HHE Health Hazard® Evaluation Program

Evaluation of Waste Anesthetic Gas Exposure at a Veterinary Hospital

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Availability of Report

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Recommended Citation

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Table of Contents

Main Report

Supporting Technical Information

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Introduction

Request

In February 2022, employees at a veterinary hospital requested the National Institute for Occupational Safety and Health (NIOSH) to conduct a health hazard evaluation because they were concerned about waste anesthetic gas exposure (WAG) and possible health effects. The requestors wanted to better understand their exposure to WAGs and learn how to protect themselves. Halogenated anesthetic agents (vapors) including isoflurane and sevoflurane are used during anesthesia procedures in veterinary hospitals. Anesthesia gases and vapors that are released or leak into the surrounding environment during anesthesia procedures, including dental or surgical procedures, are called WAGs. Epidemiologic studies have shown that WAG exposure is associated with nausea, dizziness, headache, fatigue, irritability, drowsiness, and difficulties with judgement and coordination. Chronic WAG exposure has been linked to health effects including miscarriages, genetic damage, birth defects, cancer, and liver and kidney disease.

Workplace

The veterinary hospital was located in a commercial building and open from 7 a.m. to 6 p.m. Monday through Saturday. The veterinary hospital had a reception area, pharmacy area, four examination rooms, treatment area, isolation room, surgery suite, radiology area, and laundry and storage area. Anesthesia procedures were performed daily in the surgery suite or treatment area which had two dental tables. Patients (animals) recovered from anesthesia in kennels located in the treatment room.

In general, anesthesia procedures involved the following steps:

- Inducing anesthesia
- Maintaining anesthesia with sevoflurane, the only anesthetic gas used at this facility
- Conducting dental or surgical procedures
- Patient monitoring during anesthesia recovery

This veterinary hospital used an active scavenger system which reduces WAG exposure by actively pulling gases and vapors away from the anesthesia machine and exhausting them using a vacuum system during anesthesia procedures. A connector for the active scavenger system was located at each dental table in the treatment room and one near the surgery table in the surgery suite, for a total of three scavenger system connection points.

To learn more about the workplace, go to Section A in the Supporting Technical Information

Our Approach

During July 2022, we spent three days at the veterinary hospital. During the visit, our primary objectives were to assess:

- Work practices
- Indoor ventilation
- Operation and maintenance of WAG scavenger systems
- Employee exposure to WAG (i.e., sevoflurane)
- Area sevoflurane concentrations in the air throughout the veterinary hospital
- Employee health concerns related to WAG

To learn more about our methods, go to Section B in the Supporting Technical Information

Our Key Findings

Personal air-sampling indicated employees were exposed to sevoflurane concentrations below occupational exposure limits (OELs) for WAGs.

- Personal exposures to sevoflurane collected for 60 minutes were below the NIOSH recommended exposure limit (REL) for halogenated anesthetics of 2 parts per million (ppm) ranging from less than 0.03 ppm to 1.10 ppm. In 1977, NIOSH issued a REL that no employees should be exposed to any halogenated anesthetic agent at ceiling concentrations greater than 2 ppm over a sampling period not to exceed 1 hour. Sevoflurane is a halogenated anesthetic but was not included in the NIOSH criteria document for a recommended standard for exposure to waste anesthetic gases and vapors because sevoflurane came into use after the document was published.
- Full-shift personal exposures for sevoflurane ranged from 0.03 ppm to 0.25 ppm and were below the American Conference of Governmental Industrial Hygienists (ACGIH) full-shift occupational exposure limits of 50 ppm as well as more conservative, international full-shift OELs established in Norway (5 ppm), Finland (10 ppm) and Sweden (10 ppm). The U.S. Occupational Safety and Health Administration (OSHA) and NIOSH do not have full-shift OELs for sevoflurane. (For a similar halogenated anesthetic, isoflurane, which is also commonly used in veterinary hospitals, Cal/OSHA has a full-shift OEL of 2 ppm.). WAGs should be reduced to as low as reasonably achievable (ALARA) to protect employees.

Certain anesthesia procedure tasks can result in high peak exposures to WAG. If peak (high) exposures occur multiple times during a shift, employees could potentially be exposed to concentrations of sevoflurane above OELs.

- Using real-time area monitoring, we measured sevoflurane (i.e., WAG) exceeding 100 ppm while an employee anesthetized a small mammal using a veterinary anesthesia mask over the animal followed by an anesthesia chamber box made from a modified plastic container.
- Using a direct-reading instrument, sevoflurane concentrations measured near the employee's breathing zone area ranged from 0.33 ppm to more than 100 ppm during both anesthesia techniques.

High sevoflurane concentrations were exhaled by a patient during recovery from anesthesia.

- Using real-time area monitoring in the recovery area, we measured sevoflurane concentrations near the mouth of an animal ranging from 5.6 ppm to 27.9 ppm.

Employees reported different timing of endotracheal cuff inflation and when to turn on the sevoflurane vaporizer that can be a source of WAG exposure.

- During individual employee interviews, some employees who reported performing anesthesia procedures in the past three months reported inflating the endotracheal cuff before turning on the sevoflurane, whereas other employees reported inflating the cuff after sevoflurane was turned on or at the same time. The endotracheal cuff should be inflated *before* turning on the sevoflurane to reduce exposure to sevoflurane.
- When asked how often the scavenger system was turned on before an anesthesia procedure, some employees reported all the time while other employees reported most of the time or they did not know. The scavenger system should be turned on *before* any anesthesia procedures are started.
- All employees who reported performing anesthesia procedures stated the sevoflurane vaporizer was turned on at the beginning of the procedure after the patient was connected to the anesthesia machine. The employees also reported the sevoflurane vaporizer was turned off before the patient was disconnected from the anesthesia machine. The sevoflurane vaporizer should be turned on *after* the patient is attached to the breathing system *and* the endotracheal cuff is inflated. The sevoflurane vaporizer should be turned off *before* disconnecting the patient from the anesthesia machine.

To learn more about our results, go to Section B in the Supporting Technical Information

Our Recommendations

The Occupational Safety and Health Act requires employers to provide a safe workplace.

Benefits of Improving Workplace Health and Safety:

- Improved worker health and well-being
- Better workplace morale
- Easier employee recruiting and retention
- Enhanced image and reputation
- Superior products, processes, and services
- May increase overall cost savings

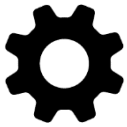
The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or practical, administrative measures and personal protective equipment might be needed. Read more about the hierarchy of controls here: https://www.cdc.gov/niosh/topics/hierarchy/.

We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in "*Recommended Practices for Safety and Health Programs*" at https://www.osha.gov/shpguidelines/index.html.

Recommendation 1: Continue to properly maintain and inspect anesthesia machines and WAG scavenger systems to minimize leaks and keep records.

Why? WAGs should be reduced to as low as reasonably achievable to protect employees. The anesthetic gas scavenger systems are the primary method to protect employees from exposure to anesthetic gases and vapors. The scavenging system traps waste gases and vapors and disposes of them to the outside atmosphere. Diligent maintenance of the anesthesia machines and scavenger system is essential to ensure proper functioning of the equipment. Each piece of equipment involved in delivering anesthesia to the patient (e.g., anesthesia machine, ventilator, vaporizer, and scavenger systems) should be evaluated for proper function based on the manufacturers' recommendations. Hospital management reported that a contractor performed anesthesia machine maintenance annually; however, the scavenger systems were not routinely inspected. If the pre-anesthesia scavenger check indicated a scavenger system was not functioning, management contacted the company who installed the scavenger system. No maintenance documents about the scavenger systems were available for review.

How? At your workplace, we recommend these specific actions:



Calibrate and follow the manufacturers' recommended maintenance schedule for the anesthesia machines and scavenger system, including leak detection tests of breathing circuits and scavenger systems. Real-time halogen leak detectors are available to detect WAGs.

Have a ventilation specialist measure the air flow of scavenger system at least annually.

Ensure the written preventive maintenance schedules include the following:

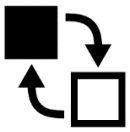
- all regularly scheduled maintenance tasks for anesthesia machines and scavenger systems, and
- who is responsible for conducting each task including leak tests on the scavenger system and breathing circuits.

Keep log/records of maintenance for anesthesia machines and scavenger system.

Recommendation 2: Discontinue use of anesthesia chamber box made from a modified plastic container.

Why? During real-time area monitoring, we measured sevoflurane exceeding 100 ppm while an employee anesthetized a small mammal using a veterinary anesthesia chamber box made from a modified plastic container. An induction chamber box designed for small mammal anesthesia with the use of the scavenger system will help reduce employee WAG exposure.

How? At your workplace, we recommend these specific actions:



Replace anesthesia chamber box made from a modified plastic container with commercial anesthesia induction box chamber.

Use existing scavenger system to remove WAG (i.e., sevoflurane) from the induction box before opening it.

Recommendation 3: Ensure the surgery suite and treatment room are properly ventilated.

Why? Properly functioning scavenger devices are the most effective ways to decrease WAGs. However, heating, ventilation, and air conditioning (HVAC) systems contribute to the dilution and help remove WAGs not collected by the scavenger system. There are no ventilation standards specifically to protect veterinary workers from WAGs in animal hospitals.

The American National Standards Institute (ANSI) and ASHRAE develop consensus standards and guidelines for HVAC systems. ANSI/ASHRAE Standard 62.1-2022, *Ventilation for Acceptable Indoor Air Quality*, has recommendations for animal facilities. *ASHRAE Standard 62.1-2022* recommends outdoor air supply rates that take into account people-related sources as well as building-related sources. For veterinary clinic examination rooms, 10 cubic feet per minute of outdoor air per person (cfm/person) is recommended for people-related sources, and an additional 0.12 cfm for every square foot (cfm/ft^2) of occupied space is recommended to account for building-related sources. For procedure rooms, operating rooms, postoperative recovery rooms, and small animal cage rooms, 10 cfm/person plus 0.18 cfm/ft^2 is recommended. ANSI/ASHRAE Standard 62.1-2022 only prescribes the amount of outdoor air ventilation to the space, and total ventilation (outdoor air plus recirculated air) will likely be higher. With that said, outdoor air is responsible for dilution of any WAGs released in the space. Particulate ventilation filters will not reduce WAG concentrations in the air recirculated through typical ventilation systems.

