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Characterization of Waste Anesthetic Gas Exposures to Veterinary Workers in the Tampa Bay area

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in the Tampa Bay area

by

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Table of Contents

List of Tables

List of Abbreviations and Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ANOVA	Analysis of Variance
CI	Confidence Interval
HVAC	Heating, Ventilation, and Air Conditioning
NIOSH	National Institute for Occupational Safety and Health
NIH	National Institutes of Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PPM	Parts Per Million
REL	Recommended Exposure Limit
TWA	Time-Weighted Average
WAG	Waste Anesthetic Gas

ABSTRACT

Veterinarians routinely conduct surgical operations on animals while veterinary technicians administer anesthetic gas to sedate the animal prior to an operation. One commonly used anesthetic agent in veterinary clinics is isoflurane. Veterinary workers have the potential to be exposed to this gas during surgical operations. The Occupational Safety and Health Administration (OSHA) does not have a specific Permissible Exposure Limit (PEL) for isoflurane, however The National Institutes for Health (NIH) does advise that workers should not be exposed to isoflurane in concentrations exceeding 2 parts per million (ppm) for an 8 hour Time Weighted Average (TWA).

Animal clinics vary in the amount of surgeries they perform. Some clinics specialize in surgical services and therefore conduct a high volume of surgeries, while others that perform general practice work may conduct a far lower volume of surgeries. The research objectives for this study were to determine if veterinary workers are exposed to isoflurane levels above the concentration recommended by NIH and to quantify any disparity that exists between worker exposures at two veterinary facilities. A portable infrared ambient air analyzer (Miran SapphIRe, XL, ThermoScientific) was used to measure area concentrations of isoflurane and sorbent tube sampling via OSHA Method 103 was used to determine personal exposures to isoflurane.

For the three days that sampling took place at the low volume clinic, personal sampling (samples taken in the breathing zone of a worker) during surgery showed that isoflurane concentrations exceeded the NIOSH recommended limit for 3 of the 5 samples when assuming a 6-hour gas exposure. When assuming exposure only lasted for the 2 hours that sampling occurred, 1 of the 5 samples exceeded the NIOSH recommended limit. For the three days that sampling was conducted at the high volume clinic, none of the 6 samples taken exceeded the NIOSH recommended exposure limit. The average isoflurane exposure to workers at the high volume clinic was 1.72 ppm while the average for the low volume clinic was 3.77 ppm. The average isoflurane exposure for veterinarians was 2.05 ppm and the average for veterinary technicians was 3.16 ppm. These data provide evidence that veterinary technicians may face higher exposures to isoflurane gas than veterinarians. There is also evidence that workers at the low volume clinic may be exposed to greater concentrations of isoflurane than workers at the high volume clinic.

The average isoflurane concentrations were lower for the high volume clinic likely due to the fact that they relied only on an injectable sedative and no delivery of anesthetic gas for most operations. The high volume clinic also used more sophisticated equipment than the low volume clinic for the capture of waste gases.

Introduction and Background

The field of veterinary science has evolved together with medical science over the course of its history. This has included the practice of surgical operations, and with it the use of anesthetic agents to sedate patients. Studies have been performed in the past conducting exposure assessments on veterinary workers for waste anesthetic gases.

Veterinary hospitals and clinics differ widely in the amount of operations they perform for any given week. Some practices perform a high volume of surgeries every week, while others spend a very small amount of time in the operating room. While past research has been conducted analyzing waste anesthetic gas (WAG) exposures to workers at veterinary clinics, no studies have evaluated the disparity that exists between high volume and low volume clinics. The purpose of this study is to assess whether anesthetic gas exposures are different between high volume and low volume veterinary clinics in the Tampa Bay area and to determine whether veterinarians or veterinary technicians receive higher exposures during their workdays. Research was conducted at two different veterinary clinics, a high volume clinic (Clinic A), and a low volume clinic (Clinic B). One of the conditions agreed upon for this study was that each of these clinics would remain anonymous.

Clinic A was built in the 1970's and constructed of concrete. Veterinary workers at this facility conduct operations involving the delivery of anesthesia reportedly for at least 5 hours each week. The volume of the room where surgeries occur is 2,230 ft^3 and the square footage was 250 ft^2. Clinic B was built in the 1950's and is constructed of brick. This clinic handles on average less than 5 hours of surgery each week and operates in a surgical suite with a volume of 1,780 ft^3 and a square footage of 165 ft^2. The high volume clinic had 2 veterinarians and 4 veterinary technicians on site during operations while the low volume clinic had 1 veterinarian and 2 veterinary technicians.

Clinic A had a larger surgical suite, which was necessary for the higher number of workers and the larger volume of surgeries being conducted. Air was supplied through two supply ducts operating at 188 ft^3/min and 128 ft^3/min, and exhausted by a duct operating at 408 ft^3/min. The number of air changes for the surgical suite was 8.6 (Table IV), 6.4 changes short of the 15 recommended by NIOSH for operating rooms (NIOSH, 2007). In addition to the HVAC system, a GasVak® active scavenging system was left running during operations, although it was only connected to a breathing system when a tracheal tube was used. When face masks were used, a passive scavenging system collected waste gases instead. Clinic B made use of two Goodman air conditioning units to provide air circulation through the building. The surgical suite had three supply ducts, operating at 58 ft^3/min, 181 ft^3/min, and 167 ft^3/min. There was also one exhaust duct in the room operating at 86 ft^3/min. The number of air changes for the room was 13.9 (Table I), 1.1 short of the amount recommended by NIOSH. This clinic used only a passive scavenging system to control waste gases during surgery.

Table I: Features of Surgical Suite at Clinic A*			
Exhaust Air Flow Rate (ft^3/min)	**Supply Air Flow Rate (ft^3/min)**	**Volume of Room (ft^3)**	**Air Changes per Hour (N)**
408	316	2,205	8.6

Table II: Features of Surgical Suite at Clinic B*			
Exhaust Air Flow Rate (ft^3/min)	**Supply Air Flow Rate (ft^3/min)**	**Volume of Room (ft^3)**	**Air Changes per Hour (N)**
86	406	1,750	13.9

*Air Changes Per Hour Calculation

N = (Supply Air Flow Rate * 60) / Volume of Room

The specific aims of this study were to collect data on the concentration of isoflurane in clinics using both area (samples taken within 3 ft. of a worker) and personal (samples taken within the breathing zone of a worker) sampling techniques. A further aim was to qualitatively assess the type of work practices and control equipment used by the two different clinics. Personal exposures to isoflurane gas for veterinarians and veterinary technicians at each clinic were then to be compared. Hypotheses were made pertaining to the expected results. These hypotheses were as follows:

1. Isoflurane gas exposure to veterinary workers at high volume clinics will be less than those at low volume clinics.
2. Veterinary technicians will receive a higher dose of isoflurane than veterinarians

The University of South Florida's Institutional Review Board determined that this study did not require their oversight since there was no intervention with human subjects. The Institutional Animal Care and Use Committee came to the same conclusion since there was no intervention with animal subjects.

Literature Review

The Veterinary Profession

The Bureau of Labor Statistics estimates that there were 70,300 veterinarians and 84,800 veterinary technicians working in the United States in 2012. These workers typically specialize in the type of animals they treat, such as large, small, domestic, or exotic animals. The majority practice on small domestic animals given that the demand for treatment is higher with these types of animals (OSHA, 2000). Veterinarians and veterinary technicians may find work in large clinics that employ a high number of workers or they may work in smaller clinics with far fewer staff members.

Veterinary workers are at risk to a number of hazards in their workplace, including exposure to radiation, biological agents, and anesthetic waste gases (Fritschi, 2000). When performing surgeries at a clinic, there are multiple opportunities for anesthetic gases to be released into the atmosphere, and eventually into the breathing zone of workers occupying the surgical suite. In order to characterize the exposures that veterinary workers face, it is necessary to learn about differences that exist between worksites where veterinarians and veterinary technicians may be employed.

Veterinary Worker Exposures to Anesthetic Gases

A significant amount of variation exists between practices at different veterinary clinics, including the method in which a surgery is conducted and the types of chemicals used during the operation (Oliveira, 2009). Disparity also exists in the number of surgeries performed, the type of equipment in use, and the job role of different personnel while surgeries are conducted. These differences can lead to a marked variation in the exposure a worker may face to waste anesthetic gases at different facilities. For example, a study that surveyed 28 veterinary clinics found that veterinarians spent an average of 4 to 6 hours each week performing surgery, while veterinary technicians spent between 3 and 9 hours each week assisting with these surgeries (Ruby, 1980).

A more recent epidemiologic survey found that 94% of practicing veterinarians are exposed to waste anesthetic gases. Of these individuals, 82% spent at least 1 hour, and 65% spent 5 or more hours conducting surgeries every week (Shirangi, 2007). A possible explanation for these statistics comes from the way in which different veterinary clinics operate. Many clinics are small businesses that fluctuate in the number of surgeries performed over the course of a week, but typically do not spend much time in the operating room. For the purpose of this study, facilities that spend fewer than 5 hours a week in surgery will be referred to as "low volume" surgical clinics. Contrast to this, some veterinary practices are designed to be extremely efficient in performing surgeries, especially common ones such as a spay or neuter. These facilities will spend a much larger portion of their workweek performing surgery on animals compared to low volume clinics. Facilities that spend 5 or more hours in surgery each week will be known as "high volume" surgical clinics.

Another interesting aspect contributing to differences in exposures at veterinary clinics involves the infrastructure of the building where surgeries are conducted. Many veterinary clinics operate out of facilities that were not designed for surgical operations. Therefore, these facilities lack control measures, such as exhaust ventilation, that would typically be found in hospitals or larger veterinary facilities to control the emission of chemicals being used during operations (Burkhart, 1990). In addition to this, it is uncommon for small firms to have sophisticated occupational health and safety programs in place, which can lead to an increased risk of exposures to employees (Burkhart, 1990).

Surgical Procedures and Equipment Overview

During surgical operations, the veterinary technician typically acts as the anesthetist and is responsible for administering the sedative. Clinics have various methods in how they sedate an animal prior to surgery. One method is to use liquid injection of a sedative into the vain of a patient (OSHA 2000). Another method involves delivery of a vaporized anesthetic gas by either placing a mask over the face of a patient or by using a tracheal tube, which consists of a tube inserted into the trachea of the patient that moves the anesthetic gas mixture into the patient and also allows waste gases to exit (Nesbitt, 2013). Vaporized anesthetic gas delivery is preferred because it is easier to control the level of sedation of an animal compared to use of an injectable anesthetic agent. Clinics will usually perform a hybrid of these methods, where a small dose of sedative is injected prior to administering anesthetic gas through a tracheal tube or face mask (OSHA, 2000). Clinics that treat small domestic animals rely most heavily on breathing systems to deliver anesthetic gases (Ruby, 1980). The larger an animal is, the less likely veterinarians are to administer anesthesia through this method. This is in part due to the fact that veterinarians often make trips into the field for animals like cows or horses; therefore injectable sedatives are more practical (Ruby, 1980).

Tracheal tubes are known to offer better protection than gas masks for the delivery of isoflurane since they fit tightly into the trachea of an animal, creating a seal that minimizes isoflurane leaks. Masks, on the other hand, are prone to slipping off during surgery and do not always fit securely around an animal's nose and mouth. Gas masks do have their benefits though. First, it is much easier and faster to administer anesthetic gas through a mask since it can easily be taken on or off. Veterinary workers are able to apply a gas delivery mask before the animal becomes unconscious from the liquid sedative. This is not the case for tracheal tubes, which cannot be inserted until the animal becomes sedated, and which take longer to fit and insert or remove from a patient. Using tracheal tubes also creates a risk to animals, especially cats, for complications such as tracheal rupture if the seal around the tube is overinflated (Bhandal, 2008).

There are four main components to an anesthetic delivery system. First is a gas source. This is usually just a compressed gas cylinder containing oxygen that is mixed with an anesthetic agent and administered to the patient (Knoll, 2003). The second component is an anesthetic machine, which may also include a vaporizer. The role of the anesthetic machine is to regulate flow of the anesthetic agent into the air mixture entering the patient. The vaporizer functions to change the anesthetic liquid into a vapor before it is added to the gas mixture (Knoll, 2003). The third component, which was mentioned earlier, is a breathing system. These systems consist of a Y-shaped tube that has one tube connected to the gas mixture, one tube going into the trachea of the patient, and an exhaust tube which allows gases that have circulated through the patient to be removed.

