and 1.0 L min⁻¹ are generally used in our department.

Patient data collection

Institutional ethics board approval was obtained. Individual informed consent was not obtained for the purposes of

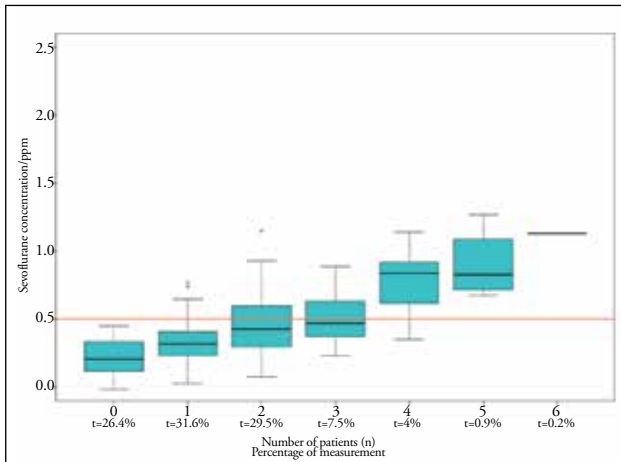


Figure 1. Ambient sevoflurane concentration and patient load from July 7 - July 11

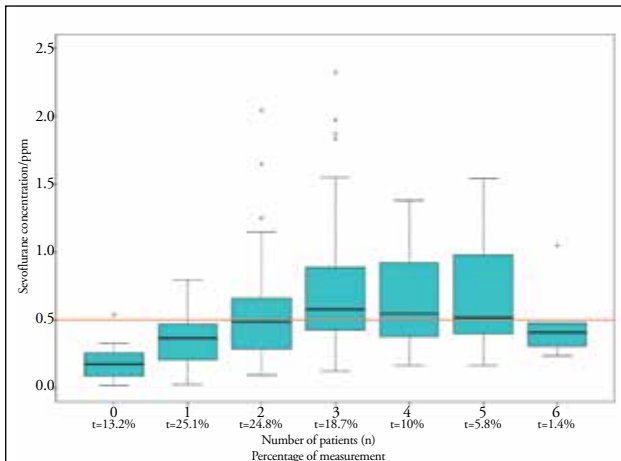


Figure 2. Ambient sevoflurane concentration and patient load from October 20 - October 24

this study. Patient data were collected retrospectively from PACU nursing admission records. Patient name, identification number, time of admission and discharge from PACU were recorded. Further patient information, such as the anaesthetic agent used, was taken from the anaesthesia record.

Statistical analysis

The ambient sevoflurane concentrations were interpreted as time series for the 5 days from each measurement period (July and October). Using the ‘forecast’ package (13) for R (14), time series polynomial models of degree 2 were fit to each time series to predict the sevoflurane concentration in dependency on the number of patients in the room having received sevoflurane, the number of patients in the room not having received sevoflurane, and the total number of patients who already had left the room on the day of measurement. In a final step, both time series were jointly analysed to assess differences.

The predictive power of the resulting models was judged using the adjusted coefficient of determination (adjusted

R-squared, adjusted R²) measuring how much of the variance in the sevoflurane concentration can be explained through the model, while adjusting for the number of variables included. Models were checked with a residual analysis for deviations from the model assumptions. A significance level of 5% was assumed for all tests. The model used for analysis is listed in supplementary materials.

Results

Measurement of sevoflurane concentrations in PACU from 7 July-11 July 2014

Looking at an 8-hour work period from 8:30 to 16:30, the recommended ceiling concentration of 0.5 ppm was exceeded on each day for 87, 69, 114, 75 and 78 minutes respectively from Monday to Friday (See Supplementary Figure A).

A correlation was observed between the level of WAG in ambient air and the patient load, that is patients admitted to PACU over time. Figure 1 provides a graphical comparison between ambient sevoflurane concentration and patient load for the week of 7-11 July. With a load of at least 2 patients in PACU, the sevoflurane concentration very often exceeds the REL of 0.5 ppm.

Measurement of sevoflurane concentrations in PACU from 20 October-24 October, 2014

The ceiling concentration of 0.5 ppm was exceeded for 243, 111, 66, 345 and 99 minutes, respectively, from Monday to Friday, from 8:30-16:30. These measurements are higher than in July (See Supplementary Figure B).