The 2007 NIOSH document, *Waste Anesthetic Gases – Occupational Hazards in Hospitals*, which was developed for human hospitals, recommends surgery rooms have at least 15 air changes per hour (ACH) with a minimum of 3 air changes of outdoor air per hour, and recovery areas have at least 6 ACH, with a minimum of 2 air changes of outdoor air per hour to prevent exposure to WAG. These ventilation recommendations are in different units than those in ANSI/ASHRAE Standard 62.1. Here, the units are air changes per hour or ACH. Many people find it easier to meet ventilation recommendations in ACH because they do not change with the number of people in the space. It is also noteworthy that the NIOSH recommendations include one for the total ventilation rate through the space as well (i.e., ACH for outdoor air and ACH for total air). Depending on the size of each space and the number of people involved with procedures performed in those spaces, the recommended amount of outdoor air might be higher using the ASHRAE standard. However, for most veterinary hospitals, using the recommendations in the NIOSH document will be protective.

How? At your workplace, we recommend these specific actions:

Consult with a ventilation engineer to ensure that the animal hospital ventilation system meets ANSI/ASHRAE Standard 62.1-2022, *Ventilation for Acceptable Indoor Air Quality*, OR the ventilation recommendations in the 2007 NIOSH document, *Waste Anesthetic Gases – Occupational Hazards in Hospitals*.

- With potential exceptions for very large spaces or spaces with many people in them (more than about 6 people), the ventilation recommendations in the NIOSH 2007 document, *Waste Anesthetic Gases – Occupational Hazards in Hospitals,* will generally be as protective as the requirements in the ANSI/ASHRAE Standard 62.1-2022, *Ventilation for Acceptable Indoor Air Quality*. The NIOSH 2007 ventilation recommendations are easier to meet all the time because they are in ACH, so they do not change with the number of people in the space. They also include a specific total ventilation target (i.e., ACH for outdoor air and ACH for total air). The ASHRAE standard only recommends cfm for outdoor air; there is no recommendation for total air exchanges. The NIOSH recommendation will ensure more total air flow through the space which equates to better air mixing helping with dilution.
- Care should be taken to meet the ventilation requirements most appropriate for your locality and building type.
- If possible, separate the recovery area from the treatment area and keep the recovery area under negative pressure so the that the air in the recovery area does not escape to other areas.

Recommendation 4: Ensure employees understand the hazards associated with working with sevoflurane and how to protect themselves from exposure to it.

Why? OSHA's Hazard Communication Standard, also known as the "Right to Know Law" (29 CFR 19.10.1200), requires that employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures. The veterinary hospital had internal anesthesia training for new employees that described patient safety, anesthesia equipment setup and care, and the physiology of anesthesia. Management ensured each employee who performed anesthesia procedures completed the anesthesia training. During employee interviews, a few employees reported they were not certain about when to inflate the endotracheal cuff. Inflating the endotracheal cuff before turning on the sevoflurane *decreases* the leaking of sevoflurane around the endotracheal tube and reduces exposure to WAGs. Peak (high) exposures to sevoflurane can occur during certain tasks, such as inflating the endotracheal tube *after* turning on the sevoflurane. Annual refreshers for employees are important to review the tasks on anesthesia checklist and to enforce safety work practices to reduce potential WAG exposure.

How? At your workplace, we recommend these specific actions:

Train employees on hire and at least annually on WAGs and what precautions they should take to protect themselves from sevoflurane, including peak exposures.

- Train employee on WAG (i.e., sevoflurane) and on potential ways they may be exposed to sevoflurane when it gets into the workplace air they breathe. Workers can be exposed in variety of ways, including:

- From leaks in the breathing circuit if the connectors, tubing, and valves are not maintained and properly connected.
- When turning on the flowmeters and vaporizer before attaching the breathing system to the patient.
- During disconnection of the system while the gas is still on.
- From around the edges of the patient's mask or around an endotracheal cuff if the cuff is not properly inflated or the wrong size is used.
- When the endotracheal tube is disconnected to reposition the patient during procedures.
- When not allowing adequate patient recovery on the anesthetic machine before detachment, extubation, and recovery.
- When using an anesthesia mask, especially if the mask is a poor fit.
- When patients are exhaling sevoflurane during recovery from anesthesia.
- When opening an induction box.
- When refilling the vaporizer.
- When cleaning spills of sevoflurane.

- Train employees on best practices, such as the following:
  - Inspect all anesthesia delivery components (reservoir bag, tubing, and connectors) and scavenger system before each use for obstructions, kinks, or cracks.
  - Perform a leak test prior to each use of the anesthesia machine and scavenger system.
  - Use properly sized and inflated endotracheal cuffs to create a sealed airway.
  - Turn off anesthetic gas flow before disconnecting a patient during a procedure (e.g., repositioning patient).
  - Reduce residual sevoflurane by flushing systems with oxygen, including breathing bag, before disconnecting a patient from the breathing system.
  - Minimize use of face masks and induction boxes.
  - Avoid being near a patient's head or mouth during recovery.

- Continue to train employees on how to properly refill the sevoflurane vaporizer to prevent spillovers of sevoflurane and when to turn on the vaporizer (*after* the patient is attached to the breathing system *and* the endotracheal cuff is inflated).

- Continue to educate employees at hire and at least annually about the signs and symptoms of WAG exposure and potential health effects, including reproductive effects, of WAGs (i.e., exposure to sevoflurane).

- Encourage employees to report health issues that they believe may be related to WAG (i.e., sevoflurane) to their healthcare providers and a designated person at their worksite.

- For additional information on control of WAGs, please see the following:
  - Waste anesthetic gases: occupational hazards in hospitals – NIOSH https://www.cdc.gov/niosh/docs/2007-151/
  - Anesthetic gases: guidelines for workplace exposures - OSHA https://www.osha.gov/dts/osta/anestheticgases/index.html
  - Commentary and recommendations from American College of Veterinary Anesthesia and Analgesia on control of waste anesthetic gases in the workplace https://acvaa.org/wp-content/uploads/2019/05/Control-of-Waste-Anesthetic-Gas-Recommendations.pdf
  - Isoflurane May Harm Veterinary Worker Health - California Department of Public Health https://www.cdph.ca.gov/Programs/CCDPHP/DEODC/OHB/HESIS/CDPH%20Document%20Library/IsofluraneGas.pdf

Recommendation 5: Encourage employees that are planning on becoming pregnant or are currently pregnant to share the sevoflurane safety data sheet (SDS) and this report with their healthcare providers.

Why? The hazard statement on the sevoflurane SDS noted sevoflurane is "Suspected of damaging fertility or the unborn child." Some studies have found that anesthetic gases are associated with miscarriages, but those studies occurred before scavenger systems were in use. Scientists do not know how much anesthetic gas exposure is needed to increase the risk of miscarriage. What causes most miscarriages is not known. Miscarriages are common, and many factors have been linked to miscarriages, including maternal age, paternal age, body-mass index, smoking, alcohol use, pesticide exposure, and health conditions. None of the interviewed employees at the veterinary hospital reported a miscarriage that occurred while working at the veterinary hospital.

For declared pregnancies at this veterinary hospital, the facility reported that pregnant employees' work was modified to include weight restrictions on lifting, avoiding radiographs, and wearing a respirator during anesthesia procedures or not performing anesthesia procedures. Please note any actions taken by the employer should not violate laws prohibiting discrimination on the basis of pregnancy, childbirth, or related medical conditions. For more information, please see the U.S. Equal Employment Opportunity Commission's Pregnancy Discrimination website at https://www.eeoc.gov/pregnancy-discrimination..

How? At your workplace, we recommend these specific actions:

Pregnant employees may consider talking to their employers to avoid possible exposures to WAG (i.e., sevoflurane) during pregnancy, such as during anesthesia procedures and in the recovery room.

If working with anesthetic gases cannot be avoided during pregnancy, respirators with organic vapor cartridges can be worn to reduce the amount of WAG that workers breathe in. Charcoal masks or surgical masks will not protect the wearer from WAG. Respirators should not be prioritized over the previously mentioned exposure control recommendations.

- Employees should talk to their healthcare providers if they think they need a respirator.
- To be effective, respirators much be fit tested and used correctly.
- Respirators should be used in conjunction with an OSHA-compliant Respiratory Protection Program (29 CFR 1910.134) that includes medical evaluation, training, and fit testing. Some states may have applicable Federal OSHA-approved State plans. Information on Federal OSHA-approved State plans can be found at https://www.osha.gov/stateplans.

Additional information on anesthetic gases and reproductive health can be found the following NIOSH websites:

- Reproductive Health and the Workplace
  https://www.cdc.gov/niosh/topics/repro/default.html
- Anesthetic Gases – Reproductive Health
  https://www.cdc.gov/niosh/topics/repro/anestheticgases.html
- Personal Protective Equipment – Reproductive Health
  https://www.cdc.gov/niosh/topics/repro/ppe.html

Recommendation 6: Provide appropriate personal protective equipment (PPE) for employees to use when filling the sevoflurane vaporizer and continue to use the sevoflurane anti-spill pour spout to prevent spillage of sevoflurane when filling the vaporizer.

Why? The exposure controls noted in the sevoflurane safety data sheet (SDS) included: 1) ensure adequate ventilation, 2) wear safety glasses with side shields, 3) wear chemical resistant gloves and appropriate protective clothing (e.g., lab coats, disposable coveralls). The SDS recommended respirators with organic vapor cartridge if engineering controls did not maintain air concentrations below recommended exposure limits (where applicable) or to an acceptable level (in countries where exposure limits have not been established).

How? At your workplace, we recommend these specific actions:

Provide PPE including safety glasses with side shields, chemical resistant gloves, and appropriate protective clothing (e.g., lab coat).

- Some chemicals can pass through gloves or other PPE quickly. Companies that sell gloves and other PPE have chemical resistance guides that show how long a specific glove type or fabric will hold up to specific chemicals. Work with a company that sells PPE to find the right gloves and other PPE. Examples of glove selection guides from companies can be found at https://www.cdc.gov/niosh/topics/repro/ppe.html.
- Ensure PPE is stored properly and available in different sizes.
- Ensure staff are trained to properly use the PPE.