Breathing systems may either be rebreathing or non-rebreathing. A breathing system is arranged in a loop and allows the patient to rebreathe gases that were previously exhaled. After gases are exhausted from the animal, they move through a filter or scavenger to trap carbon dioxide and waste anesthetic gas before being recirculated into the fresh gas mixture being administered to the patient (OSHA, 2000). In a non-rebreathing system gases are not recirculated, but are instead routed out of the breathing tube system and either into the room air or collected by a scavenging system (Knoll, 2003). The scavenging system is the fourth and final component of an anesthetic delivery system. When gases are exhausted from the animal, they are collected by a scavenging system, which will exhaust the gas out of the room or will trap harmful gases in a canister. Scavenging systems may either be active or passive. The passive system relies on positive pressure from the anesthetic gas machine to move exhaust gas into the scavenger. An active system is more efficient in removing gases because it uses a pump to facilitate movement of exhaust gases into the scavenger (Knoll, 2003).

Once anesthesia has been administered and the animal is sedated, the veterinarian at the clinic will be called into the operating room to perform the surgery. A veterinary technician may remain with the veterinarian throughout the surgery or they may exit the room for a period of time to perform other tasks while surgery is conducted. After surgery, the animal is moved to a recovery room by the veterinary technician, who will continue to monitor the animal until it has regained consciousness. During this time, the animal is still exhausting concentrations of waste anesthetic gas, which may be spread to other areas of the veterinary facility if proper controls are not present in the recovery room (Burkhart 1990).

Halogenated Anesthetic Agents

One of the most commonly used anesthetic agents in animal labs and veterinary clinics is isoflurane, which entered the market in 1980 (OSHA, 2000). Isoflurane is what is termed a halogenated ether compound and sometimes goes by the name forane or aerrane. It is a non-flammable and highly volatile liquid (Tufts, 2010). Isoflurane has, for the most part, replaced anesthetic agents such as halothane, enflurane, and methoxyflurane in recent years since it is believed to be safer for both patients and workers in the operating room (OSHA, 2000). This is largely due to the fact that isoflurane undergoes hepatic metabolism in the human body to a lesser degree than agents such as halothane and methoxyflurane (Stein, 2005). This is not to say that isoflurane is considered a safe gas for human exposure, however. Epidemiologic data has shown that isoflurane is closely associated with liver diseases in humans as a result of inhalation (Franco, 2011). Acute exposure to isoflurane has been linked to depression of the central nervous system, headaches, fatigue, irritability, nausea, and drowsiness (Nesbitt, 2013). Long-term exposures are believed to be casually associated with neurological and reproductive problems (Nesbitt, 2103).

The Occupational Safety and Health Administration (OSHA) does not define a specific Permissible Exposure Limit (PEL) for isoflurane. The National Institute for Occupational Safety and Health (NIOSH) does advise, however, that exposures should not exceed 2 ppm over a 1-hour period for all halogenated anesthetic agents (NIOSH, 1977). More recently, NIOSH has taken the stance that workers should not be exposed to isoflurane in concentrations exceeding 2 ppm for an 8-hour Time Weighted Average (TWA) (NIOSH, 2012). The American Conference of Governmental Industrial Hygienists (ACGIH) does not have a Threshold Limit Value (TLV) set for isoflurane, however they do have one for enflurane, which has a similar chemical composition and molecular weight as isoflurane. The TLV for enflurane is 75 ppm for an 8-hr exposure (OSHA, 2013). NIOSH states in their Waste Anesthetic Gas Surveillance Report that more research is needed on the health effects of isoflurane, especially because of its widespread use among veterinarians (NIOSH, 2012).

In addition to the health effects specific to isoflurane, it is believed that halogenated anesthetic agents in general are related to kidney disease, spontaneous abortions, cancer, and congenital abnormalities (Burkhart, 1990). A correlation has been shown between anesthetic gases and preterm delivery in female veterinarians (Shirangi, 2009). However, evidence has also been presented that shows anesthetic gas exposure causes no increased risk for spontaneous abortions or birth defects (Shuhaiber, 2002). Veterinary workers as a whole appear to have an increased mortality from certain cancers, although it is noted that this may result not just from anesthetic gas exposure, but also from other factors such as radiation and pesticide use (Fritschi, 2000).

Exposure Assessments in Veterinary Clinics

Numerous exposure assessments have been conducted in both veterinary practices and animal testing labs, which may administer anesthetic gases in similar fashions. Burkhart & Stobbe (1990) performed exposure assessments in the breathing zone of workers at six stages of surgery in a veterinary clinic and found TWA concentrations of halothane ranging from 0.5 to 45.5 ppm. The first task involved connecting the animal to the anesthetic gas and averaged a 3.44 ppm concentration over 3.75 minutes. Task 2 involved checking the endotracheal tube's seal, which averaged 5.3 ppm over 4.5 minutes. Task 3 was the actual surgical procedure, which lasted about 11 minutes and averaged a concentration of 4.1 ppm. Task 4 was to again check the endotracheal tube, averaging 10.2 ppm over 1.9 minutes, and task 5 was closing the incision site, which averaged 8.3 ppm over 9.6 minutes. Finally, task 6 involved turning off the gas and removing the endotracheal tube. Concentrations of anesthetic gas peaked at 45 ppm and averaged 18.1 ppm for the 3.6 minutes taken to complete the task. No scavenging systems were used when performing these measurements. When the authors took a sample of the halothane gas mixture and ran it though a charcoal filter, they found a 95% reduction in concentration of the gas in air. Therefore it was highly recommended by the authors that veterinary professionals make use of charcoal absorbers to control waste anesthetic gas concentrations (Burkhart, 1990).

In another study (Nesbitt, 2013) personal samples were taken for a surgeon and an assisting technician in a laboratory animal surgery suite. Isoflurane 8-hr TWA exposures were sampled twice for each worker using passive organic vapor monitors. The results showed that when no scavenger was used, the 8-hr TWA exposures were 5.3 ppm and 9.9 ppm for the surgeon. For the assisting technician, the 8-hr TWA reached 1.9 ppm for each of the two samples collected. Sampling was again conducted with and without scavenging equipment in the breathing zone of the surgeon, however this time samples were taken for a TWA of 10 seconds. The results showed that use of a scavenger reduced the TWA concentration from 2.9 ppm to 1.3 ppm, a reduction of 53%.

In another exposure assessment (Ruby, 1980), scientists sampled anesthetic gas exposures for 74 different surgical operations, comparing the use of rebreathing systems, nonrebreathing systems, and scavenging systems. The results showed that for animals in the small to medium size range, concentrations of anesthetic gases averaged 1.0 ppm for veterinarians and 1.3 ppm for veterinary technicians when rebreathing systems were used. For nonrebreathing systems, personal samples from the veterinarian averaged 8.8 ppm, while the veterinary technician's averaged 4.2 ppm. When samples were collected for rebreathing systems with a scavenger, average gas concentration dropped to 0.3 ppm and 0.4 ppm for the veterinarian and veterinary technician, respectively. For nonrebreathing systems, the use of a scavenger brought personal samples for both workers down to 0.9 ppm, further showing how effective these devices are in reducing exposure to waste anesthetic gas (Ruby, 1980).

Another study (Potts, 1988) examined the association between anesthetic gas exposure and conducting back-to-back surgeries. To do this, they sampled for concentrations of methoxyflurane and halothane during eight separate surgeries, four where scavengers were used and four where they were not. For halothane, the surgeries ranged from 20 minutes to 33 minutes, with concentrations averaging 1.3 ppm, 4.3 ppm, 5.5 ppm, and 4 ppm for four back-to-back surgeries performed without a scavenger. When a scavenger was used, the halothane concentrations dropped to 0.08 ppm, 0.75 ppm, 0.91 ppm, and 0.5 ppm for surgeries 1 thru 4, respectively (Potts, 1988).

The surgical operations using methoxyflurane as the anesthetic agent had surgery times lasting between 21 and 46 minutes. When no scavenger was used, the first surgery had an average methoxyflurane concentration of 1.9 ppm, the second 2.5 ppm, the third 3.5 ppm, and the fourth 2.7 ppm. When a scavenger was used, the resulting concentrations of the four surgeries were 0.36 ppm for the first, 1.5 ppm for the second, 2.3 ppm for the third, and 1.6 ppm for the fourth. From this data, it was concluded that scavengers are effective at removing waste gas from the atmosphere, however when surgeries are performed back-to-back it allows a buildup of gas in the room, which can reach above threshold levels without additional means of controlling exposures, such as exhaust ventilation (Potts, 1988).

Sources of Gas Contamination to Veterinary Facilities

As stated earlier, work practices and lack of effective control equipment are often to blame as sources of anesthetic gas exposure in veterinary practices. Breathing systems are made with tubing of various diameters in order fit properly into the tracheal tube of the animal being operated on. It is important that the veterinary technician fitting the breathing system to the animal is careful, making sure there are no leaks from tubing, connectors, or valves that are not securely connected (NIOSH, 2007). Failure to establish a tight connection between fittings can result in leakage of anesthetic gas into the operating room. Other sources of anesthetic gas exposure come from when the anesthesia machine is first hooked up or disconnected, when the mask over the animal's nose and mouth does not fit properly, during induction of anesthesia, and during dental operations (NIOSH, 2007).

As pointed out by numerous studies above, absence of an effective scavenging system when using anesthesia can lead to significantly higher exposures to anesthetic waste gases. In a recent survey of veterinary professionals in Australia, it was found that 22% of the 1,197 study participants did not make use of scavenging systems when using anesthesia (Shirangi, 2007). It was shown in this study that younger veterinarians are more likely to use scavenging systems, with 71% of professionals who graduated in the 1960's using scavengers compared to 90% of those who graduated in 1990s using them (Shirangi, 2007). Fritschi *et. al.* discovered a similar trend in their study towards increased usage of waste anesthetic gas scavenging systems by young veterinary professionals. However it was also observed that young veterinary professionals are working longer hours and spending more time in surgery than past generations, meaning an increased time spent exposed to lower concentrations of waste anesthetic gases (Fritschi, 2007).

Veterinary staff must refill vaporizer machines from time to time with liquid anesthetic. During this time it is possible for the liquid to spill onto the floor and contaminate the air when they evaporate (Oliveira, 2009). NIOSH recommends vaporizers to be filled while under a hood with an active exhaust system, and to fill them either before or after the anesthetic procedure (NIOSH, 2007). Unfortunately many veterinary clinics lack sophisticated equipment such as exhaust hoods. An alternative method for spill prevention is to use key-indexed systems, which provide a tubed connection between the bottle of anesthetic agent and the vaporizer (Oliveira, 2009).

In addition to using control equipment such as exhaust ventilation and scavenging systems, proper care and maintenance must be performed to ensure that control devices are working properly (Shirangi, 2007; NIOSH, 2007). Canisters used to trap anesthetic gases need to be replaced according to the manufacturers directions. Usually the length of life for these respirators is 12-15 hours of surgery, or when the canister reaches 50 g in weight (Smith, 2003). There are many different manufacturers of canisters designed to collect and trap waste anesthetic gases. The reliability and effectiveness of these canisters to protect against halogenated anesthetic agents has been questioned in the past. In one study, the effectiveness of canisters manufactured by three popular brands were compared. It was determined that 46% of Breath Fresh canisters, 8% of EnviroPure canisters, and 27% of F/Air canisters began leaking between 5 ppm and 100 ppm isoflurane before reaching the end of their manufacturer-suggested life (Smith, 2003). Of the 24 Breath Fresh units tested, 42% emitted over 100 ppm isoflurane, noted as a complete failure in the ability to control anesthetic gas. This showed that the reliability of these canisters differs greatly not only between different canister manufacturers, but also between individual canisters that these manufacturers produce (Smith, 2003).

After completion of surgery, the patient is brought to a recovery room where they are held until the effect of the anesthesia has worn off. It is typically the veterinary technician's role to remove the breathing system and transfer the animal from the surgical suite to the recovery room. During the time spent in the recovery room, the animal is still breathing out anesthetic gas (NIOSH, 2007). In a recovery room where gases are not properly vented or scavenged, the concentration of anesthetic gas can reach above the NIOSH recommended 2 ppm threshold for up to 2 hours (Milligan, 1982). Depending on the work practices of the veterinary clinic, a veterinary technician may remain in the recover room with the animal until the anesthesia wears off or they may come and go from the room to check on patients.