There was a correlation between the patient load and the level of sevoflurane in ambient air. Figure 2 provides a graphical comparison between ambient WAG concentration and patient load for the week of 20-24 October.

The mean ambient sevoflurane concentration in July (0.31 ppm, SD=0.20 ppm) was significantly lower than in October (0.42 ppm, SD=0.40) ($t(1544.7)=8.3382$, $p<2.2e-16$). In October, more patients were admitted to PACU than in July, of which a higher percentage had received sevoflurane. In July, in 85 of 99 (86%) procedures and in October in 112 of 126 (89%) procedures, sevoflurane was employed. The number of measurements exceeding 0.5 ppm was 141 in July versus 288 in October ($\chi^2(1)=63.225$, $p=1.843e-15$).

For both sets of measurements, July and October, polynomial regressions of degree 2 revealed that the number of patients in the room having received sevoflurane, the number of patients in the room not having received sevoflurane, and the total number of patients who already had left the room on the day of measurement contributed to ambient sevoflurane contamination (Tables 1 and 2).

A polynomial regression of degree 2 for the combined datasets confirmed that the number of patients in the room hav-

ing received sevoflurane, the number of patients in the room not having received sevoflurane, and the total number of patients who had already been discharged and the month of measurement all affected the measured sevoflurane concentration (Table 3). The mean ambient sevoflurane concentration was higher in October after correcting for the respective numbers of patient subgroups. The model fit the data with an adjusted R-squared of 41.1%. Residual analyses showed the data to be consistent with all fitted models.

Discussion

There were two main findings in our study. Firstly, the WAG levels in ambient air exceed the NIOSH recommendations at various points throughout the regular work day, which was even more pronounced with the higher patient loads seen outside the less busy summertime. There was a direct correlation between the number of patients admitted to PACU per hour and increases in the WAG levels in ambient air. This correlation was also seen in our mathematical regression model when considering the number of patients admitted to PACU, discharged from PACU and having either received sevoflurane or not. The adjusted R² in our mathematical model indicates that the number of patients admitted to and discharged from PACU are strong predictors of ambient sevoflurane concentrations. It is obvious that the ventilation of our PACU is not sufficient to eliminate WAG produced by more than 2 patients per hour to a degree that sevoflurane levels are kept below 0.5 ppm. Krenzischek et al. (15) showed that concentrations of WAG in a patient's breathing zone usually peak 1 hour after admission. Their interpretation is that this was due to patients waking progressively and improving their ventilation, while at the same time, oxygen masks which would initially have diluted WAG on a patient's breath, would be removed at some point.

Waste anaesthetic gas and their potential harmful effects on exposed HCP have been a contentious topic over the last decades. Even in the absence of scientific evidence for toxicity of WAG on HCP, it is understood that the highly lipophilic nature of WAG is a reason for concern, since no such substrates exist in nature and thus the human defence system is not inherently equipped to deal with them. The recommendation to reduce HCP's exposure to WAG should therefore be taken seriously.

The REL have not changed since 1977, even after anaesthetic practice has almost entirely shifted away from halothane or enflurane and moved on to isoflurane, sevoflurane and desflurane. In 1994, NIOSH released a bulletin update warning that researchers had not been able to identify a safe level of exposure, and it recommended periodic monitoring of the WAG level conducted by an industrial hygienist (16).

The paediatric patient population and the type of anaesthetics administered offer distinct differences from the adult pa-

tient population. From these differences, it may be inferred that the load of WAG coming from the patient should be lower in a paediatric PACU versus an adult PACU.

In our series, measurements were carried out at the central desk in an area outside of the direct working zone of our nurses. We can thus only report general levels of WAG in ambient air and not how these may differ in the direct vicinity of patients. In paediatric PACU, it is also very common for nurses to take children into their arms and to hold them while they recover from anaesthesia. Accordingly, exposure of the individual nurse to WAG may be well above what we have measured.

One limitation with respect to drawing conclusions is that concentrations measured in our PACU are not necessarily valid for PACU units in other hospitals. The presence or absence of laminar air flow patterns alone influence the total cleaning capacity of a ventilation system to a degree not as easily quantifiable as air exchange rates.