Supporting Technical Information

Evaluation of Waste Anesthetic Gas Exposure at a Veterinary Hospital

HHE Report No. 2022-0032-3399

May 2024

Section A: Workplace Information

Building

- The veterinary hospital was located within a commercial retail building.
- Veterinary hospital and other commercial retail space share heating, ventilation, and air conditioning (HVAC) system.

Veterinary hospital areas (Figure 1):

- Treatment area: large area for performing variety of veterinary tasks, including dental and non-surgical anesthesia procedures, patient (animal) recovery from anesthesia, surgery anesthesia induction and surgical site preparation (clip and scrub surgical site), kennels for hospitalized patients, laboratory area for in-house clinical laboratory tests, and veterinarian medical record charting area. There was an active scavenger system near each dental table for a total of two active scavenger system connection points in the treatment area.
- Surgery suite: small room off the treatment area containing one surgery table with an active scavenger system connection point near the surgery table.
- Isolation room: small room with its own ventilation system off the treatment area with kennels for isolating patients suspected of having contagious infections.
- Reception area: large area outside the general examination rooms containing receptionist's desk, balance to collect patient weights, and sitting area for clients waiting to see the veterinary staff.
- Pharmacy area: small room behind the reception area for storing medications and filling prescriptions.
- General examination rooms: four small rooms off the reception area for patient evaluation and client communication.
- Reception area, pharmacy area, and examination rooms did not share space with veterinary hospital areas that performed anesthesia procedures.

Employee Information

- Total employees: 25
- Number of employees working during evaluation: 15
- Length of shift: 6 hours–12 hours
- Mean age of employees: 26 years (range: 19 years–65 years)
- Mean tenure: 1.2 years (range: 0.1 year–9 years)
- Sex: 92% female

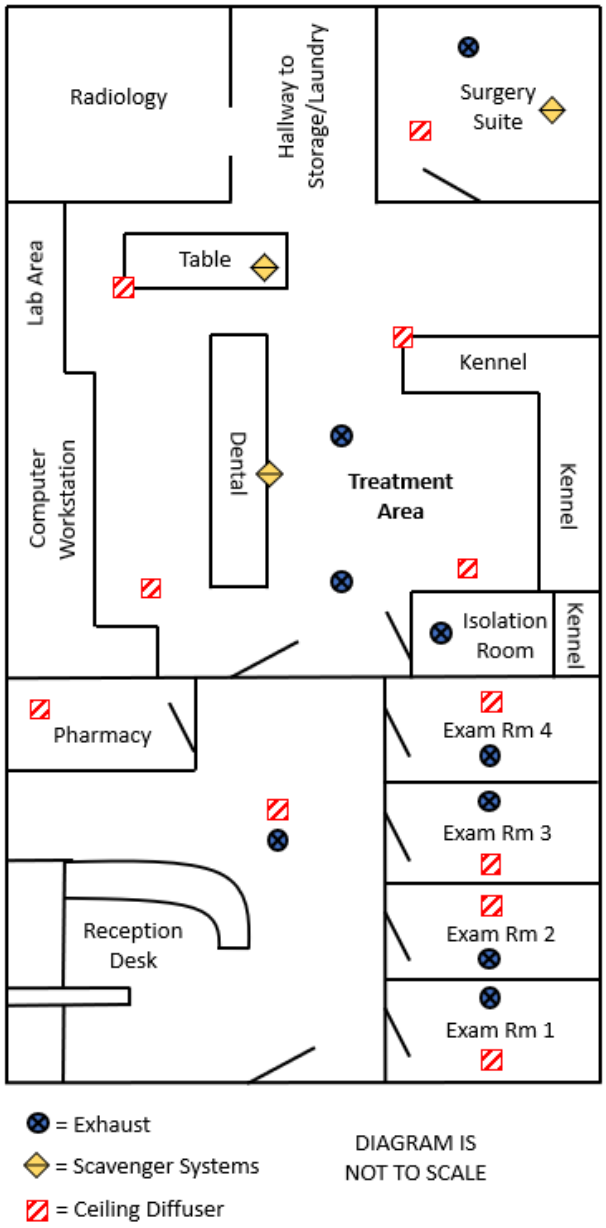


Figure 1. Diagram of the veterinary hospital.

History of Issue at Workplace

In February 2022, employees of a veterinary hospital requested a health hazard evaluation because they were concerned about waste anesthetic gas (WAG) exposure and potential health effects. The requestors wanted to better understand their exposure to WAG and learn how to protect themselves.

Process Description

Anesthesia Machine Preparation

The veterinary hospital used an active scavenger system to remove WAG from the anesthesia machine and exhaust the WAG using a vacuum system. When veterinary staff who perform anesthesia arrived at

the veterinary hospital, they began setting up for the anesthesia procedures scheduled that day. Employees were instructed to follow the hospital's anesthesia machine checklist for each animal patient undergoing anesthesia, including the following:

1) Checking to ensure routine maintenance had been performed on the anesthesia machine, and the date of the maintenance was recorded.
2) Recording the oxygen volume and verifying available back-up oxygen and the oxygen flowmeter was working.
3) Verifying the vaporizer was full and the port was tightly closed.
4) Verifying the carbon dioxide absorbent was fresh, and the replacement date was recorded.
5) Verifying the scavenger system was on and functioning.
6) Confirming all the anesthesia machine tubing was connected correctly and the correct size rebreathing bag was attached.
7) Performing an anesthetic machine leak test.

Once the employee completed the checklist, it became part of the patient's anesthesia record.

Induction and Anesthesia Maintenance

After premedicating the patient, two employees placed an intravenous catheter and administered propofol to induce anesthesia. For surgical procedures, the patient was clipped and scrubbed for the surgical procedure in the treatment area and then moved into the surgery suite. Once in the surgery suite, the patient was intubated with an endotracheal tube and provided oxygen through the anesthesia machine. The employee then checked the endotracheal tube placement, inflated the endotracheal tube cuff, and initiated sevoflurane for anesthetic maintenance. After sevoflurane was introduced, one employee monitored the patient's vital signs and level of anesthesia while the other finalized preparation of the surgical site.

Induction and maintenance of anesthesia for dental procedures were very similar to the surgical anesthesia process. However, during dental procedures, the veterinary assistant performed the dental prophylaxis under the supervision of the veterinarian and monitored the patient's vital signs and level of sevoflurane. If surgical tooth extractions were needed, they were performed by the veterinarian.

Post Anesthesia and Recovery

After the surgical or dental procedure was completed, the employee who monitored the patient under anesthesia turned off the sevoflurane but kept the patient connected to the anesthesia machine on oxygen. The employee then deflated the endotracheal tube cuff and prepared the patient for extubation. If the patient's swallowing reflex returned quickly, the endotracheal tube was removed on the surgery or dental table and then the patient was transported to a recovery area kennel. Patients requiring more time for the swallow reflex to return were transported to a recovery kennel and extubated in the kennel. Once in a recovery kennel, patients were placed on heating pads, and patient's vitals were monitored regularly until the patient was sitting in a sternal position and fully recovered from anesthesia. Monitoring vitals in a recovery kennel sometimes required the veterinary employee to be in close contact with the patient in the kennel.

Section B: Methods, Results, and Discussion

The objectives of our evaluation were to:

- Determine if the scavenger system and hospital ventilation system were effectively removing WAG.
- Assess employee exposures to sevoflurane WAG.
- Determine if there were any acute or chronic work-related health symptoms among employees.

Methods: Workplace Observations

We observed work practices during anesthesia preparation, induction, maintenance, and recovery.

Results: Workplace Observations

Observations

We observed six routine dental procedures during our first day onsite. On the second day, we observed four routine dental procedures and eight surgical procedures which included five ovariohysterectomies (i.e., spays) and three orchiectomies (i.e., neuters). Surgical procedures ranged from 10 minutes to 40 minutes in length. Dental procedures ranged from 15 minutes to 35 minutes.

During surgical procedures, we observed the veterinarians wearing surgical caps, sterile gowns, surgical masks, and sterile gloves. We observed the veterinary technicians and veterinary assistants, monitoring the patient under anesthesia during the surgical procedures, wearing surgical caps and surgical masks. During dental procedures, veterinary technicians and veterinary assistants wore masks, gloves, and eye protection.

We observed employees setting up for anesthesia procedures, including filling the sevoflurane vaporizer, checking the scavenger system, and completing the anesthesia machine checklist. When filling the sevoflurane vaporizer, employees used a sevoflurane anti-spill pour spout to prevent spillage. Once the patient was induced with propofol and the endotracheal tube placed, we observed the employees turning on the oxygen supply and inflating the endotracheal cuff before turning on the sevoflurane. At the end of anesthesia procedures, we observed employees turning off the sevoflurane before disconnecting the patients, deflating the endotracheal tube cuff, extubating the patients, and moving the patients to their recovery kennel in the treatment room.

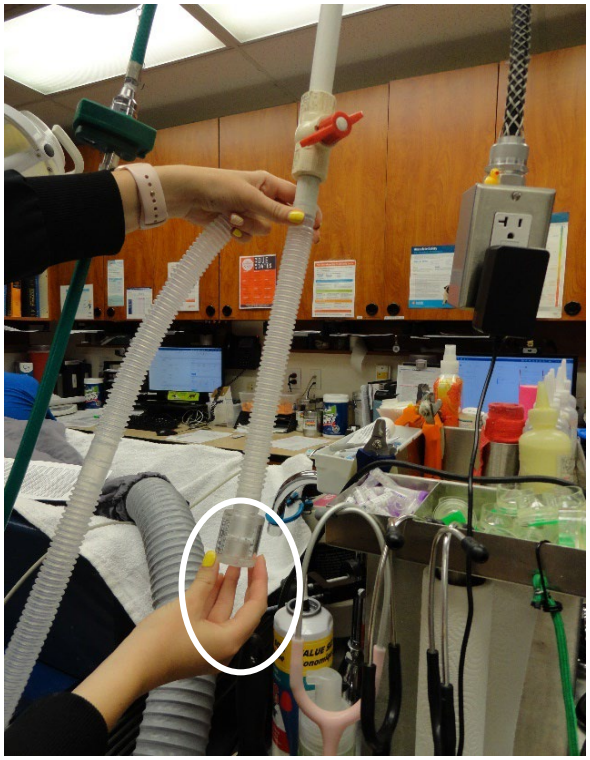
We observed the anesthesia of a small mammal using a veterinary anesthesia mask over the mammal followed by a general plastic food storage container that had been converted into an anesthesia chamber box. An employee's head was near the anesthesia mask and the anesthesia chamber box to monitor the small mammal during the procedure.