Methods of Controlling Waste Gases

Effective ventilation systems are important for controlling any waste gases that end up in the operating room atmosphere. NIOSH recommends that operating room ventilation systems have at least 15 air changes per hour, with a minimum of 3 air changes of fresh air every hour. In addition, recovery rooms should have a ventilation system capable of at least 6 air changes an hour, with a minimum of 2 air changes of fresh air per hour (NIOSH, 2007). Veterinary clinics that operate as small businesses are less likely to have such effective ventilation systems compared to larger clinics and hospitals, presumably leading to increased exposures of veterinary staff to waste anesthetic gases (Burkhart, 1990).

Also important to the safety and health of workers is a formal safety and health plan that trains workers on exposure hazards and ways to control them (NIOSH, 2007). Hazard communication (keeping material safety data sheets updated, labeling containers with their contents, etc.) is another important aspect in protecting the health of workers in a veterinary clinic. As stated above, however, small private practices are much less likely to develop and implement these programs compared to large clinics and hospitals (Burkhart, 1990). Failure to establish such safety and health programs may lead to an increased risk of accidental waste anesthetic gas release, leading to higher exposures for veterinary workers.

As a final protection against anesthetic waste gases, the use of an organic vapor respirator may offer defense against inhalation of agents such as isoflurane (Stein, 2005). Personal protection equipment should not be relied on exclusively to control exposures due to the inconsistent protection offered to workers. Wearing the mask incorrectly, or failing to wear the mask at all, will lead to gas exposure. Therefore the best management options are ensuring proper maintenance of equipment, providing training programs, adopting effective work practices, and using engineering controls such as a scavenging system or exhaust ventilation whenever possible.

Methods

Participants

A total of eight veterinary clinics in the Tampa Bay area were contacted requesting participation in this study. Of those eight, four responded and agreed to be a part of the research. A meeting was arranged in order to interview the lead veterinarian at each clinic and determine the type of anesthetic agent being used, the procedure that is followed to administer anesthetic agents, the average amount of time spent in surgery each week, and the types of controls used to reduce anesthetic gas exposure. From these interviews, two clinics were selected for sampling (Results of interviews can be found in Appendix 1). These clinics were the high volume Clinic A and low volume Clinic B.

The participants of Clinic A included one male veterinarian, one female veterinarian, one male veterinary technician and three female veterinary technicians. The participants of Clinic B included one female veterinarian and two veterinary technicians.

Area Sampling

A portable infrared ambient air analyzer (Miran SapphIRe XL, Thermo Fisher Scientific, Waltham, Mass) was used to take area concentrations of isoflurane at each of the clinics sampled. According to the manufacturer's manual, the instrument operates with an accuracy of $^{+}/_{-}$ 10% for isoflurane. Inaccurate with the instrument can also arise from interferences when multiple chemicals are present in the atmosphere. The researcher confirmed with workers at each clinic before sampling that no solutions (disinfectants, etc.) had been sprayed in the room. The Miran was set to sample for isoflurane with a high range limit of 10 ppm, a detection limit of 0.5 ppm, and a long pathlength. Per the manufacturer's recommendation, the instrument was zeroed in locations within 20% of the relative humidity observed in the room where surgery was to be conducted.

The area sampling instrument was taken to Clinic A on February 4th, 2014 to sample for area concentrations of isoflurane in the air surrounding the veterinarian and two veterinary technicians helping perform operations. Sampling took place from about 9:15am to 11:30am, during which time 1 dental operation and 7 surgical operations were performed. As the instrument was warming up, the first animal was being prepared for surgery and eventually moved to the operating table. The veterinarian sat over the animal while the researcher stood about 3 feet from the veterinarian with the wand of the Miran about 1-2 feet from the veterinarian's nose and mouth. Collection of data began when the first incision was made on the animal for all surgeries. Sampling ended about a minute after the mask or rebreathing system was removed from the animal. Data was collected in the area of the veterinarian for 5 of the surgeries, and in the area of the lead veterinary technician for 2 surgeries and the dental operation. The machine was then brought back to the parking lot after surgery to confirm that the zero was still valid.

On February 11th 2014 the researcher sampled isoflurane levels at Clinic B from 9:00am until 11:30am. The Miran SapphIRe XL instrument was set up as described in the previous section prior to sampling. The instrument was initially zeroed outside in the parking lot of the veterinary clinic and then brought in to the surgical suite shortly before the first operation began. A total of three surgeries were sampled during this site visit. For all three surgeries, sampling began when the anesthetic gas machine was turned on and sampling concluded once the animal was removed from the operating table. Both the veterinarian and a single veterinary technician stood over the operating table during surgery. The primary investigator stood at the end of the operating table with the wand of the sampling instrument about 1-2 feet from the nose and mouth of the workers while sampling was conducted. After the conclusion of the second surgery, the Miran was taken outside to re-check the zero calibration. It was at this time that the researcher noticed the instrument was giving off a reading of 3.89 ppm in an environment that was within 20% relative humidity of the surgical suite. The instrument was determined to have an incorrect zero value, so the data collected for the first two surgeries were corrected by subtracting each reading by 3.89 ppm. Before the third surgery began, the researcher re-zeroed the machine in the parking lot of the clinic in order to obtain an accurate zero value. The validity of this zero was confirmed following the final surgery.

Personal Sampling

OSHA Method 103 recommends sampling for isoflurane using Anasorb® 747 sorbent tubes set to a flow rate of 0.05 L/min for four hours in order to sample 12 L of air. For personal samples taken at clinics, SKC Inc Category 226-81A sorbent tubes were used in a series with Sensidyne® Gilian personal air sampling pumps. In order to calibrate these pumps, a BIOS Dry-Cal primary flow meter was used. The researcher ensured the validity of the primary flow meter's readings by testing it against a soap film meter. Calibration data for the BIOS Dry-Cal primary flow meter can be found in Appendix 2.

Personal samples were prepared by breaking the ends of the sorbent tube and using Tygon tubing to connect one side to the air sampling pump and the other to the collar of the worker being sampled. The sampling plan called for taking personal samples for one veterinarian and one veterinary technician on three separate days at each clinic. This was followed for each day of collection except for the first round of personal sampling at Clinic B, where only the veterinary technician was sampled. In total, three sorbent tubes from veterinary technicians and three samples from veterinarians at Clinic A were analyzed. At Clinic B, three sorbent tubes from veterinary technicians and two sorbent tube from the veterinarian were analyzed.

On March 18th, April 8th, and April 9th, 2014, personal samples for worker exposure to isoflurane were collected at Clinic A. The lead veterinarian and lead veterinary technician were each chosen to wear a personal sampling pump with sorbent tube in line. Personal samples from Clinic B were taken on March 17th, April 7th, and

April 10th, 2014. The veterinary technician was sampled on the first day and both the veterinarian and primary veterinary technician were sampled on the second two days.

For personal samples, a sorbent tube was connected in line between the personal air sampling pump and BIOS primary flow meter with Tygone tubing. A special low-flow adapter made by Sensidyne® was attached to the personal sampling pump and a low flow sorbent tube holder was used to adjust the flow rate of the pump. With the sorbent tube in line, the pump was turned on and set to operate at a flow rate of 1500 cubic centimeters per minute (cc/min). The screw on the low flow sorbent tube holder was then adjusted with a screwdriver until the primary flow meter gave three readings near the desired flow rate, 0.10 L/min. Just before surgery began, the personal sampling pump was placed on the worker's belt and the clip from the sorbent tube holder was placed on the worker's collar. The pump was then turned on and allowed to suck air through the sorbent tube for a total of two hours, collecting a total of 12 L of air. After sampling, pump flow rates were checked to make sure they did not change more than 5% between the start and end of sampling. Finally, sorbent tubes, including a blank, were labeled and stored in a refrigerator before being sent to Galson Laboratories for analysis.

Evaluation of Ventilation Systems

On the first dates that personal samples were taken at each clinic, a TSI® Alnor Balometer used to determine the flow rate of air into and out of the surgical suites. The dimensions of the surgical suite at Clinic A were 11'8"x9'x21' and the dimensions of the surgical suite at Clinic B room were 10′3″x16′x10′8″. These data then were used to find out the number of air changes per hour offered by the clinic's ventilation system. A full list of equipment used in this study can be found in Appendix 3.

Results

The results from area and personal sampling at Clinic A and Clinic B are presented in the tables and figures below.

Sampling Results for Clinic A

Table III: Area Concentration of Isoflurane at Clinic A*

Surgery Number	Type of Operation	Delivery System	Length of Operation (min)	Average (ppm)	Max (ppm)	Min (ppm)
1	Spay	Mask	9.85	2.86	3.80	1.81
2	Spay	Mask	11.34	7.81	17.07	4.88
3	Spay	Mask	12.34	10.04	24.58	5.11
4	Spay	Mask	9.77	9.34	17.40	5.63
5	Spay	Mask	5.10	23.23	50.47	10.81
6	Spay	Mask	13.04	5.05	8.94	3.61
7	Neuter	Tracheal Tube	12.03	5.15	5.80	3.87
8	Dental	Mask	6.62	5.77	17.69	3.68

Total Length of Operations (min):	**80.09**
Average Isoflurane Concentration (ppm):	**8.66**
Max Isoflurane Concentration (ppm):	**50.47**

*Active and passive scavenging systems were used to control waste anesthetic gas

The total length of time that operations involving isoflurane were conducted was 80.09 minutes. The average and maximum isoflurane concentrations during this time were 8.66 ppm and 50.47 ppm, respectively.

Isoflurane concentrations from the first day of area sampling are shown in Figures 1-A through 9-A below. These operations match up with the list of operations shown in Table IV. All sampling was conducted with the Miran SapphIRe XL probe placed about 1.5 ft from the veterinary worker.