When looking at hospital building standards (17), it is apparent that PACU areas are not afforded the same ventilation standards as operating rooms in regard to overall and to fresh air gas exchanges. Further and potentially even more important is how airflow patterns are created in a room. A laminar flow from up to down with an active exhaust just above the ground level will provide steady turnover and exchange of air, while a central air diffuser with side vents could lead to turbulences with more air churning than exchange, the more so the higher the rate of air exchanges is.

Conclusion

Our data show that recommended levels of WAG in ambient air are exceeded daily, despite ventilation standards in our PACU meeting or exceeding the building standards. While we do not know if these exposure levels actually place HCP working in PACU at risk for any long-term morbidity, we do know that we need to find ways to reduce the amount of gas they are exposed to.

Future research will hopefully help us understand the impact of WAG on health more clearly and how to limit the exposure of health care workers to WAG when working in a PACU environment.



You can reach the questionnaire of this article at <https://doi.org/10.5152/TJAR.2018.35683>

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of University of Alberta.

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - T.J.P.Ö., S.K., K.B., B.T.; Design - T.J.P.Ö., S.K., K.B., B.T.; Supervision - T.J.P.Ö., S.K., K.B., B.T.; Resources - T.J.P.Ö., S.K., K.B., B.T.; Data Collection and/or Processing - T.J.P.Ö., S.K., K.B., B.T.; Analysis and/or Interpretation - T.J.P.Ö., S.K., K.B., B.T.; Literature Search - T.J.P.Ö.; Writing Manuscript - T.J.P.Ö.; Critical Review - T.J.P.Ö., S.K., K.B., B.T.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.



Bu makalenin ekine <https://doi.org/10.5152/TJAR.2018.35683> adresinden ulaşabilirsiniz.

Etik Komite Onayı: Bu çalışma için etik komite onayı Alberta Üniversitesi'nden alınmıştır.

Hasta Onamı: Yazılı hasta onamı bu çalışmaya katılan hastalardan alınmıştır.

Hakem Değerlendirmesi: Dış bağımsız.

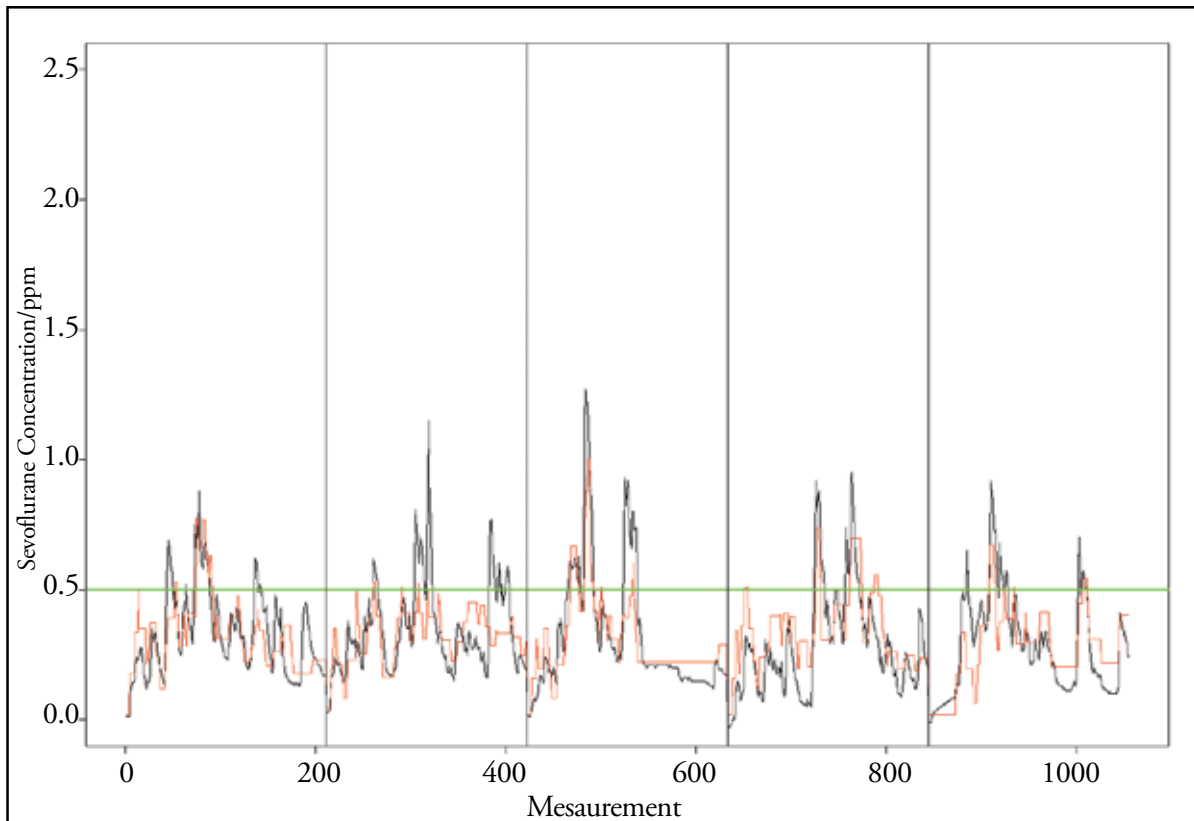
Yazar Katkıları: Fikir - T.J.P.Ö., S.K., K.B., B.T.; Tasarım - T.J.P.Ö., S.K., K.B., B.T.; Denetleme - T.J.P.Ö., S.K., K.B., B.T.; Kaynaklar - T.J.P.Ö., S.K., K.B., B.T.; Veri Toplanması ve/veya İşlenmesi - T.J.P.Ö., S.K., K.B., B.T.; Analiz ve/veya Yorum - T.J.P.Ö., S.K., K.B., B.T.; Literatür Taraması - T.J.P.Ö.; Yazıyı Yazan - T.J.P.Ö.; Eleştirel İnceleme - T.J.P.Ö., S.K., K.B., B.T.