Scavenger System

An active scavenger system was used to pull waste anesthetic gas away from the anesthesia machine and exhaust WAG using a vacuum system. The anesthesia machines were connected to the scavenger

system in the surgery suite and the treatment area. Before each anesthesia procedure, veterinary technicians checked to make sure the system was turned on and the vacuum was functioning.

We observed an employee checking the scavenger system while preparing the anesthesia machine. To check the scavenger system, the employee attached a tube with a thin strip of flutter paper inside at the end of the tube to test the suction function of the scavenger system (Figure 2a and 2b). The employee reported that the scavenger system function was evaluated daily before anesthesia procedures are performed.



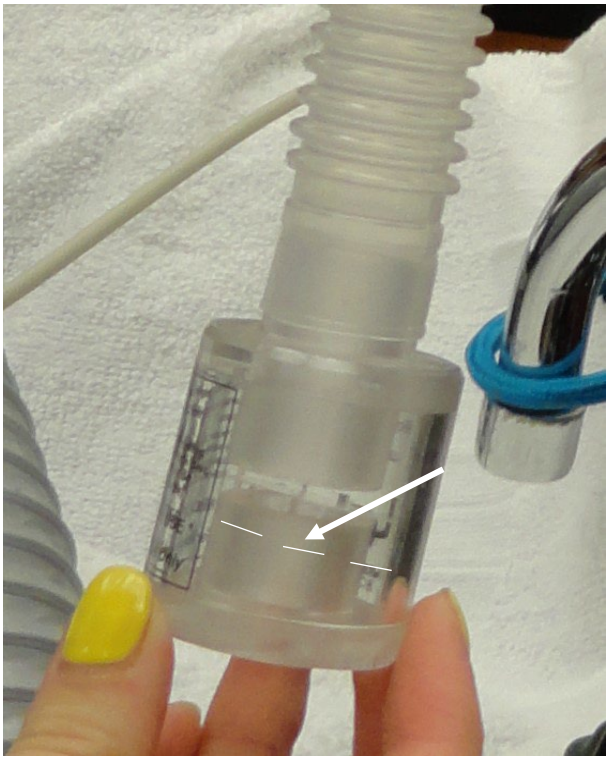


Figure 2a) Veterinary assistant checking function of scavenger system for an anesthesia machine before anesthesia procedure by attaching a tube with a thin strip of flutter paper inside area within the white circle. 2b) Closeup of circled area in Figure 2a) showing the flutter paper elevated from the suction in the scavenger system (see arrow and dashed line). Photos by NIOSH.

Methods: Document Review

We reviewed the following documents:

- Anesthesia training material
- Anesthesia machine checklist
- Previous air sampling report from an independent laboratory
- Sevoflurane safety data sheet (SDS)

In addition, we had informal discussions with hospital management about the anesthesia machine maintenance.

Results: Document Review

Internal Anesthesia Training

The veterinary hospital had internal anesthesia training for new employees that described patient safety, anesthesia equipment setup and care, and the physiology of anesthesia. Management ensured each employee who performed anesthesia procedures completed the anesthesia training.

Anesthesia Checklist

The anesthesia machine checklist provided a list of steps each employee must complete before starting an anesthesia procedure. The employee performing anesthesia completed the anesthesia checklist, and the checklist became part of the patient's medical record.

Air Sampling Report

We reviewed the Lab Report prepared by Assay Technology, Inc. dated May 19, 2022. Four full-shift air samples for sevoflurane, two personal and two area, were collected on May 12, 2022, using Assay Technology 574A passive monitors (reporting limit of 0.0001 parts per million [ppm] for an 8-hour period). Area samples were collected from the treatment area and surgery suite. The reported concentrations were 0.54 ppm and 0.20 ppm for the personal samples and 0.20 ppm for both area samples. Since the sample duration for each of the four full-shift personal air samples was 480 minutes, the sample results were not directly comparable to the NIOSH ceiling limit for halogenated anesthetics agents of 2 ppm over a sampling period not to exceed 60 minutes [NIOSH 1977]. All air sampling measurements reported in the air sampling report were considerably lower than the ACGIH TLV-TWA for sevoflurane of 50 ppm and full-shift occupational exposure limits (OELs) for sevoflurane in other countries (e.g., 10 ppm in Finland and Sweden and 5 ppm in Norway).

Sevoflurane SDS

The SDSs for all chemicals used in the hospital, including sevoflurane, were accessible for all employees on the hospital computers. The hazard statement on the sevoflurane SDS (CAS number 28523-86-6) was the following: "Causes skin irritation. Causes serious eye irritation. May cause drowsiness or dizziness. Suspected of damaging fertility or the unborn child. Harmful to aquatic life with long lasting effects." [Zoetis 2016]. Exposure controls noted on the SDS during handling of sevoflurane included: 1) ensure adequate ventilation, 2) wear safety glasses with side shields, 3) wear chemical resistant gloves and appropriate protective clothing (e.g., lab coats, disposable coveralls); respirators with organic vapor cartridge are recommended if engineering controls do not maintain air concentrations below recommended expose limits (where applicable) or to an acceptable level (in countries where exposure limits have not been established) [Zoetis 2016].

Anesthesia Machine Maintenance Report

Hospital management reported that a contractor performed anesthesia machine maintenance annually. The valves and vaporizers were checked, and no system leaks were detected. Hospital management reported that the scavenger system was not routinely inspected. If the pre-anesthesia scavenger check indicated the scavenger system was not functioning properly, management contacted the company who

installed the scavenger system. Since the hospital opened, they have not had any failed scavenger system checks. No maintenance documents about the scavenger system were available for review.

Methods: Exposure Assessment

We collected an exposure assessment survey consisting of the following:

(1) personal 60-minute air sampling for sevoflurane,

(2) personal full-shift air sampling for sevoflurane,

(3) area full-shift air sampling for sevoflurane,

(4) real-time monitoring for sevoflurane, and

(5) evaluating the performance of the ventilation system.

Personal 60-minute air sampling for sevoflurane

We collected 82 personal 60-minute air samples from employees' breathing zones to measure sevoflurane exposure using sorbent tubes. For sorbent tubes, Anasorb 747 tubes (Part No. 226-81A, SKC, Inc.) were attached to personal air sampling pumps (SKC Pocket Pump) flowing at 50 milliliters per minute (mL/min). Participating employees' job titles included veterinary technician, veterinary assistant, veterinarian, and practice manager. We collected five to six samples per shift for each participating employee.

Sorbent tube samples were analyzed for sevoflurane in accordance with the Occupational Safety and Health Administration (OSHA) method 103 [OSHA 1994]. A limit of detection (LOD) is the lowest mass that can be measured by an analytical method. The LOD for sevoflurane was 0.9 micrograms (µg) for a sample duration of 60 minutes, corresponding to 0.03 parts per million (ppm). The limit of quantitation (LOQ) is the lowest analyte mass that can be reliably detected along with predefined bias and imprecision. The LOQ for sevoflurane was 3.0 µg for a sample duration of 60 minutes, corresponding to 0.12 ppm.

We summarized sevoflurane air concentrations by job title and sampling day. Currently, OSHA has no OELs regulating sevoflurane. In 1977, NIOSH published a criteria document setting a recommended exposure limit (REL) that no employee should be exposed to greater than 2 ppm of any halogenated anesthetic agent over a sampling period not to exceed one hour [NIOSH 1977]. All individual exposure data were compared with the NIOSH REL for halogenated anesthetics of 2 ppm. Sevoflurane is a halogenated anesthetic but was not included in the NIOSH criteria for a recommended standard for exposure to waste anesthetic gases and vapors because sevoflurane came into use in after the document was published.

Personal full-shift air sampling for sevoflurane

We collected 19 personal full-shift air samples for sevoflurane using passive monitors. For passive monitors, we used Assay Technology 574 monitors (Part No. 574AT, Assay Technology, Inc.). The

sampling was open to all employees who participated in the personal 60-minute air sampling and administrative staff who were interested.

The collected passive monitors were analyzed for sevoflurane in accordance with modified OSHA method 103 [OSHA 1994]. The LOD for sevoflurane was 0.8 µg for a full-shift, corresponding to 0.02 ppm. The LOQ for sevoflurane was 2.7 µg per sample, corresponding to 0.07 ppm for a full-shift.

We reported individual sevoflurane air concentrations by job title and sampling day. OSHA and NIOSH do not have full-shift time-weighted average (TWA) OELs for sevoflurane. (For a similar halogenated anesthetic, isoflurane, which is also commonly used in veterinary hospitals, Cal/OSHA has a full-shift OEL of 2 ppm [CDPH 2019; DIR, no date]). The American Conference of Governmental Industrial Hygienists (ACGIH®) has a TWA threshold limit value (TLV®) for sevoflurane of 50 ppm over an 8-hour workday [ACGIH 2024]. The individual exposure data results were compared to the ACGIH TWA-TLV for sevoflurane (50 ppm) and full-shift OELs for sevoflurane in Finland (10 ppm), Sweden (10 ppm), and Norway (5 ppm). WAGs should be reduced to as low as reasonably achievable (ALARA) to protect employees. For information on OELs, see Section D.

Area full-shift air sampling for sevoflurane

We collected 13 area full-shift air samples for sevoflurane using Assay Technology 574 passive monitors. We collected air samples in the pharmacy, kennels/recovery area, dental cleaning tables, surgical suite, and medical charting area. The collected samples were analyzed for sevoflurane in accordance with modified OSHA method 103 [OSHA 1994].