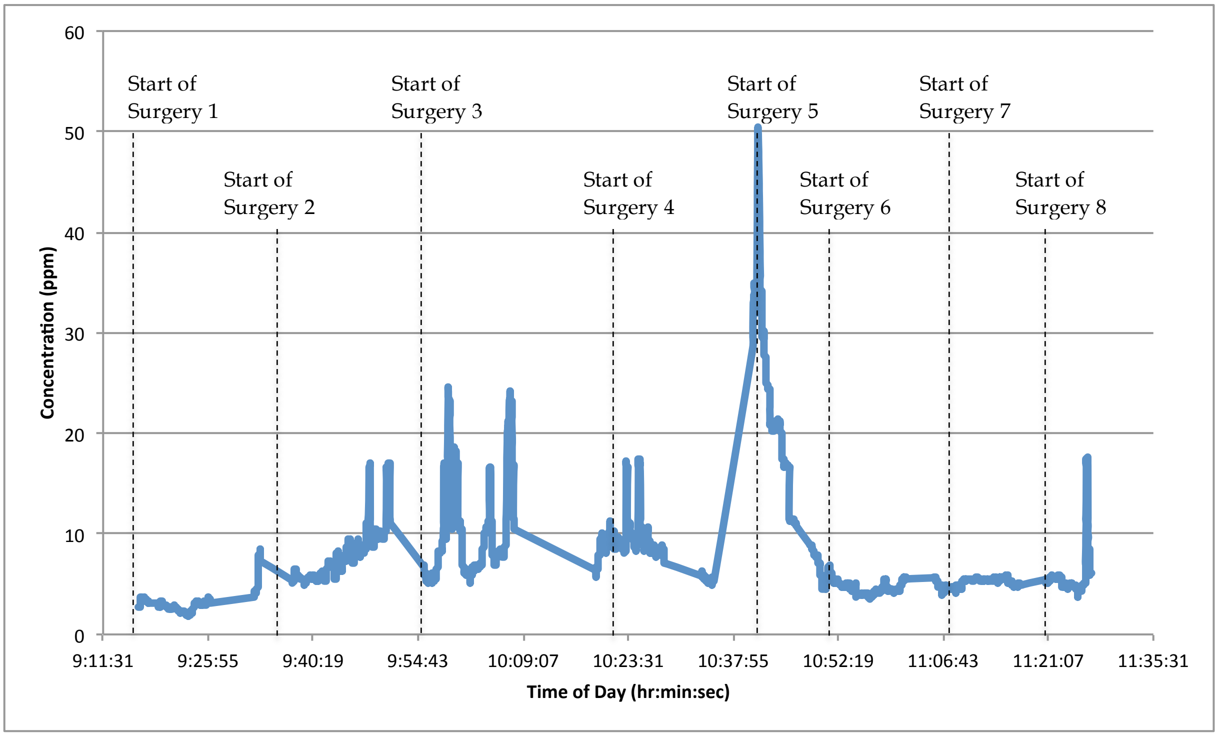

Figure 1-A: Isoflurane Concentration vs. Time for All Surgeries

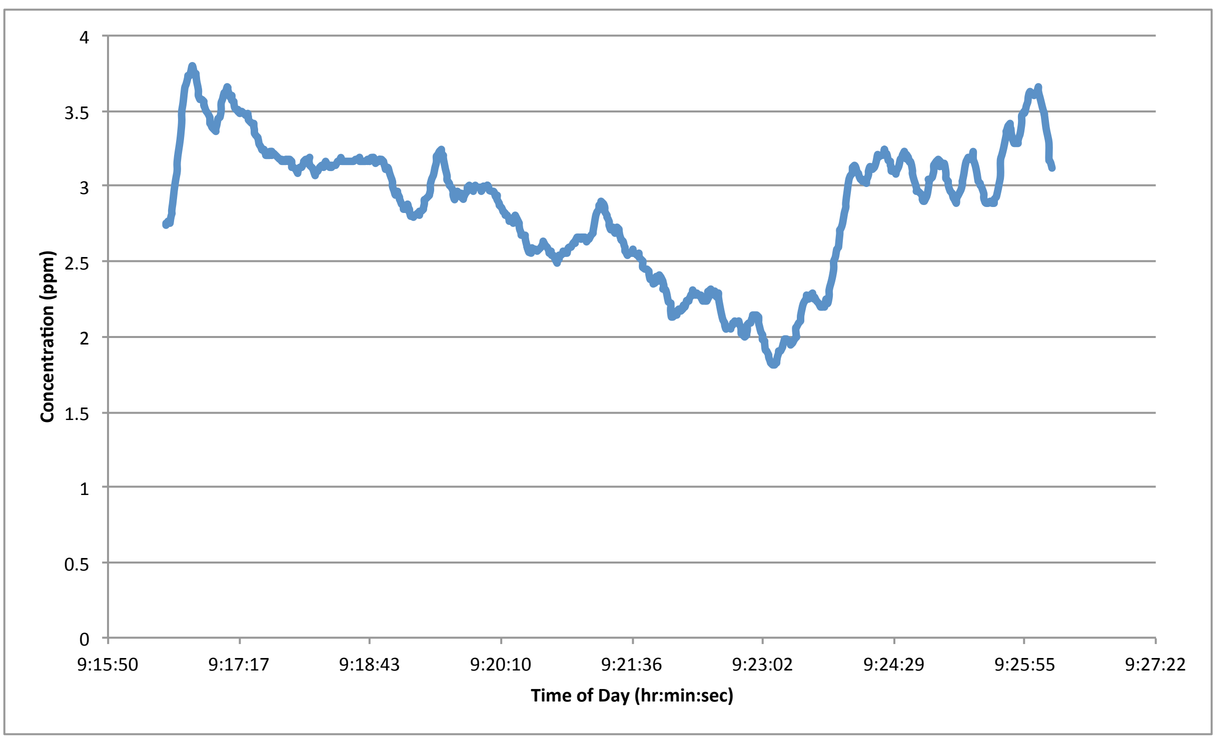

Figure 2-A: Isoflurane Concentration vs. Time for Surgery 1

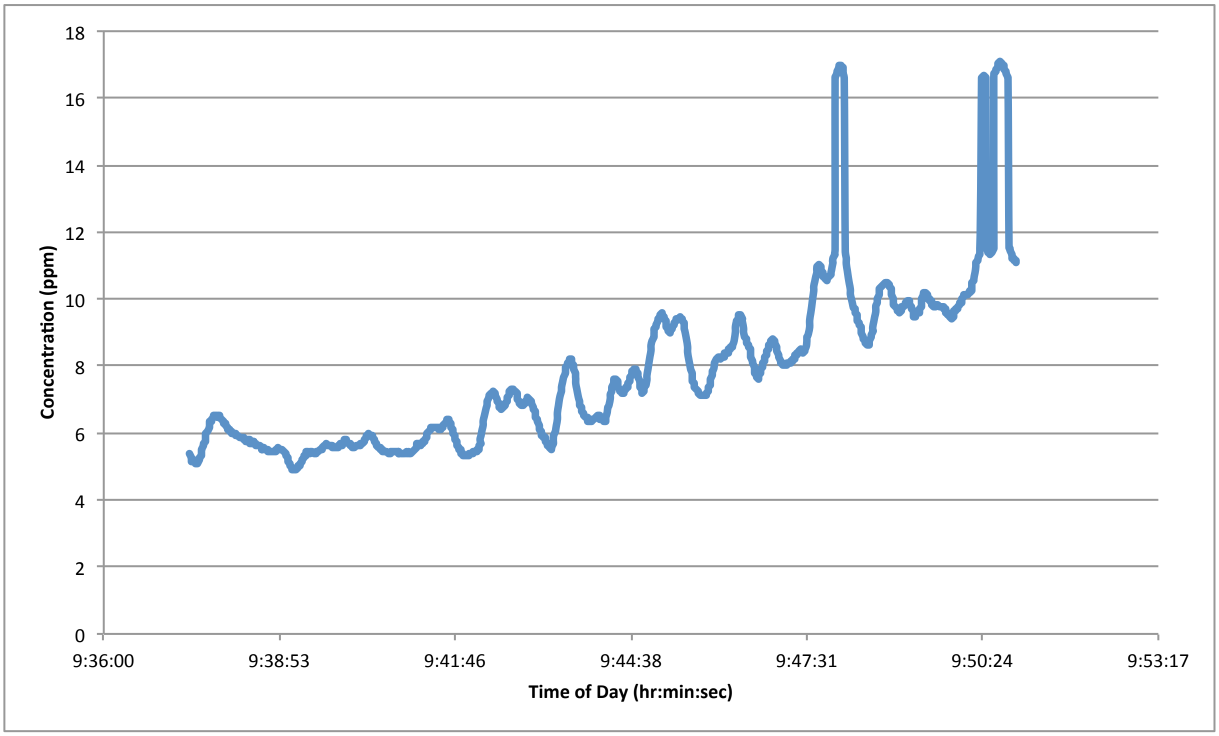

Figure 3-A: Isoflurane Concentration vs. Time for Surgery 2*

*A spare anesthetic gas machine was accidently left on during this surgery.

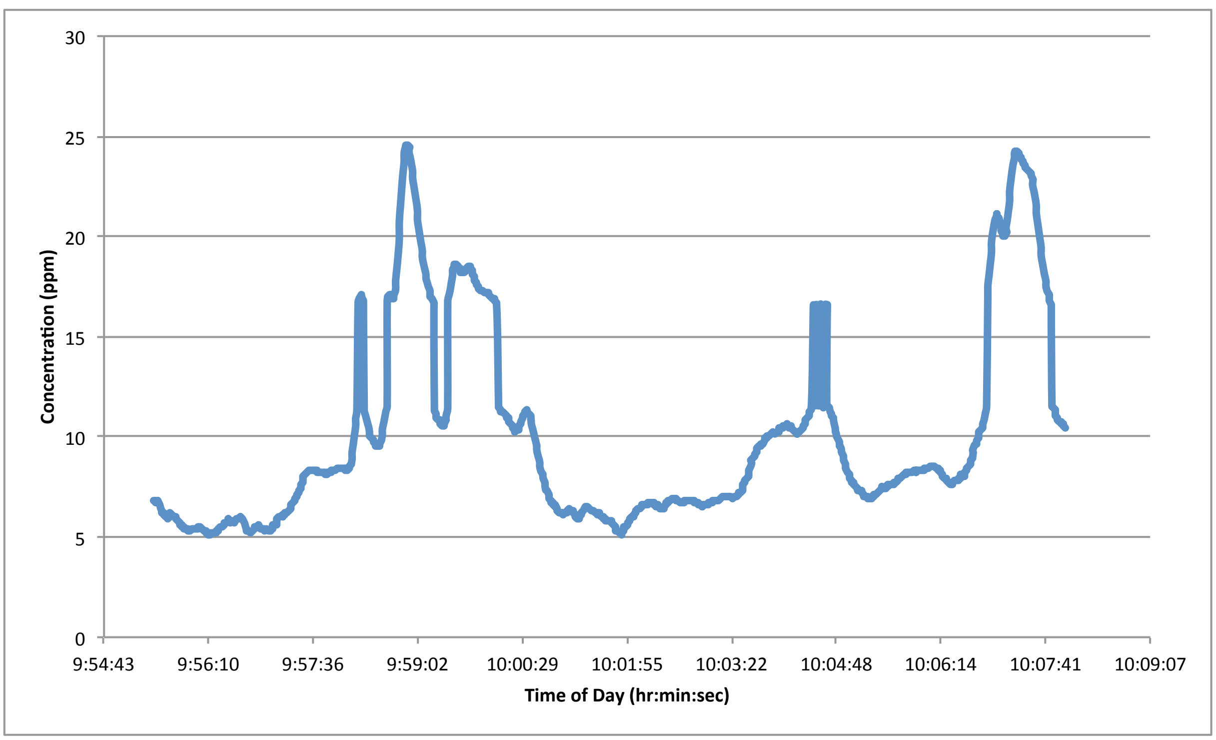

Figure 4-A: Isoflurane Concentration vs. Time for Surgery 3

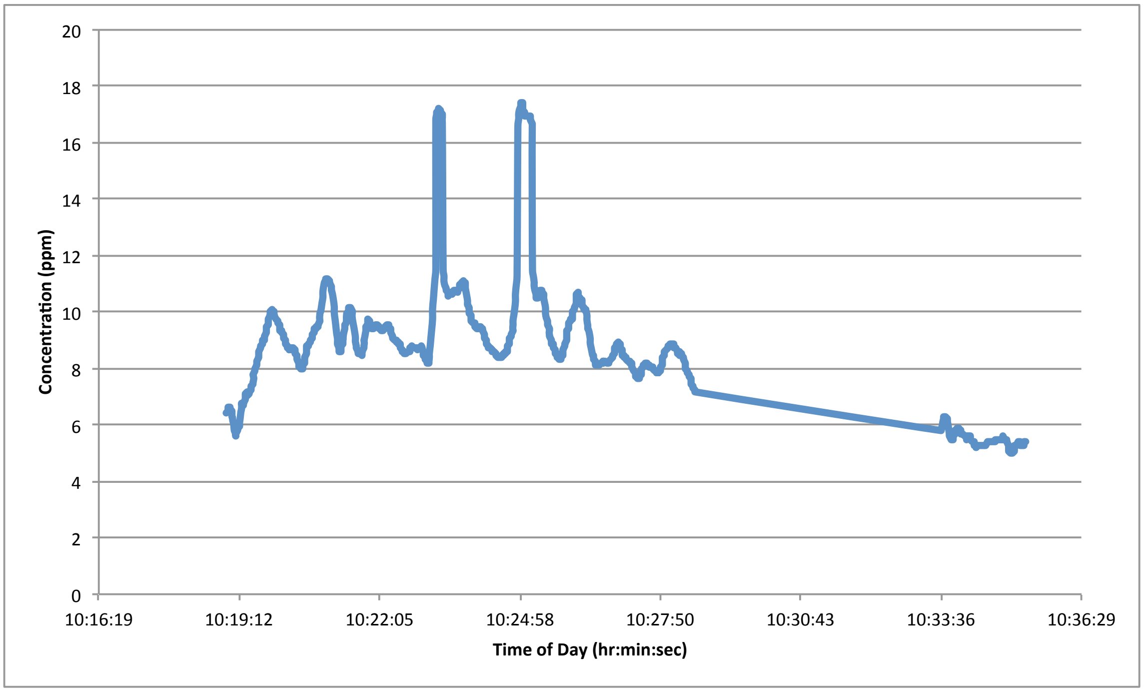

Figure 5-A: Isoflurane Concentration vs. Time for Surgery 4*

*The gas mask slipped off the animal two times during surgery.