Çıkar Çatışması: Yazarlar çıkar çatışması bildirmemişlerdir.

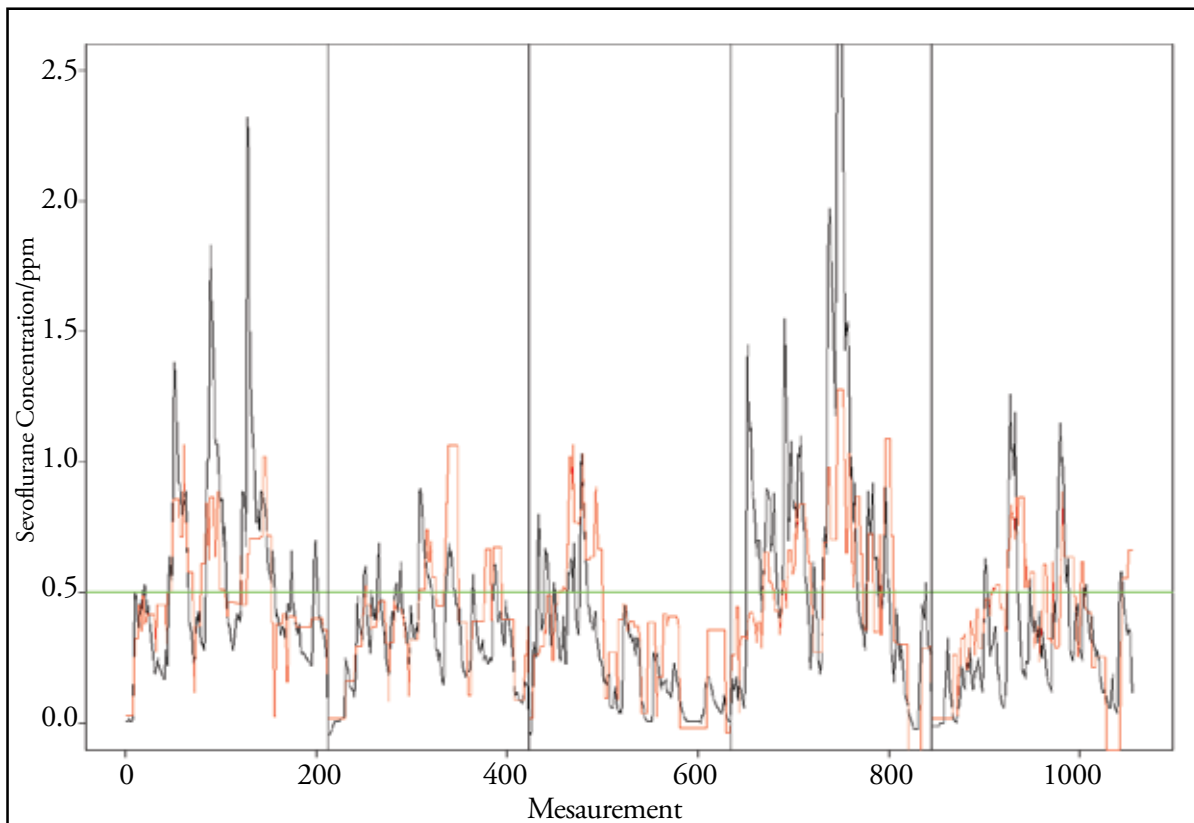
Finansal Destek: Yazarlar bu çalışma için finansal destek almadıklarını beyan etmişlerdir.