We reported individual sevoflurane air concentrations by location and day. The estimated concentrations were compared with the ACGIH TLV-TWA (50 ppm) for sevoflurane and full-shift OELs for sevoflurane in Finland (10 ppm), Sweden (10 ppm) and Norway (5ppm) [ACGIH 2024; IFA 2024].

Real-time monitoring for sevoflurane

We collected real-time measurements of sevoflurane concentrations in the air using a GasmetTM DX4040 XL portable Fourier Transform Infrared Spectroscopy (FTIR, Gasmat Technologies Inc.) ambient analyzer calibrated to measure sevoflurane (limit of detection 3 parts per billion [ppb] based on a 60-second measurement time, high range limit 100 ppm). Sevoflurane air concentration measurements were done in kennels/recovery area, surgical suite, and dental cleaning tables before, during, and after dental procedures. In addition, we measured sevoflurane concentrations near the employee's head while the employee was holding a veterinary anesthesia mask on a patient followed by placing the patient in an anesthesia chamber box where a small mammal was anesthetized.

Ventilation system performance

During our site visit, no patients were kenneled in the isolation room, and the door was open to the treatment area. The surgery suite was always open to the treatment area even during surgeries. Thus, we measured the pressurization only between the treatment area and the hallway outside the treatment area

using a DG-8 digital pressure gauge (TEC Inc.). In addition, we had informal discussions with hospital management regarding the maintenance of ventilation.

Results: Exposure Assessment

Sevoflurane Exposures

Personal 60-minute air sampling for sevoflurane

Personal air sampling results for sevoflurane are shown in Table C4. On Day 1, only dental procedures were performed, while dental procedures and other surgeries including ovariohysterectomies and orchiectomies were conducted on Day 2. For the veterinarians, 60-minute concentrations ranged from 0.07 ppm to 0.13 ppm on Day 1 and less than 0.03 ppm to 0.61 ppm on Day 2. On Day 2, three veterinarians, one each for dental procedures, other surgeries, and patient examinations, worked in the hospital. Among these veterinarians, the veterinarian who examined patients near the dental tables and recovery kennels in the treatment area showed slightly higher exposure concentrations (median = 0.29 ppm) than two other veterinarians who performed dental and other surgery procedures (median = 0.20 and 0.22 ppm).

Veterinary assistants' exposures to sevoflurane were 0.06 ppm to 0.53 ppm on Day 1 and <0.03 to 1.10 ppm on Day 2. Veterinary technicians had measured 60-minute concentrations ranging from 0.07 ppm to 0.15 ppm on Day 1 and <0.03 ppm to 0.07 ppm on Day 2. Among these, a higher median concentration was observed from a veterinary assistant who assisted other surgeries (0.47 ppm) compared to those who performed dental procedures (0.16 ppm on Day 1 and 0.12 ppm on Day 2). This can be explained by performing more other surgeries (number of surgeries = 8) than dental procedures (number of procedures = 6 on Day 1 and 4 on Day 2). The practice manager's exposures ranged from 0.09 ppm to 0.20 ppm (median = 0.15 ppm) on Day 1 and 0.03 to 0.04 ppm (median = 0.13 ppm) on Day 2.

Overall, personal exposures measured Day 2 were higher than Day 1 for veterinarians and a few veterinarian assistants/technicians who spent most of the time in the treatment area or surgery suite. Nevertheless, all personal exposures measured on both days were lower than the NIOSH ceiling limit of 2 ppm. Among the air concentrations reported in Table C4, some job titles and tasks showed concentrations less than LOD (e.g., 40% for veterinarian technicians performing miscellaneous tasks).

Personal full-shift air sampling for sevoflurane

Personal air sampling results using passive monitors are shown in Table C5. On Day 1, the full-shift concentrations ranged from 0.03 ppm to 0.14 ppm. Among employees who participated in the air sampling, two veterinary assistants who performed dental procedures showed higher concentrations than other employees.

On Day 2, the full-shift concentrations ranged from 0.05 ppm to 0.25 ppm. The employees who spent majority of their time either in the treatment area or in the surgery suite showed concentrations greater

than 0.12 ppm. The employees who spent the majority of their shift in the examination rooms and reception area showed concentrations between 0.05 ppm and 0.07 ppm.

All measured personal full-shift concentrations were considerably lower than the ACGIH TLV-TWA (50 ppm) for sevoflurane as well as more conservative, international OELs established in Finland (10 ppm), Sweden (10 ppm), and Norway (5 ppm).

Area full-shift air sampling for sevoflurane

Full-shift passive area air samples for sevoflurane collected throughout the veterinary hospital are shown in Table C6. The concentrations ranged from 0.04 ppm to 0.12 ppm on Day 1 and 0.07 ppm to 0.17 ppm on Day 2. The pharmacy area located outside the treatment area and surgery suite measured 0.04 ppm on Day 1 and 0.07 ppm on Day 2. The concentration in the surgery suite on Day 1 was 0.05 ppm.

All measured area full-shift concentrations were considerably lower than the ACGIH TLV-TWA (50 ppm and OELs from Finland (10 ppm), Sweden (10 ppm), and Norway (5ppm). Because area air samples are not collected directly on employees (known as personal air samples), exposure limits are not directly applicable to area air sampling results for exposure monitoring purposes. However, area air samples can highlight areas with higher or lower exposure risk, and the OELs can be used as points of reference.

Real-time area monitoring for sevoflurane

We performed real-time area monitoring of sevoflurane using a portable FTIR (Gasmet Technologies Inc.) in the kennels/recovery area, surgery suite, and dental procedure tables before, during, and after surgeries. The sevoflurane concentrations measured near the mouth of patients during anesthesia recovery in the kennel area were notably higher than those measured above or near the patients' mouth during dental procedures and other surgeries. Figure 3 is an example plot of air concentrations measured near the mouth of a patient in the recovery area (range = 5.6 ppm to 27.9 ppm). Figure 4 represents air concentrations measured near a patient's mouth during an ovarian hysterectomy procedure in the surgery suite (range = 0.24 ppm to 1.18 ppm).

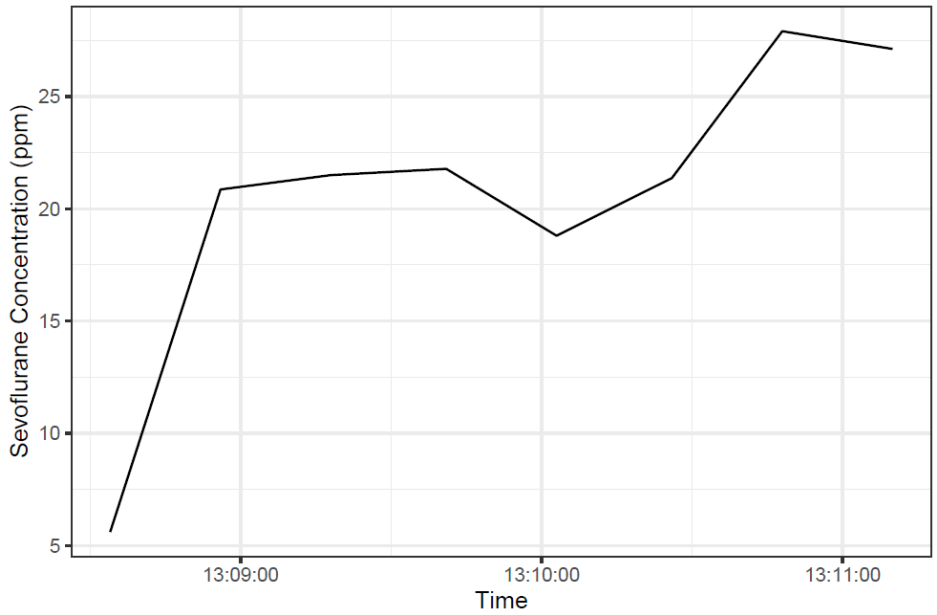


Figure 3. Sevoflurane real-time area air concentrations measured near a patient's mouth in the recovery area (Day 2).

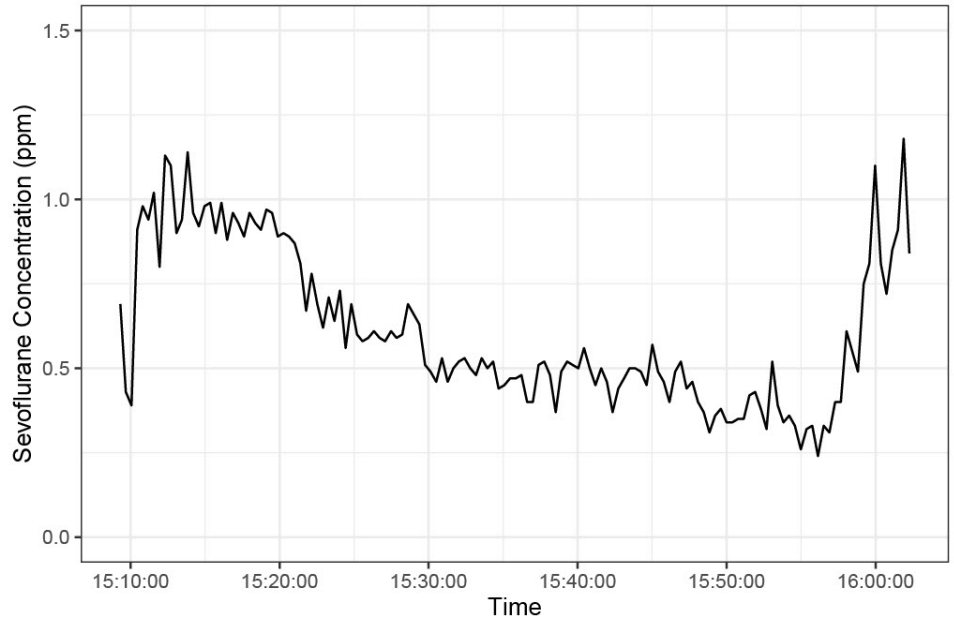


Figure 4. Sevoflurane real-time area air concentrations measured near a patient's mouth during an ovarian hysterectomy procedure (i.e., spaying) with endotracheal tube inflated and connected to anesthesia machine in the surgery suite (Day 2).