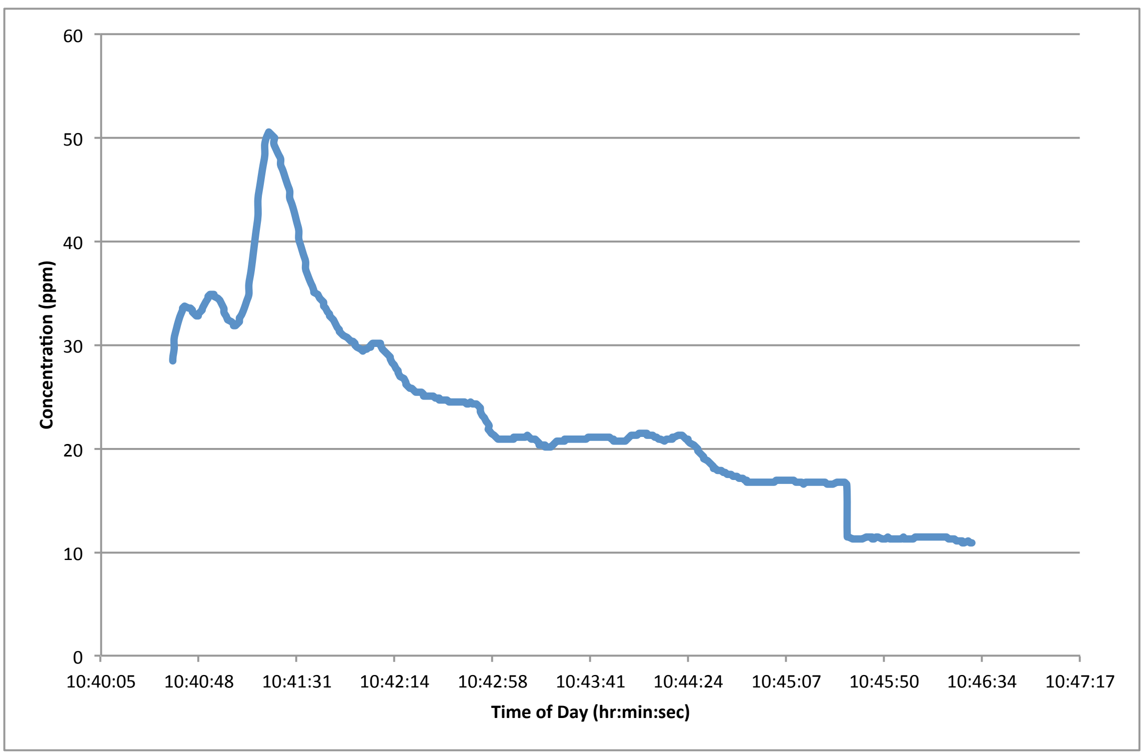

Figure 6-A: Isoflurane Concentration vs. Time for Surgery 5*

*The concentration of gas delivered to the animal was increased when the animal started waking up during surgery. Sampling began halfway through the surgery once the isoflurane concentration was increased.

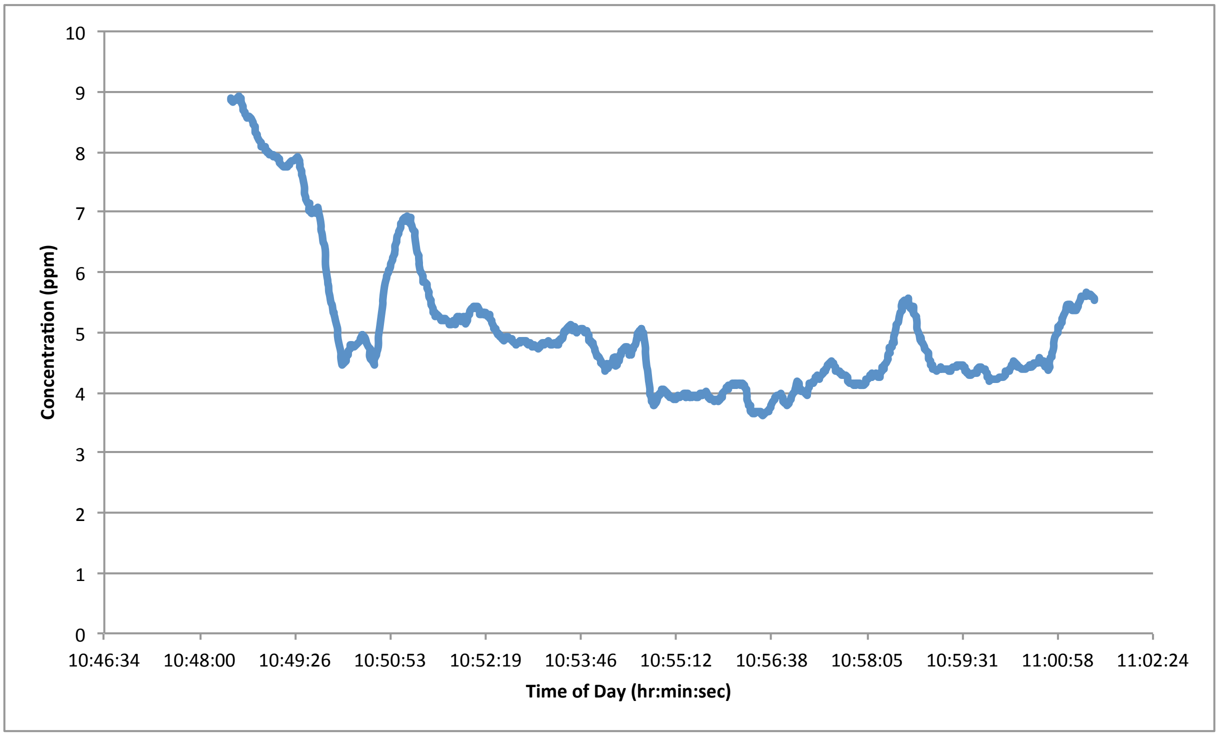

Figure 7-A: Isoflurane Concentration vs. Time for Surgery 6

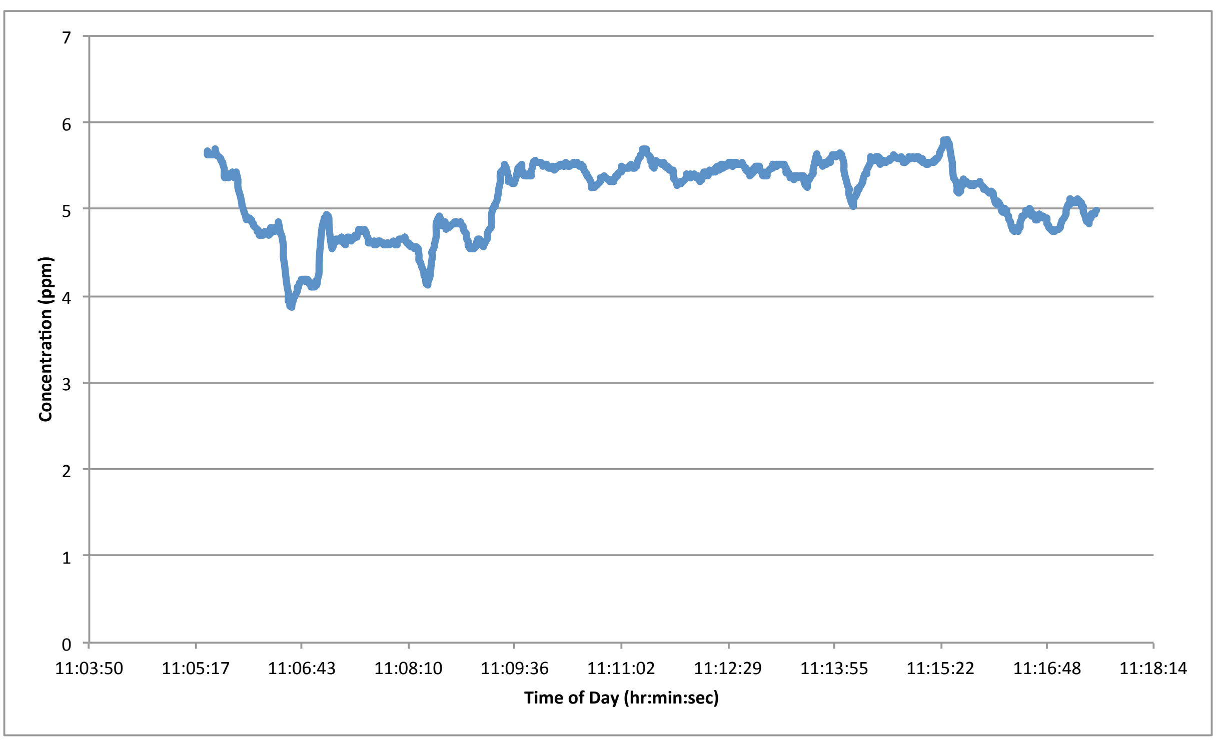

Figure 8-A: Isoflurane Concentration vs. Time for Surgery 7*

*Range between maximum (5.80 ppm) and minimum (3.87 ppm) isoflurane concentration was the smallest during this surgery.

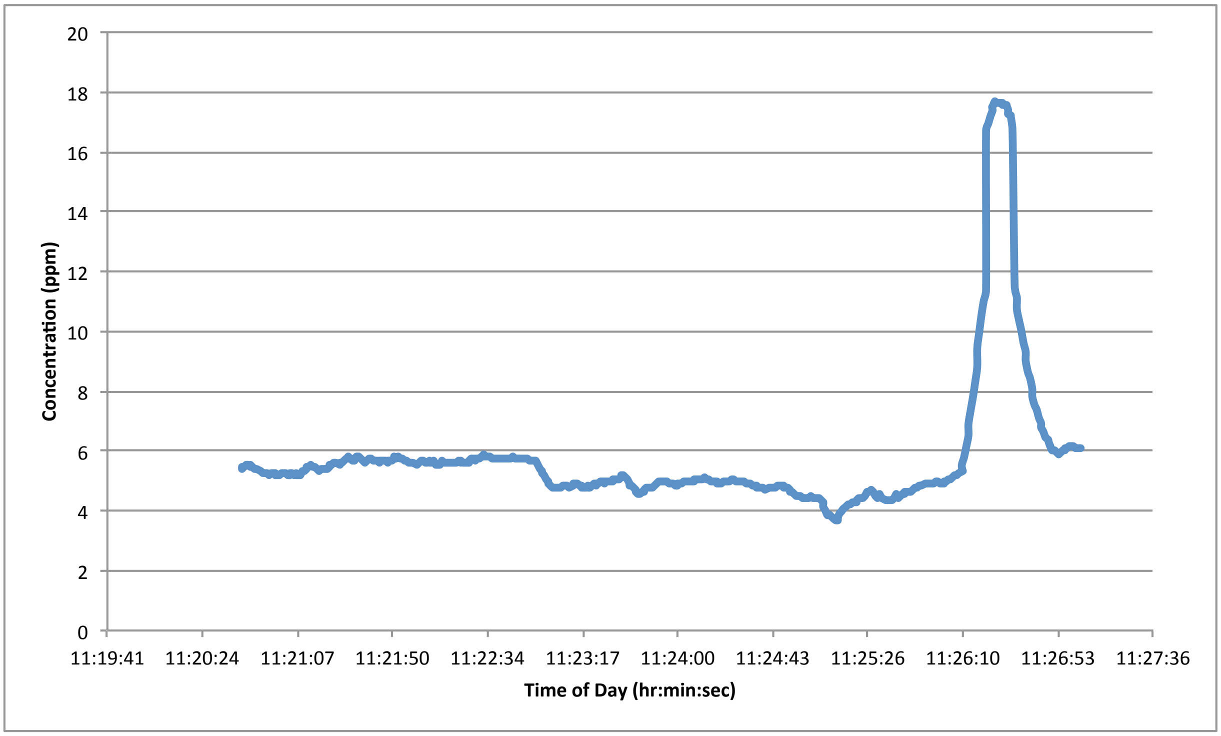

Figure 9-A: Isoflurane Concentration vs. Time for Surgery 8

Table IV: Personal Sampling for Isoflurane at Clinic A*					
Sample Number	**Worker Sampled**	**Sample Length (min)**	**Concentration (ppm)**	**8-hr TWA (ppm)****	**8-hr TWA (ppm)*****
1	Veterinarian	120	1.60	1.20	0.40
2	Veterinary Technician	120	2.00	1.50	0.50
3	Veterinarian	120	2.30	1.73	0.58
4	Veterinary Technician	120	1.80	1.35	0.45
5	Veterinarian	120	1.90	1.43	0.48
6	Veterinary Technician	120	0.73	0.55	0.18

*Analysis of sorbent tube samples included a blank sample from which no isoflurane was detected
**Assumed exposure lasted for 6 hours with no exposure for the remaining 2 hours
***Assumed an exposure of 0 ppm following the 2 hour sampling period

Sampling Results for Clinic B

Table V: Area Concentrations of Isoflurane at Clinic B*						
Surgery Number	Type of Operation	Delivery System	Length of Operation (min)	Average (ppm)	Max (ppm)	Min (ppm)
1	Dental	Tracheal Tube	30.17	1.53	14.88	0.00
2	Spay	Tracheal Tube	22.27	3.60	5.79	1.16
3	Spay	Tracheal Tube	36.32	2.11	6.41	0.07

*Only passive scavenging systems were used to control waste anesthetic gas

The total length of time that operations involving isoflurane were conducted was 88.76 minutes. The average and maximum isoflurane concentrations during this time were 2.41 ppm and 14.88 ppm, respectively.