References

1. CCOHS. "Waste Anesthetic Gases, Hazards of." Last accessed September 23, 2017. Available from: http://www.ccohs.ca/oshanswers/chemicals/waste_anesthetic.html
2. Vaisman AI. Working conditions in the operating room and their effect on the health of anesthetists [in Russian]. *Eksp Khir Anesteziol* 1967; 12: 44-9.
3. Buring JE, Hennekens CH, Mayrent SL, Rosner B, Greenberg ER, Colton T. Health experiences of operating room personnel. *Anesthesiology* 1985; 62: 325-30. [CrossRef]
4. Tannenbaum TN, Goldberg RJ. Exposure to anesthetic gases and reproductive outcome. *J Occup Med* 1985; 27: 659-68.
5. Bolvin JF. Risk of spontaneous abortion in women occupationally exposed to anesthetic gases: a meta-analysis. *Occup Environ Med* 1997; 54: 541-8. [CrossRef]
6. Occupational disease among operating room personnel: a national study. Report of an Ad Hoc Committee on the Effect of Trace Anesthetics on the Health of Operating Room Personnel, American Society of Anesthesiologists. *Anesthesiology* 1974; 41: 321-40.
7. National Institute of Occupational Safety and Health: Criteria for a Recommended Standard: Occupational Exposure to Anesthetic Gases and Vapors. Cincinnati, OH, US Dept. of Health Education, and Welfare (DHEW), 1977, Publication number 77-140.
8. Cope KA, Merritt WT, Krenzischek DA, Schaefer J, Bukowski J, Foster WM, et al. Phase II Collaborative Pilot Study: Preliminary analysis of central neural effects from exposure to volatile anesthetics in the PACU. *J Peri-anesth Nurs* 2002; 17: 240-50. [CrossRef]
9. Eroglu A, Celep F, Erciyes N. A comparison of sister chromatid exchanges in lymphocytes of anesthesiologists to nonanesthesiologists in the same hospital. *Anesth Analg* 2006; 102: 1573-7. [CrossRef]
10. Karabiyik L, Sardas, S, Polat U, Kocabas NA, Karakaya AE. Comparison of genotoxicity of sevoflurane and isoflurane in human lymphocytes studied in vivo using the comet assay. *Mutat Res* 2001; 492: 99-107. [CrossRef]
11. Behne M, Wilke HJ, Harder S. Clinical pharmacokinetics of sevoflurane. *Clin Pharmacokinet* 1999; 36: 13-26. [CrossRef]
12. Kims S, Özelsel T, Tsui B. Monitoring waste anesthetic gas in the pediatric postanesthesia care unit. *Can J Anesth* 2016; 63: 1301-2. [CrossRef]
13. Hyndman RJ. 2015. *_forecast: Forecasting functions for time series and linear models_*. R package version 5.9, Available from: <http://github.com/robjhyndman/forecast>
14. R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from: <http://www.R-project.org>
15. Krenzischek DA, Schaefer J, Nolan M, Bukowski J, Twilley M, Bernacki E, et al. Phase I Collaborative pilot study: Waste anesthetic gas levels in the PACU. *J Peri-anesth Nurs* 2002; 17: 227-39. [CrossRef]
16. National Institute for Occupational Safety and Health: NIOSH Pocket Guide to Chemical Hazards, DHHS (NIOSH) Publication No. 94-116, U.S. Government Printing Office, Washington, D.C., 1994.
17. ANSI/ASHRAE Standard 62.1 - 2013.



Supplementary Figure A. 1055 Sevoflurane measurements from July 7 - July 11 in ppm



Supplementary Figure B. 1055 Sevoflurane measurements from October 20 - October 24 in ppm