On Day 2, sevoflurane real-time air area concentrations were measured during the process of anesthetizing a small mammal that was too small to use an endotracheal tube. The anesthesia procedure was completed using two methods: a veterinary anesthesia mask and an anesthesia chamber box. During both anesthesia methods, the veterinary assistant's head was near the mask or the container to check the status of the mammal. When using the veterinary anesthesia mask over the mammal,

sevoflurane concentrations measured near the assistant's head were considerably higher (0.33 ppm to greater than 100 ppm; Figure 5) than concentrations measured during surgeries (range = 0.24 ppm to 1.18 ppm; Figure 4) and recovery (range = 5.6 ppm to 27.9 ppm; Figure 3). For the anesthesia chamber box, sevoflurane air concentrations were also considerably higher (0.33 ppm to greater than 100 ppm) but only rose above 100 ppm when the veterinary assistant removed the lid (Figure 6). As noted earlier, because area air samples are not collected directly on employees (known as personal air samples), exposure limits are not directly applicable to area air sampling results for exposure monitoring purposes. However, area air samples can highlight areas with higher exposure risk, and the OELs can be used as points of reference.

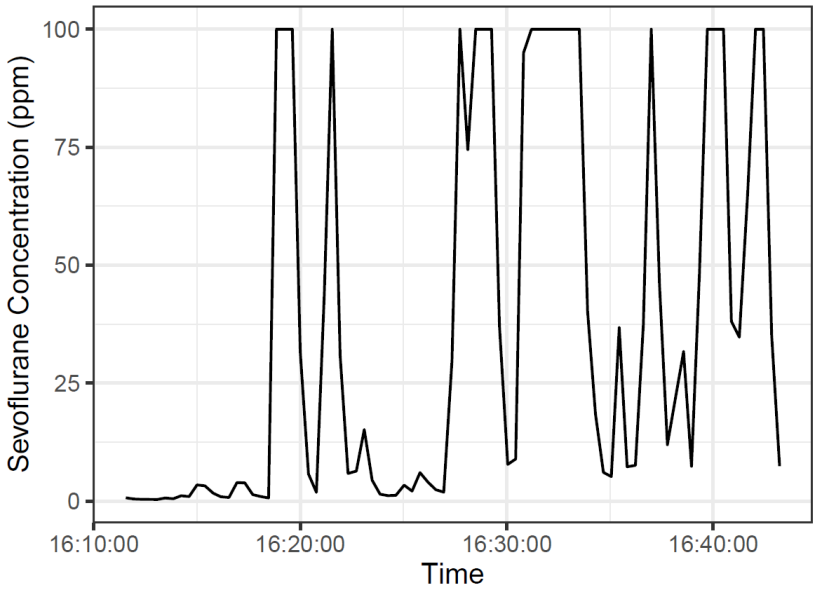


Figure 5. Sevoflurane real-time area air concentrations measured during the process of anesthetizing a small mammal using a veterinary anesthesia mask. No endotracheal tube was used during the anesthesia procedure. Note that concentrations greater than 100 ppm were not reported because of the instrument reaching its upper limit for sevoflurane.

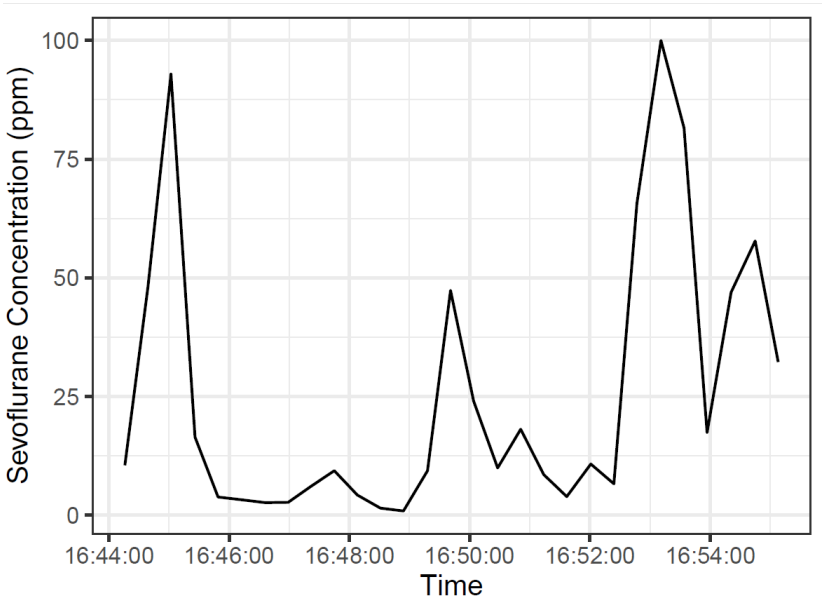


Figure 6. Sevoflurane real-time air area concentrations measured during the process of anesthetizing a small mammal using an anesthesia chamber box. No endotracheal tube was used during the anesthesia procedure. Note that concentrations greater than 100 ppm were not reported because of the instrument reaching its upper limit for sevoflurane.

Ventilation system performance

The treatment area was under positive pressure compared to the hallway outside the treatment area (Pressure = 2.1 Pa), meaning that air would flow from the treatment area into the hallway. Because this hospital is part of a commercial building, the building ventilation was managed by a third party, and we were not able to obtain a ventilation maintenance report.

Methods: Employee Interviews on Work and Health

We used an interviewer-administered questionnaire to collect information on work and health. The questionnaire included questions about demographic information, work history in the veterinary profession, anesthesia tasks, personal protective equipment (PPE) use, and health, including symptoms at work and reproductive health history. We asked employees if they worked in the treatment room or surgery suite or performed anesthesia job tasks for surgical and dental procedures. We summarized descriptive statistics for demographic, work, and health information. We asked about acute health symptoms, obstetric history, and infertility history that has been associated with WAG exposure in the literature [Johnson et al. 1987; Boivin 1997; Shirangi and Fritschi 2005; Shirangi et al. 2008]. For acute health symptoms, we defined a work-related symptom as a symptom experienced at work that improved when away from work on vacations or weekends. We grouped employees by reporting if they assisted with or performed anesthesia procedures in the previous three months compared to employees who have not assisted with or performed anesthesia procedures in the previous three months.

Results: Employee Interviews on Work and Health

Confidential interviews using interviewer-administer questionnaire

We conducted confidential interviews with 13 of 15 available employees working during the site visit. The 13 interviewed employees reported working for a median of 37 hours per week (range: 16–45 hours per week). Interviewed employees had a median tenure working at this veterinary hospital of 1.2 years (Range 0.1–9 years). Job titles included veterinarian (n=2), certified veterinary technician (n=3), veterinary assistant (n=5), receptionist (n=2), and practice manager (n=1) (Table C1). In the past three months, eight (62%) employees reported working for three hours or more per week in the treatment area during anesthesia procedures.

Surgery suite

Nine (69%) employees interviewed reported ever working in the surgery suite at this veterinary hospital with a median duration time of 2.5 years (range 1 year–9 years) in the surgery suite. Eight (88%) of the nine employees reported working in the surgery suite in the past three months with a median time of six hours per week (range: 2–18 hours per week). Six (75%) of the eight employees reported their role in the surgery suite was monitoring anesthesia, and the other two employees reported their role as surgeon. For employees who reported working in the surgery suite in the past three months, we asked about specific tasks (Table C2). Notably, there was some variation in timing of endotracheal cuff inflation which can be a source for WAG exposure. Six of the eight employees reported inflating the endotracheal cuff before the sevoflurane was turned on, one employee reported inflating the endotracheal cuff after the sevoflurane was turned on, and one employee reported inflating the endotracheal cuff at the same time the sevoflurane was turned on.

Dental procedures

Nine (69%) employees interviewed reported working on dental procedures at this veterinary hospital with a median time of 2.5 years (range 1–9 years). Eight of the nine employees reported working on dental procedures in the past three months with a median time of 11.5 hours per week (range 7–30 hours per week). Six (75%) of the eight reported performing both dental prophylaxis which included scaling and polishing teeth and anesthesia duties in the past three months. For employees who reported performing dental procedures in the past three months, we asked about specific tasks (Table C3). Again, there was some variation in timing of endotracheal cuff inflation. Six (75%) of the eight employees reported before the sevoflurane was turned on, one (12.5%) employee reported after the sevoflurane was turned on, and one (12.5%) employee reported at the same time the sevoflurane was turned on.

Sevoflurane vaporizer

Seven (54%) employees reported they have recovered a patient animal from anesthesia with a median time of three hours per week recovering patients (range: 0.5 to 10 hours per week). Eight employees reported ever filling the sevoflurane vaporizer with a median of 1.75 times per week (range 0 to 5 times per week). Of the eight employees who reported ever filling the sevoflurane vaporizer, one (13%) employee reported wearing gloves, three (38%) employees reported wearing a surgical mask, and four did not report using any PPE while filling the sevoflurane vaporizer. When asked how often the

scavenger system was turned on before an anesthesia procedure, eight (62%) reported all the time, one (8%) reported most of the time, and four (30%) reported they did not know.

Nine (69%) of the 13 employees reported receiving training on how to use the scavenger system. Ten (77%) of the 13 employees reported receiving training on the potential health effects of waste anesthetic gases, and 10 (77%) employees reported receiving training on the appropriate PPE to use during anesthesia procedures. Of the 10 employees who reported receiving PPE training, all (100%) reported wearing gloves; nine (90%) reported wearing goggles; nine (90%) reported wearing surgical masks, and one (10%) reported wearing an N95® respirator[1].

Health symptoms

Of the 13 interviewed employees, three (23%) employees reported experiencing headaches, one reported experiencing drowsiness, and two reported eye irritation. When asked if their health symptom were same, worse, or better, when away from work, only one employee reported their eye irritation was better when away from work. The other replies for health symptoms when away from work included: headache – same away from work, n=2, worse away from work, n= 1; drowsiness – same away from work, n= 1; and eye irritation – same away from work, n=1.

Obstetric and infertility history

Of the 13 interviewed employees, 10 (77%) were women of childbearing age. All 13 interviewed employees were asked whether they had concerns about their ability to become pregnant or carry a pregnancy to term related to their work at the veterinary hospital, none of the ten employees of childbearing age reported having concerns. Among the 12 female employees interviewed, three employees reported eight total pregnancies. This consisted of seven pregnancies that resulted in a live birth and one miscarriage. Two pregnancies were reported to the employer. For disclosed pregnancies, the facility reported the pregnant employee's work was modified to included weight restrictions on lifting, avoiding radiographs, and wearing a respirator for during anesthesia procedures or not performing anesthesia procedures. None of the interviewed employees reported a miscarriage that occurred while working at the veterinary hospital.