Isoflurane concentrations from the first day of area sampling are shown in Figures 10-B through 13-B below. These operations match up with the list of operations shown in Table V. All sampling was conducted with the Miran SapphIRe XL probe placed about 1.5 ft from the veterinary worker.

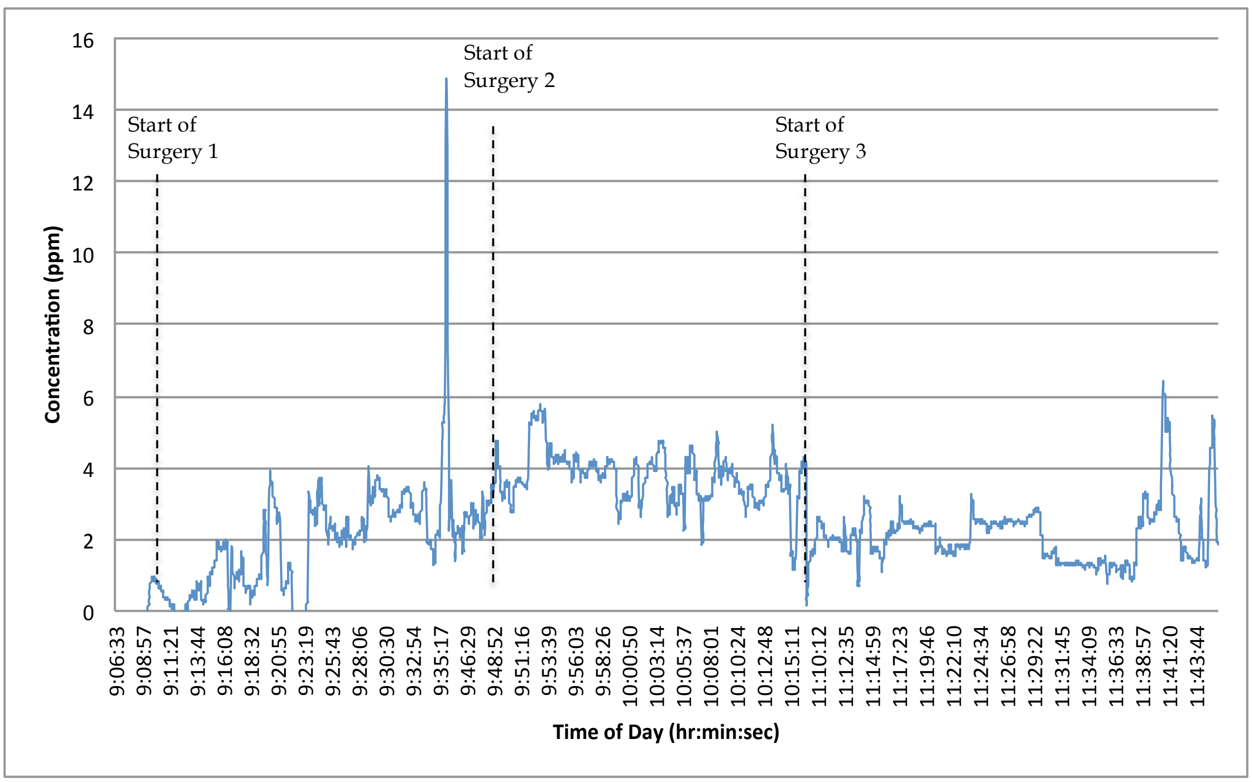

Figure 10-B: Isoflurane Concentration vs. Time All Surgeries

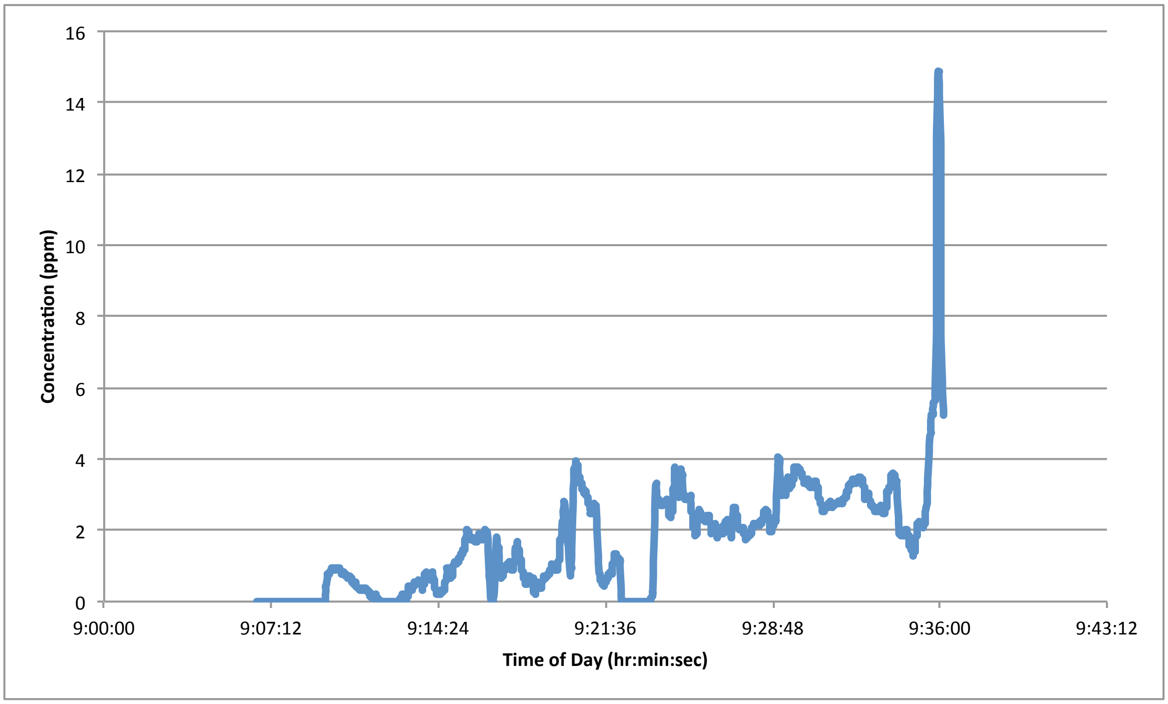

Figure 11-B: Isoflurane Concentration vs. Time for Surgery 1

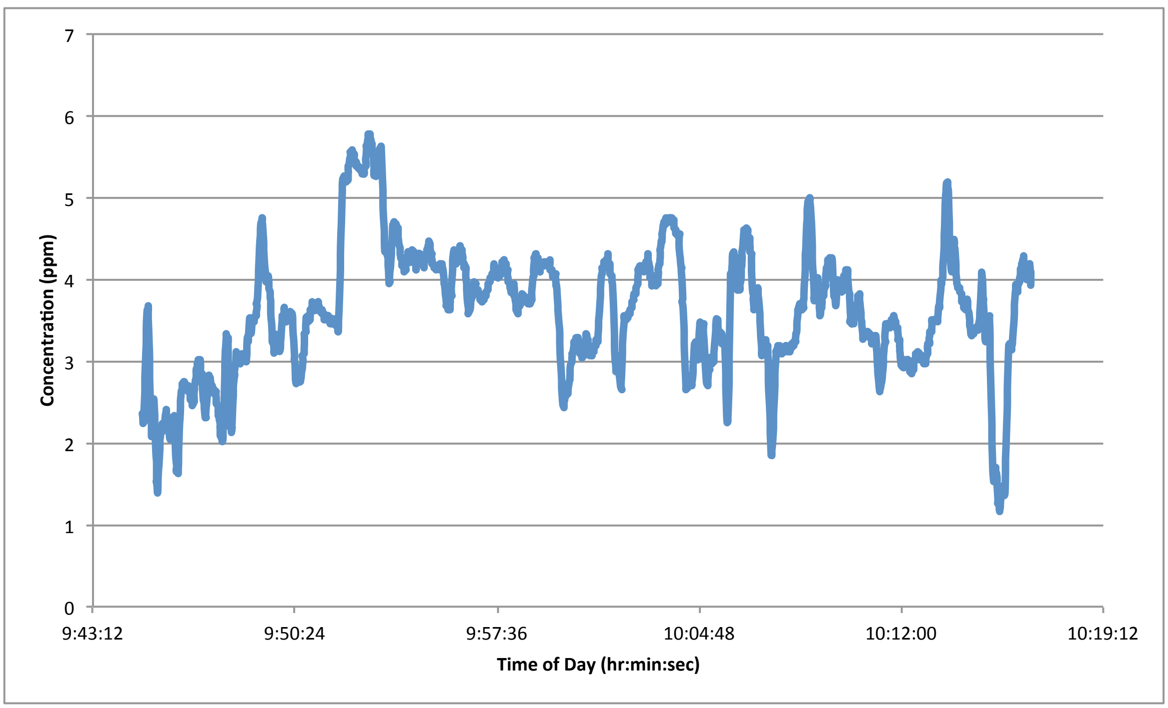

Figure 12-B: Isoflurane Concentration vs. Time for Surgery 2

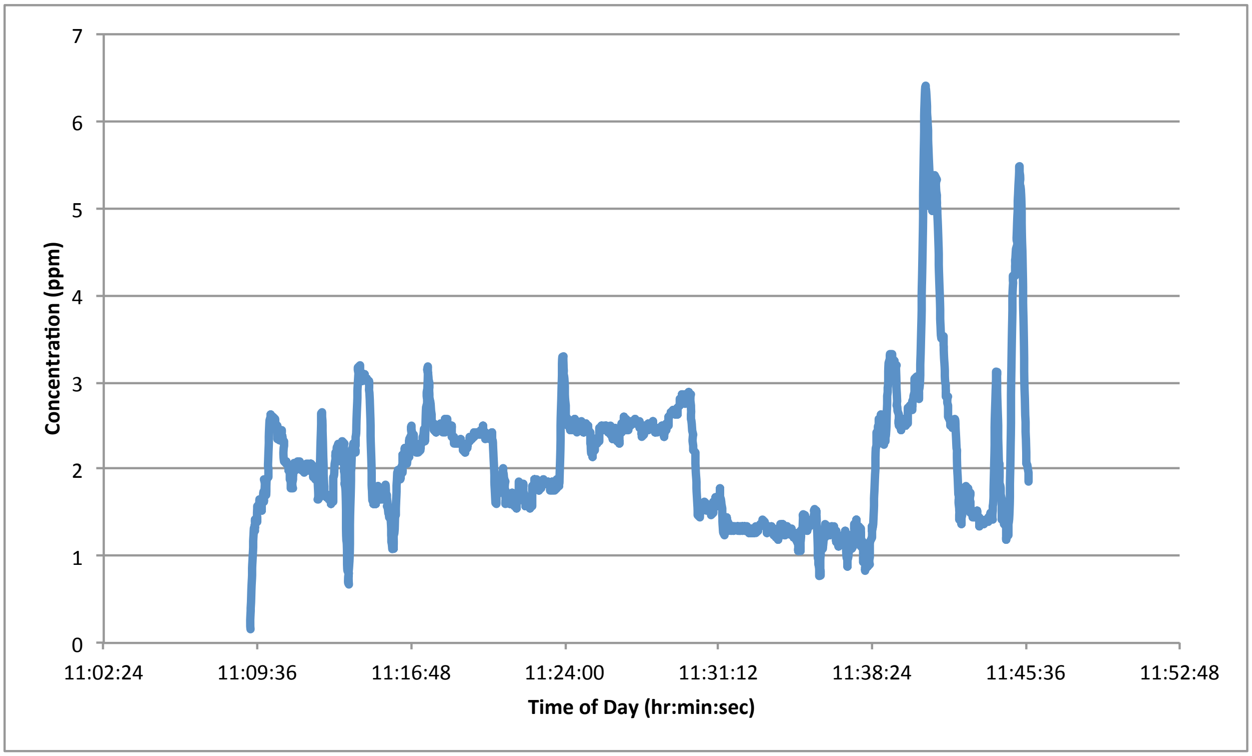

Figure 13-B: Isoflurane Concentration vs. Time for Surgery 3

Table VI: Personal Sampling for Isoflurane at Clinic B*					
Sample Number	**Worker Sampled**	**Sample Length (min)**	**Concentration (ppm)**	**8-hr TWA (ppm)****	**8-hr TWA (ppm)*****
1	Veterinary Technician	120	8.90	6.68	2.23
2	Veterinarian	120	0.65	0.49	0.16
3	Veterinary Technician	120	1.40	1.05	0.35
4	Veterinarian	120	3.80	2.85	0.95
5	Veterinary Technician	120	4.10	3.08	1.03

*Analysis of sorbent tube samples included a blank sample from which no isoflurane was detected
**Assumed exposure lasted for 6 hours with no exposure for the remaining 2 hours
***Assumed an exposure of 0 ppm following the 2 hour sampling period

Statistical Analysis of Data

Table VII: Statistical Analysis of Personal Sampling Data Between Veterinary Clinics*		
Statistic	**Clinic A**	**Clinic B**
Count	6	5
Mean (ppm)	1.72	3.77
Standard Deviation (ppm)	0.54	3.23

*A two-tailed T-test assuming unequal variance between personal sampling data at Clinic A and Clinic B gave a p-value of 0.23

Table VIII: Statistical Analysis of Isoflurane Exposures Between Veterinary Workers*		
Statistic	**Veterinarian**	**Veterinary Technician**
Count	5	6
Mean (ppm)	2.05	3.16
Standard Deviation (ppm)	1.15	3.03

*A two-tailed T-test assuming unequal variance between exposures to veterinarians and veterinary technicians gave a p-value of 0.44

Discussion

Surgeries conducted at the high volume clinic (Clinic A) were generally fast-paced, with the veterinary technicians preparing animals for surgery while the veterinarians performed operations. The process worked very efficiently, with one surgery being conducted almost immediately following the conclusion of the one before it. To do this, two operating tables were used in the surgical suite. Depending on the day, either one or two veterinarians would be performing surgeries while two to four veterinary technicians prepared animals for surgery and carried animals out of the operating room to a recovery area after surgery was completed. For all days that sampling occurred, the veterinarian remained in the surgical suite during the entire sampling period, while the veterinary technician moved from the surgical suite to the kennels to the surgical preparation and recovery areas

Surgeries at the low volume clinic (Clinic B) were conducted more slowly than at Clinic A. Only one veterinarian and one veterinary technician were involved with surgical procedures, with a second technician helping between operations. The primary veterinary technician would prepare an animal for surgery before the veterinarian came into the room to conduct the operation. After surgery, the veterinarian exited the operating room and the veterinary technician remained with the animal until the anesthetic wore off. A tracheal tube was used to deliver isoflurane to patients for all days that samples were obtained.

Area Sampling

Clinic A

Area sampling was conducted at Clinic A on February 4th, 2014. Area concentrations of isoflurane were recorded within 3 ft. of each veterinary worker for a total of 8 operations lasting roughly 80 minutes. Isoflurane concentrations in the area of the veterinarian were recorded for 5 surgeries and in the area of the veterinary technician for 3 surgeries. Surgeries ranged between 5 minutes and 15 minutes with an average surgery time of about 10 minutes. The average area isoflurane concentration was 8.7 ppm with a maximum concentration of 50 ppm. The average isoflurane concentration measured in the area (within 3 ft.) of the lead veterinarian was 9.7 ppm and the concentration in the area of the veterinary technician was 7 ppm. These data gives evidence that isoflurane exposures may be elevated in the high volume clinic.

Clinic B

Area sampling was conducted at Clinic B on February 11th, 2014. Area concentrations of isoflurane were recorded in the area (within 3ft.) of workers for a total of 3 operations lasting about 90 minutes. The average surgery time was just under 30 minutes. Both the veterinarian and veterinary technician remained in the same area during surgery, and the average isoflurane concentration within 3ft. of them was 2.41 ppm, with the maximum concentration reaching 14.88 ppm. These data provide evidence that elevated concentrations of isoflurane may also exist in the low volume clinic.

Personal Samples

All sorbent tubes were analyzed by Galson Laboratories, which is an American Industrial Hygiene Association (AIHA) accredited lab for anesthetic gas analysis. The analytical reports from Galson Laboratories can be found in Appendix 4.

Clinic A

Personal sampling was conducted on March 18th, April 8th, and April 9th, 2014 in accordance with OSHA Method 103 at Clinic A. Three personal samples were collected for the lead veterinarian and three were collected for the lead veterinary technician. During these days, a general trend was noticed with the delivery of isoflurane through a face mask substantially reduced. An injectable sedative was relied upon for sedation of animals instead, with face masks only being utilized when the effect of the injectable sedative started wearing off. Therefore the time that the anesthetic gas machines were turned on was much less than what was observed during area sampling.

Personal samples from March 18th, 2014 showed an exposure of 2 ppm for the veterinarian and 1.6 ppm for the veterinary technician. Personal samples from April 8th, 2014 showed that the veterinary technician was exposed to an isoflurane concentration of 1.8 ppm and the veterinarian exposed to an isoflurane concentration of 2.3 ppm. The third round of personal sampling, conducted on April 9th, 2014, showed an isoflurane exposure of 0.73 ppm to the veterinary technician 1.9 ppm to the veterinarian. These data give evidence that veterinary technicians may receive a higher dose of isoflurane than veterinarians at the high volume clinic, which is not surprising since these workers spend more time with the patient while isoflurane is being used.

Clinic B

Personal sampling was conducted on March 17th, April 7th, and April 10th, 2014 in accordance with OSHA Method 103 at Clinic B. The veterinary technician was the only worker sampled on the first day and both the veterinarian and veterinary technician were sampled on the second two days. Similar to the day that area sampling was conducted, the veterinary technician spent a longer duration of time in the surgical room compared to the veterinarian, who spent more time in the administration and patient rooms of the clinic.

The sorbent tube from personal sampling on March 17th, 2014 showed an isoflurane concentration of 8.9 ppm for the veterinary technician. Personal samples taken on April 7th, 2014 showed that the veterinary technician was exposed to an isoflurane concentration of 0.65 ppm and the veterinarian exposed to an isoflurane concentration of 1.4 ppm. Personal samples collected on April 10th, 2014 showed an isoflurane exposure of 3.8 ppm to the veterinary technician and an isoflurane exposure of 4.1 ppm to the veterinarian. As with Clinic A, data from Clinic B provides evidence that isoflurane exposure to veterinary technicians may be higher than exposures to veterinarains. These data also give evidence that worker exposures at the low volume clinic are greater than at the high volume clinic.

Differences in Exposure Between Veterinary Clinics

Statistical analysis of the personal sampling data showed that the average isoflurane exposure at Clinic B (3.77 ppm) was about 75% higher than the average exposure at Clinic A (1.72 ppm). An F-Test was run to determine if the variance between data sets was significantly different. The result of this test showed that the variance between samples was different, so the T-Test comparing data was done assuming unequal variance. The two-tailed T-Test between isoflurane exposures at high and low volume clinics gave a p-value of 0.23, therefore it was concluded that differences between the data were not statistically significant. Constraints on time and money did not allow for any additional samples to be collected, but given the high percentage difference between average exposures at the clinics, there is evidence that the low volume clinic had higher worker exposures to isoflurane.

Sources of Worker Exposure

Each veterinary clinic sampled had a unique method of delivering anesthesia and conducting surgeries. The equipment used for the delivery and collection of isoflurane, the size of the operating room, and the number operations performed also varied between clinics. Clinic A (High volume) conducted more operations, leaving workers with more opportunities for errors such as leaving an anesthetic gas machine on or allowing a gas delivery mask to slip off during surgery. Clinic A conducted more operations on more animals than the low volume clinics, which meant more connecting and disconnecting animals from breathing systems, allowing waste gases to contaminate the operating room air. However, this clinic made use of both active and passive scavenging systems, which allowed for more efficient and effective collection of waste gases compared to Clinic B.

Each clinic stated that they changed their passive waste canisters according to the manufacturer's suggestion, however given the inconsistency of these devices to trap isoflurane, it is possible that one canister was operating more effectively than the other even if they were being properly maintained. Clinic A was more likely to use anesthetic gas delivery masks, however they also avoided using gas delivery in the operating room for the majority of surgeries on the days when personal samples were taken. This work practice appears to be highly effective in reducing the exposure of workers to isoflurane gas. Clinic B made use of tracheal tubes, which are known to offer more reliable protection than gas masks, however escape of anesthetic gas can still occur any time the anesthetic gas machine is delivering isoflurane to a patient. Clinic B took longer to perform operations; therefore workers at this clinic spent a higher proportion of time in the surgical suite while the anesthetic gas machine was on.

It was noted in each of the veterinary clinics sampled that the concentration of isoflurane had a tendency to spike towards the end of an operation when the tracheal tube or mask was taken out of the patient. When these devices are removed, isoflurane can still be present in the tube going to the animal, which could cause the gas to spill into the air. To avoid this problem, veterinary workers can simply leave an animal connected to the breathing system for a few minutes after the supply of isoflurane is shut off. The problem with this is that it is expensive to keep the animal on oxygen and it results in a loss of productivity since the workers must wait a period of time before starting an operation on the next animal. This is of particular concern for high volume clinics, which have work practices designed around efficiency, allowing them to conduct a large number of operations.

Exposure Differences Between Veterinary Workers

After comparing exposures to workers between clinics, a statistical comparison of data was made between veterinarians and veterinary technicians. The results showed that veterinarians faced an average exposure of 2.05 ppm while veterinary technicians had exposures averaging about 40% higher at 3.12 ppm. Another F-Test was run and the result showed unequal variance between samples, so the ensuing T-Test was performed assuming unequal variance. The result of the two-tailed T-Test gave a p-value of 0.44, which is too high to imply statistical significance. As stated earlier, the small sample size of workers from which data was collected is likely to blame for the high p-value, these data still provide evidence that veterinary technicians may receive higher WAG exposures compared to their veterinarian co-workers.

Veterinary technicians at both clinics remained with patients for longer periods of time than the veterinarian. The technicians from both clinics were responsible for delivering isoflurane to patients prior to surgery and monitoring patients after surgery. Given that animals can exhale isoflurane for up to 2 hours after surgery, veterinary technicians may be exposed to air concentrations of isoflurane for a considerable period of time before and after an actual operation is performed. Veterinarians at Clinic A remained in the surgical suite throughout surgery, however scavenging systems were in place in this suite, which prevented the buildup of isoflurane gas. Veterinary technicians spent less time in the surgical suite of this clinic, however they spent much more time in the recovery area, which lacked a scavenging system, and in the surgical preparation area, which made use of an active scavenging system. Each worker had relatively equal opportunity to be exposed to isoflurane, which may explain why the variance was so low (0.29) between worker exposures at Clinic A.

In Clinic B, the surgical preparation area, recovery area, and surgical suite were all in the same room, and since there was no active scavenging system in place, gas concentrations were more likely to build up during back-to-back operations. The veterinary technician spent over 90% of her time in the surgical room while the veterinarian spent roughly 40-50% of her time in this room during sampling. This may explain why the variance between worker exposures (10.44) was so high.

Implications of Worker Exposures

Of the 11 samples taken, only 1 reached above the NIOSH recommended value of 2 ppm for an 8-hr TWA assuming no exposure after sampling. This sample came from the veterinary technician at Clinic B on a day when two operations were conducted at the clinic. This exposure would be representative of a day when only a small portion of the day is spent performing surgeries. For days when a greater amount of time is spent in the operating room, it is helpful to assume 6 hours of exposure followed by 2 hours of no exposure. When this is done, 3 samples from the low volume clinic and 0 samples from the high volume clinic exceed the recommended 8-hr TWA. In addition to long-term exposures over the course of a day, short-term exposures may also be of concern. There is currently no Short Term Exposure Limit (STEL) for isoflurane in America, but other countries have adopted STELs for worker exposure. It is important to note that there is a high amount of variation among STEL concentrations. For example, Switzerland recommends a STEL of 80 ppm for 15 minutes while the Czech Republic recommends a STEL of 3.99 ppm for an equal duration of time. Another country, Austria, has set a peak limit of 20 ppm not to be reached more than 4 times during a worker's shift. Samples from this study were all longer in duration than 15min, but two samples from Clinic B had concentrations exceeding the 3.99 ppm STEL from the Czech Republic. From these data there is evidence to support the possibility that exposures to veterinary workers may exceed occupational exposure limits set by some countries, while remaining well within standards set by other countries.