Discussion

Sevoflurane is a halogenated anesthetic gas and commonly used in veterinary medicine. During anesthesia procedures, anesthesia gases and vapors that are released or leak into the work environment are called waste anesthesia gases. The veterinary hospital employees who submitted this health hazard evaluation request were concerned about waste anesthesia gas exposures and associated health effects.

Although a few employees reported work-related symptoms, we did not identify any work-related symptoms associated with waste anesthesia gas. Epidemiology studies have shown that WAG exposure is associated with nausea, dizziness, headache, fatigue, irritability, drowsiness, and difficulties with

[1] N95 and NIOSH Approved are certification marks of the U.S. Department of Health and Human Services (HHS) registered in the United States and several international jurisdictions.

judgement and coordination [McGregor 2000; Byhahn et al. 2001; Summer et al. 2003; Smith 2010; Chaoul et al. 2015; Sarkany et al. 2016]. Epidemiologic studies have also shown that anesthetic gases in general are associated with an increased risk of miscarriages. Congenital abnormalities are also health effects of concern [NIOSH 1977; Teschke et al. 2011]. However, most studies about anesthetic gases and miscarriages were performed before scavenger systems were common and did not measure levels of anesthetic gases in air [Boivin 1997; Byhahn et al. 2001; Shirangi et al. 2008]. What causes most miscarriages is not known. Miscarriages are common, and many factors have been linked to miscarriages, including maternal age, paternal age, body-mass index, smoking, alcohol use, pesticide exposure, and health conditions [Quenby et al. 2021]. Approximately half of early miscarriages are associated with chromosomal abnormalities in the fetus [Alijotas-Reig and Garrido-Gimenez 2013; American Society for Reproductive Medicine 2012; Cunningham et al. 2018]. Medical workup for early miscarriage is generally not recommended until a woman has experienced her second consecutive early miscarriage [Practice Committee of the American Society for Reproductive Medicine 2012]. Recurrent miscarriage remains unexplained despite a medical workup in approximately half of the cases, but recognized causes of recurrent miscarriage include chromosomal abnormalities in either parent, antiphospholipid syndrome, or some uterine abnormalities [Cunningham et al. 2018].

OSHA has no current permissible exposure limit (PEL) regulating sevoflurane. In 1977, NIOSH published a criteria document setting a REL for halogenated anesthetic agents. The ceiling concentration was set at 2 ppm when the agents were used alone, or 0.5 ppm when used with nitrous oxide (N_2O) over a sampling period not to exceed 1 hour. At the time, the NIOSH ceiling limit could not be defined as safe levels because information on adverse health effects was not conclusive, and the set limit was the "lowest feasible" level for these agents. The agents included in this document were chloroform, trichloroethylene, halothane, methoxyflurane, enflurane, and fluroxene [NIOSH 1977]. Sevoflurane was not included in this criteria document because it was not in clinical use at the time. Since the publication of the NIOSH criteria document, other anesthetic agents (e.g., isoflurane, desflurane, sevoflurane) have become more commonly used due to their reduced anesthesia recovery time and perceived low toxicity [Ard et al. 2016; McGain et al.2019]. While the NIOSH REL of 2 ppm represents a ceiling concentration over one-hour, ACGIH has full-shift TLV-TWA of 50 ppm [ACGIH 2024]. Other countries have full-shift TWA OELs for sevoflurane, including Norway (5 ppm), Finland (10 ppm), and Sweden (10 ppm) [IFA 2024]. More information about sevoflurane OELs can be found in Section D.

We measured high sevoflurane concentrations with a portable FTIR during the procedure of anesthetizing a small mammal. Notably, the highest concentrations were observed when an employee used a veterinary anesthesia mask over the mammal and when the employee opened a modified plastic food container which served as an anesthesia chamber box for the procedure. Induction of anesthesia on mammals that are too small for an intravenous catheter or an endotracheal tube can be conducted using a veterinary anesthesia mask or an anesthesia chamber box. Small patients commonly anesthetized using these methods include hamsters, guinea pigs, rats, and mice. The veterinary anesthesia mask, which can be used to induce and maintain anesthesia, is connected to the anesthesia machine by the anesthesia breathing tube before the mask is placed over the nose and mouth of the small mammal. Anesthesia gas and oxygen then flows into the mask through the anesthesia breathing tube. If the veterinary anesthesia mask does not have a tight fit over the mouth and nose of the small mammal

being anesthetized, there is a risk for WAG to leak around the mask. Induction chambers or anesthesia chamber boxes are alternatives to the mask method which are also effective at inducing anesthesia for small mammals [Wolforth and Dyson 2011]. Additionally, the anesthesia chamber box method may be used to humanely euthanize small mammals. The small mammal is placed into an anesthesia chamber box that is connected to the anesthesia machine by the anesthesia breathing tube. Anesthesia gas and oxygen flow into the box through the breathing tube. The veterinary employee observes the small mammal until it loses consciousness. At this point, the anesthesia chamber box is opened, and the anesthetized small mammal is removed from the box. When opening the anesthesia chamber box, veterinary employees can be exposed to high concentrations of anesthesia gas like sevoflurane [Short and Harvey 1983; Smith 1993]. While not documented during this health hazard evaluation, other reports have documented veterinary employees experiencing headaches and lightheadedness after using an anesthesia chamber box [Wolforth and Dyson 2011]. In general, during the induction of anesthesia on small mammals, high (peak) concentrations (e.g., > 50 ppm) would occur short-term (e.g., less than 30-minutes). Nevertheless, it would be prudent to minimize exposure as much as possible through engineering controls and ventilation. For anesthesia chamber boxes, WAG released from the chamber could be decreased by using a commercially available chamber box connected to an active scavenger system.

Overall, the personal 60-minute exposures for Day 2 were higher than Day 1 for the veterinarians and a few veterinary assistants/technicians involved in dental and other surgery procedures. This might have occurred because more anesthetic procedures for dental and other surgeries were conducted on Day 2 than Day 1. Another explanation could be higher background concentrations measured on Day 2 compared to Day 1, indicating improper functioning of the HVAC in the veterinary hospital after closing leading to higher concentrations of employees' exposure to sevoflurane on Day 2. Background concentrations measured before starting surgery were non-detectable for Day 1 while the background concentrations for Day 2 were 0.09 ppm and 0.06 ppm. Nevertheless, we found that none of the employees were exposed to levels of sevoflurane over the NIOSH ceiling limit of 2 ppm over a 60-minute time period for WAG. The full-shift personal and area concentrations observed in this evaluation were considerably lower than the ACGIH TLV-TWA and OELs issued by other countries. However, even though all employees had TWA sample results below 2 ppm or full-shift OELs, we measured instantaneous sevoflurane concentrations near patients' mouths during recovery that were considerably higher than 2 ppm. These results indicate that employees may be exposed to high concentrations of sevoflurane exhaled from patients during patient care in the recovery area. If peak (high) exposures occur multiple times during a shift, employees could potentially be exposed to concentrations of sevoflurane above OELs.

During our evaluation, the surgery suite door off the treatment area remained open. For the purpose of infection control, surgical suites are generally designed to be under positive pressure relative to the surrounding hallways and areas, so that air flows from operating rooms into the hallway. While this may not be ideal for WAG containment, a properly functioning active scavenger system should capture most or all WAG. An effective HVAC system in the veterinary hospital will help dilute and remove WAG not collected by the active or passive scavenger systems.

Although the hospital was utilizing numerous methods to reduce WAG exposure, we identified several actions hospital management could implement to further reduce employee exposure. A few employees

reported either inflating the cuff after sevoflurane was turned on or were not certain about the proper timing to inflate the endotracheal cuff. Inflating the endotracheal cuff before turning on the sevoflurane would decrease the leaking of sevoflurane around the endotracheal tube; thus, would reduce exposure to waste anesthesia gas [Smith 1993; OSHA 2000]. Providing continuing education for employees who perform anesthesia procedures could help those employees understand the appropriate timing to inflate the endotracheal cuff. Furthermore, when asked about how often the scavenger system was turned on before anesthesia procedures, only two-thirds reported the scavenger system is consistently turned on before anesthesia procedures. There is a potential for higher employee exposures to sevoflurane when the scavenger system is not turned on before anesthesia procedures. Reinforcing training procedures would help all employees understand the importance and proper timing of turning on the scavenger system to prevent employee exposures to sevoflurane.

Limitations

A limitation of our evaluation is its cross-sectional design. Cross-sectional studies collect information on exposures and health outcomes at the same time, so a causal relationship between exposures and health outcomes cannot be proven. Exposure assessment sampling can only document exposures on the days of sampling in the locations sampled. In addition, responses from the interviews were self-reported, and there is the possibility of recall bias when employees responded to the interview questions.

Conclusions

Veterinary hospital employees were concerned about WAG exposures causing adverse health effects. High sevoflurane concentrations were measured in the employee breathing zone during certain procedures or tasks. Elevated sevoflurane concentrations were also measured during recovery when WAG could not be captured by the scavenger system. During our site visit, veterinary employees were not in close contact with the animal patients during anesthesia recovery; however, this could be a possible WAG exposure for the veterinary profession. All personal exposures were below the NIOSH ceiling limit (2 ppm) for sevoflurane for the 60-minute sampling results, and the full-shift sampling results were below the ACGIH TLV-TWA (50 ppm) and the more conservative OELs established in Finland (10 ppm), Sweden (10 ppm), and Norway (5 ppm). WAGs should be reduced to as low as reasonably achievable (ALARA) to protect employees. The hospital should continue to minimize exposure by ensuring the scavenger system is turned on and reinforce trainings on workplace exposures and safe work practices to minimize exposures to WAG.

Section C: Tables

Table C1. Employment information for interview participants (N = 13), NIOSH survey, July 2022	
	No. (%)
Hours work per week (median)	37 (Range: 16-45 hours)
Job titles Veterinarian Certified veterinary technician Veterinary assistant Receptionist Practice manager	 2 (15) 3 (23) 5 (38) 2 (15) 1 (8)
Job tenure (mean)	1.2 (Range: 0.1–9 years)
Surgical Procedures*	9 (69)
Dental Procedures†	9 (69)
*Employees who reported ever working in surgery suite. †Employees who reported ever working on dental procedures.	

Table C2. Questionnaire responses from veterinary employees who work in surgery suite, NIOSH survey, July 2022		
	Ever	**Past 3 months**
Number reported working in surgery suite	9	8
Time working in surgery suite	2.5 years (Range 1-9 years)	6 hours per week (Range 2-18 hours)
Roles in surgery suite		
Surgeon	—	2 (25)
Anesthesia monitoring	—	6 (75)
Anesthesia tasks performed during surgical procedures:		
During surgical procedures, is sevoflurane turned on before or after the patient is hooked up to the anesthesia machine?		
Before	—	0
After	—	8 (100)
Do not know	—	0
After surgical procedures, is sevoflurane turned off before or after the patient is disconnected from the anesthesia machine?		
Before		8 (100)
After		0
Do not know	—	0
When an endotracheal tube is used, how often were you required/instructed to inflate the endotracheal tube cuff?		
Every surgical procedure	—	8 (100)
Some surgical procedures	—	0
Never	—	0
Do not know	—	0
Is the endotracheal tube cuff inflated before or after the sevoflurane is turned on?		
Before	—	6 (75)
After	—	1 (12.5)
At the same time	—	1 (12.5)
Do not know	—	0

Table C3. Questionnaire responses from veterinary employees who work on dental procedures, NIOSH survey, July 2022		
	Ever	**Past 3 months**
Number reported	9	8
Time performing dental procedures	2.5 years (Range 1-9 years)	11.5 hours per week (Range 7-30 hours)
Anesthesia tasks performed during surgical procedures:		
During dental procedures, is sevoflurane turned on before or after the patient is hooked up to the anesthesia machine?		
Before	—	0
After	—	8 (100)
Do not know	—	0
After dental procedures, is sevoflurane turned off before or after the patient is disconnected from the anesthesia machine?		
Before	—	8 (100)
After	—	0
Do not know	—	0
How often were you required/instructed to inflate the endotracheal tube cuff?		
Every surgical procedure	—	8 (100)
Some surgical procedures	—	0
Never	—	0
Do not know	—	0
Is the endotracheal tube cuff inflated before or after the sevoflurane is turned on?		
Before	—	6 (75)
After	—	1 (12.5)
At the same time	—	1 (12.5)
Do not know	—	0

Table C4. 60-minute personal air sample measurements for sevoflurane, NIOSH survey, July 2022						
Job title	Day	Task	No. of samples	Median concentration (ppm)	Concentration range (ppm)	N (%) less than LOD
Veterinarian	1	Dental procedures	4	0.09	0.07–0.13	0 (0%)
		Miscellaneous	1	0.10	0.10	0 (0%)
	2	Dental procedures	4	0.20	0.11–0.22	0 (0%)
		Other surgeries	6	0.23	0.18–0.35	0 (0%)
		Miscellaneous	6	0.29	<0.03–0.61	2 (33%)
Veterinarian Assistant	1	Dental procedures	20	0.16	0.06–0.53	0 (0%)
		Miscellaneous	5	0.15	0.09–0.21	(0%)
	2	Dental procedures	10	0.12	0.04–0.88	1 (10%)
		Other surgeries	6	0.47	<0.03–1.10	1 (17%)
Veterinarian Technician	1	Dental procedures	5	0.12	0.07–0.15	0 (0%)
	2	Miscellaneous	5	0.04	<0.03–0.07	2 (40%)
Practice Manager	1	Miscellaneous	5	0.15	0.09–0.20	0 (0%)
	2	Miscellaneous	5	0.13	0.03–0.44	0 (0%)
Occupational exposure limit (60-minute)		NIOSH REL = 2 ppm				

Note: N (%) less than LOD=number (percentage) of samples less than limit of detection (LOD); <indicates below the LOD; ppm=parts per million.

Table C5. Full-shift personal air sample measurements for sevoflurane, NIOSH survey, July 2022				
Job title	Day	No. Of samples	Concentration (ppm)	N (%) less than LOD
Veterinarian	1	1	0.07	0 (0%)
	2	3	0.16, 0.17, 0.17	0 (0%)
Veterinarian Assistant	1	5	0.05, 0.05, 0.08, 0.08, 0.14	0 (0%)
	2	3	0.13, 0.21, 0.25	0 (0%)
Veterinarian Technician	1	1	0.06	0 (0%)
	2	1	0.07	0 (0%)
Practice Manager	1	1	0.05	0 (0%)
	2	1	0.18	0 (0%)
Receptionist	1	1	0.03	0 (0%)
	2	2	0.05, 0.06	0 (0%)
Full shift Occupational Exposure Limits ft)		ACGIH: 50 ppm Norway: 5 ppm Finland and Sweden: 10 ppm		

Note: N (%) less than LOD=number (percentage) of samples less than limit of detection (LOD); <indicates below the LOD; ppm=parts per million; ACGIH= American Conference of Governmental Industrial Hygienists.

Table C6. Full-shift area air sample measurements for sevoflurane, NIOSH survey, July 2022				
Location	Day	No. Of samples	Concentration (ppm)	N (%) less than LOD
Lab bench	1	1	0.07	0 (0%)
	2	1	0.17	0 (0%)
Dental procedure table	1	2	0.08, 0.08	0 (0%)
	2	2	0.15, 0.17	0 (0%)
Pharmacy	1	1	0.04	0 (0%)
	2	1	0.07	0 (0%)
Recovery/Kennel area	1	1	0.12	0 (0%)
	2	1	0.14	0 (0%)
Surgery suite	1	1	0.05	0 (0%)
	2	2	0.16, 0.17	0 (0%)
Full shift Occupational Exposure Limits		ACGIH: 50 ppm Norway: 5 ppm Finland and Sweden: 10 ppm		

Note: N (%) less than LOD=number (percentage) of samples less than limit of detection (LOD); <indicates below the LOD; ppm=parts per million; ACGIH= American Conference of Governmental Industrial Hygienists.

Section D: Occupational Exposure Limits

NIOSH investigators refer to mandatory (legally enforceable) and recommended occupational exposure limits (OELs) for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects.

However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a preexisting medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limits (STEL) or ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- OSHA, an agency of the U.S. Department of Labor, publishes permissible exposure limits [29 CFR 1910 for general industry; 29 CFR 1926 for construction industry; and 29 CFR 1917 for maritime industry] called PELs. These legal limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2020]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, PPE, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Another set of OELs commonly used and cited in the United States include the threshold limit values or TLV®s, which are recommended by the American Conference of Governmental Industrial Hygienists (ACGIH®). The ACGIH TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2023].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at https://www.dguv.de/ifa/gestis/gestis-stoffdatenbank/index-2.jsp [IFA 2024], contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA (Public Law 91-596) requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions.

Sevoflurane

Sevoflurane is a halogenated anesthetic gas introduced in the U.S. the 1990s [Clarke 1999]. Other common halogenated anesthetic gases include halothane, enflurane, desflurane, and isoflurane. Acute exposure to sevoflurane has been associated with fatigue, headache, dizziness, and attention deficit [McGregor 2000; Summer et al. 2003; Sarkany et al. 2016; Dehghani et al. 2021]. There is limited data on the health effects of long-term sevoflurane exposure to humans. Most studies concerned with anesthetic gas exposure to humans have focused on nitrous oxide. Additionally, anesthetic gases are often used together. Therefore, few studies have focused specifically on sevoflurane exposure. The Health Council of the Netherlands reviewed the literature on sevoflurane and concluded that there were insufficient data to assess the reproductive hazard for sevoflurane [Sabar and Hougaard 2009].

Currently, OSHA has no PELs regulating these halogenated anesthetic agents. For isoflurane, the California Division of Occupational Safety and Health (better known as Cal/OSHA) has a full-shift OEL of 2 ppm [CDPH 2019; DIR, no date].

In 1977, NIOSH published a criteria document that recommended an REL that no employee should be exposed to ceiling concentrations greater than 2 ppm of any halogenated anesthetic agent over a sampling period not to exceed one hour. At the time, the REL was based on the "lowest feasible" level. The agents included in this document were chloroform, trichloroethylene, halothane, methoxyflurane, enflurane, and fluroxene [NIOSH 1977]. Sevoflurane was not included in this criteria document because it was not in clinical use at the time. Since publication of the NIOSH criteria document, other anesthetic agents (e.g., isoflurane, desflurane, sevoflurane) have become more commonly used because of their perceived low toxicity and because of rapid patient recovery from anesthesia. These newer halogenated anesthetics are often used as the sole anesthetic, therefore requiring much higher concentrations for induction of anesthesia.

In research studies and clinical applications, the REL for halogenated gases has been applied to sevoflurane and other newer halogenated ethers because of the lack of established OELs for these agents and lack of research on chronic health effects. ACGIH recommends a TLV-TWA of 50 ppm for

a full-shift. WAGs should be reduced to as low as reasonably achievable (ALARA) to protect employees, including vulnerable or sensitive employees.

Table D1: Selected sevoflurane occupational exposure limits			
Agency/Country		Full-shift TWA (ppm)	Short-term TWA (ppm)
United States	OSHA	-	-
	ACGIH	50	-
	NIOSH	-	2 (ceiling)*
Finland		10	20**
Norway		5	-
Sweden		10	20**

Note: OSHA=Occupational Safety and Health Administration; ACGIH=American Conference of Governmental Industrial Hygienists; NIOSH=National Institute for Occupational Safety and Health; TWA=time-weighted average; ppm=parts per million; "-"=no exposure limit available.
* In 1977, NIOSH issued a recommended REL that no employees should be exposed to any halogenated anesthetic agent at ceiling concentrations greater than 2 ppm (or 0.5 ppm if used with nitrous oxide) over a sampling period not to exceed 1 hour [NIOSH 1977]. Sevoflurane was not included in this document because it was not used at that time.
**15 minute average value

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