Workers Clinic B do not spend as much time using anesthetic gas, therefore even though they have higher exposures to WAG during surgery, the amount of time they spend exposed to WAG is far less than what workers face at high volume clinics. This is because the high volume clinic conducts surgery every week for at least 5 hours, while the low volume clinic may go a week without any surgeries being conducted at all. Therefore it is presumable that acute exposures with health effects such as headaches, nausea, fatigue, irritability, drowsiness, and central nervous system depression, may be more relevant to workers at low volume clinics. Contrast to this, chronic exposures with health effects such as liver disease, neurological damage, reproductive problems, and cancer may be more pertinent to workers at high volume clinics. It is important to note, however, that the high volume clinic sampled in this study had exposures that were far below the recommended threshold exposure limit believed to increase risk to the health effects described above.

Study Analysis

While other studies have discussed anesthetic gas exposures to veterinary workers, they have not defined how frequently participating clinics conduct surgeries. This study is unique in the way exposures to workers were compared between a clinic that routinely conducts operations and one that performs them far less frequently. Sampling results in this study were most similar to findings by Nesbit *et. al* (2013) and Potts & Craft (1988), where exposures ranged around 0.5 ppm and 9 ppm. However unlike the findings in this paper, those authors found that anesthetic gas exposures to the surgeons/veterinarians were greater than the exposure to the veterinary technicians. Research performed by Ruby *et. al* (1980) found that veterinary technicians had a higher exposure for some surgeries while veterinarians had higher exposures for others.

Future research should involve a larger sample size of clinics and workers in order to establish statistical significance of data. Long-term epidemiological studies could be conducted monitoring the health status of veterinary workers employed at high volume clinics to track chronic disease. Additional research could also be done at more unique veterinary clinics, such as those that treat exotic animals or large farm animals. Birds, for example, do not have a nose and mouth that will fit well around gas delivery masks. Similar complications may arise from animals that are too large to fit with a mask or tracheal tube. The concentration of gas must also be increased based on the weight of an animal. Therefore a very large animal, such as a giraffe or hippopotamus at a zoo, must be given a high dose of anesthetic to become sedated. Any leakage of waste anesthetic gas during an operation on such an animal would allow a high concentration of gas to contaminate the workers' breathing zones.

The chief weakness of this study was the low number of samples that were taken due to time and monetary constraints. A higher number of samples taken over a greater period of time would have allowed for improved statistical analysis of data. Another weakness came from the low number of clinics participating in the study. Collecting data from more than just two clinics would provide a better idea of what exposures are like at the average clinic and show what should be considered a higher or lower than normal exposure to workers.

Conclusions

The goals of this study were to determine whether workers at veterinary clinics in the Tampa Bay area are being exposed to isoflurane gas concentrations exceeding recommended exposure limits, if any disparity exists between exposures to veterinarians and veterinary technicians, and to compare the average worker exposure at high volume and low volume clinics. The hypotheses were that isoflurane exposure to workers would be higher in the low volume clinic than the high volume clinic and that veterinarian technicians would receive a greater dose of isoflurane than veterinarians. The data presented in this study suggests that the average exposure was higher for workers in the low volume clinic (Clinic B) and the average isoflurane exposure to veterinarians was less than the average exposure to veterinary technicians. Although statistical significance was not detected, likely due to the small sample size, the relatively large percentage differences between data suggests that a real difference may exist between isoflurane exposures to veterinary workers and between high and low volume clinics.

Work practices can be very effective in controlling exposures, as can sophisticated control equipment. Good work practices for limiting WAG exposure include leaving an animal connected to the breathing system for at least 5 minutes after isoflurane delivery is discontinued, using a tracheal tube instead of face masks for isoflurane gas delivery, and using only an injectable sedative for anesthesia.

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Appendix 1:

Interview Questions for Clinic A and Clinic B

Clinic A:

1. **What kind of control equipment do you use when performing surgery? (ventilation, scavenging system, ect.)**

We use an active scavenging system with rebreathing equipment and a passive scavenging system with non-rebreathing equipment. The active scavenger is running during all opeartions.

2. **What gases are used to sedate animals prior to surgery?**

Only isoflurane is used.

3. **How is gas administered (mask, injection?)**

A liquid sedative is first administered by injection. The animal is then given gas through a mask until completely sedated. Cats will usually be given gas through a gas mask on the operating table while dogs are incubated (gas delivery through a tracheal tube). Sometimes an injectable protocol is followed where only injectable and no anesthetic gas is used.

4. **How many surgeries are performed on average at the clinic during the course of a week?**

Varies seasonally. Usually 15-50 surgeries performed per week.

5. **How long does the average surgery last? From administration of anesthesia to veterinary workers leaving the side of the animal being operated on.**

Surgeries may last anywhere between 2 and 20 minutes. The average is around 10-15minutes. The veterinary technician remains with the animal pre and post surgery.

6. **Which veterinary worker (vet tech or veterinarian) prepares the animal for sedation? Who spends more time in the surgical room during the surgical process, from beginning to end?**

The veterinary technician administers and maintains gas flow to the animal. The vet tech spends longer with the animal during the surgical process but the veterinarian spends a longer amount of time in the surgical room.

7. **What kinds of animals are typically operated on at the clinic? (large, small, domestic, exotic, ect.)**

Mostly domestic animals, including dogs and cats. Less frequent operations are performed on other animals, such as rabbits and birds.

Clinic B:

1. **What kind of control equipment do you use when performing surgery? (ventilation, scavenging system, ect.)**

A passive scavenging system is used to collect waste gases.

2. **What gases are used to sedate animals prior to surgery?**

Only isoflurane is used.

3. **How is gas administered (mask, injection?)**

A liquid sedative is first administered by injection. Once the animal becomes sedated, a tracheal tube is inserted and isoflurane gas is delivered for the duration of the operation.

4. **How many surgeries are performed on average at the clinic during the course of a week?**

It depends on the month, sometimes we will go an entire week without performing a surgery and sometimes we will have 5-10 operations in a week. The average is between 3-5 operations.

5. **How long does the average surgery last? From administration of anesthesia to veterinary workers leaving the side of the animal being operated on.**

Most surgeries last 20-30 minutes. Very simple surgeries will go faster and complicated surgeries may take longer.

6. **Which veterinary worker (vet tech or veterinarian) prepares the animal for sedation? Who spends more time in the surgical room during the surgical process, from beginning to end?**

The veterinary technician administers and maintains gas flow to the animal. The veterinarian is only in the room during the operation, but the tech prepares the animal for surgery and monitors their recovery afterwards.

7. **What kinds of animals are typically operated on at the clinic? (large, small, domestic, exotic, ect.)**

This clinic sees primarily dogs and cats.

Appendix 2:

Calibration Data

Calibration Data for BIOS Primary Flow Meter					
Volume Traveled (L)	Time (sec)	Time (min)	Flow Rate (L/min)	BIOS Primary Flow Meter Reading	Average Flow Rate (L/min)
0.1	57.03	0.951	0.105	0.1002	**0.1050**
	56.89	0.948	0.105		
	56.93	0.949	0.105		

Appendix 3:

List of Equipment and Instrumentation

Thermo Scientific *
Miran Sapphire XL
*At the time of sampling, the manufacturer had last calibrated the instrument in May of 2010

Sensidyne
Gilian Air Sampling Pump

Alton Balometer

BIOS Dry-Cal Primary Flow Meter*
*At the time of sampling, the manufacturer had last calibrated the instrument in 2009

SKC Inc.
Sorbent Tube
Category 226-81A

Tygone Tubing

Appendix 4:

Analytical Results

ANALYTICAL RESULTS

Date: *27-Mar-14*

Client: GALSON LABORATORIES
Project: L313639 **Work Order No:** 14031129

Sample Identification: 0318VTA1
Lab Number: 001A **Date Sampled:** 3/18/2014
Sample Type: Anasorb 747 Tube **Date Received:** 3/21/2014
Analyst: MRD **Air Volume (L):** 12

Analyte	Analytical Results (μg)	Analytical Results (mg/m³)	Analytical Results (ppm)	Reporting Limit (μg)	Test Method	Date Analyzed
Isoflurane	180	15	2.0	4	OSHA 103/106	03/26/2014

Sample Identification: 0318VA1
Lab Number: 002A **Date Sampled:** 3/18/2014
Sample Type: Anasorb 747 Tube **Date Received:** 3/21/2014
Analyst: MRD **Air Volume (L):** 12

Analyte	Analytical Results (μg)	Analytical Results (mg/m³)	Analytical Results (ppm)	Reporting Limit (μg)	Test Method	Date Analyzed
Isoflurane	140	12	1.6	4	OSHA 103/106	03/26/2014

Sample Identification: 0317VTB1
Lab Number: 003A **Date Sampled:** 3/17/2014
Sample Type: Anasorb 747 Tube **Date Received:** 3/21/2014
Analyst: MRD **Air Volume (L):** 12

Analyte	Analytical Results (μg)	Analytical Results (mg/m³)	Analytical Results (ppm)	Reporting Limit (μg)	Test Method	Date Analyzed
Isoflurane	810	67	8.9	4	OSHA 103/106	03/26/2014

ANALYTICAL RESULTS

Date: ***27-Mar-14***

Client:	**GALSON LABORATORIES**		
Project:	**L313639**	**Work Order No:**	**14031129**
Sample Identification:	**BLANK**		
Lab Number:	**004A**	**Date Sampled:**	**3/18/2014**
Sample Type:	**Anasorb 747 Tube**	**Date Received:**	**3/21/2014**
Analyst:	**MRD**	**Air Volume (L):**	**NA**

Analyte	**Analytical Results (μg)**	**(mg/m³)**	**(ppm)**	**Reporting Limit (μg)**	**Test Method**	**Date Analyzed**
Isoflurane	<4	--	--	4	OSHA 103/106	03/26/2014

General Notes:
<: Less than the indicated reporting limit (RL).
--: Information not available or not applicable.
Back sections (if applicable) were checked and showed no significant breakthrough unless otherwise noted.

ANALYTICAL RESULTS

Date: *21-Apr-14*

Client: GALSON LABORATORIES

Project: L315743 **Work Order No:** 14040762

Sample Identification: 0408VTA
Lab Number: 004A **Date Sampled:** 4/8/2014
Sample Type: Anasorb 747 Tube **Date Received:** 4/14/2014
Analyst: CAW **Air Volume (L):** 12

Analyte	Analytical Results (μg)	Analytical Results (mg/m³)	Analytical Results (ppm)	Reporting Limit (μg)	Test Method	Date Analyzed
Isoflurane	170	14	1.8	4	OSHA 103/106	04/18/2014

Sample Identification: 0409VA
Lab Number: 005A **Date Sampled:** 4/9/2014
Sample Type: Anasorb 747 Tube **Date Received:** 4/14/2014
Analyst: CAW **Air Volume (L):** 12

Analyte	Analytical Results (μg)	Analytical Results (mg/m³)	Analytical Results (ppm)	Reporting Limit (μg)	Test Method	Date Analyzed
Isoflurane	180	15	1.9	4	OSHA 103/106	04/18/2014

Sample Identification: 0409VTA
Lab Number: 006A **Date Sampled:** 4/9/2014
Sample Type: Anasorb 747 Tube **Date Received:** 4/14/2014
Analyst: CAW **Air Volume (L):** 12

Analyte	Analytical Results (μg)	Analytical Results (mg/m³)	Analytical Results (ppm)	Reporting Limit (μg)	Test Method	Date Analyzed
Isoflurane	66	5.5	0.73	4	OSHA 103/106	04/18/2014

ANALYTICAL RESULTS

Date: *21-Apr-14*

Client: GALSON LABORATORIES

Project: L315743 **Work Order No:** 14040762

Sample Identification: 0410VB

Lab Number: 007A **Date Sampled:** 4/10/2014

Sample Type: Anasorb 747 Tube **Date Received:** 4/14/2014

Analyst: CAW **Air Volume (L):** 12

Analyte	Analytical Results (μg)	Analytical Results (mg/m³)	Analytical Results (ppm)	Reporting Limit (μg)	Test Method	Date Analyzed
Isoflurane	340	29	3.8	4	OSHA 103/106	04/18/2014

Sample Identification: 0410VTB

Lab Number: 008A **Date Sampled:** 4/10/2014

Sample Type: Anasorb 747 Tube **Date Received:** 4/14/2014

Analyst: CAW **Air Volume (L):** 12

Analyte	Analytical Results (μg)	Analytical Results (mg/m³)	Analytical Results (ppm)	Reporting Limit (μg)	Test Method	Date Analyzed
Isoflurane	370	31	4.1	4	OSHA 103/106	04/18/2014

General Notes:
<: Less than the indicated reporting limit (RL).
--: Information not available or not applicable.
Back sections (if applicable) were checked and showed no significant breakthrough unless otherwise noted.