Radiation Safety Behaviours Among Small Animal Veterinary Radiography and Fluoroscopy Workers

A Thesis Submitted to the College of Graduate and Postdoctoral Studies in Partial Fulfillment of the Requirements for the Degree of Master of Science

in the Department of Small Animal Clinical Sciences
University of Saskatchewan, Saskatoon

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ABSTRACT

This thesis incorporates two different studies investigating occupational exposure to ionizing radiation in veterinary workers. The first study evaluated the frequency of use of protective eyeglasses and gloves, and the frequency of protective behaviors (increasing distance from the body and head eye region to the radiation source), during manual restraint for radiography among small animal workers in a veterinary hospital before and after a video training module. In the second study we evaluated self-reported radiation safety behaviours among small animal veterinary diplomate and resident fluoroscopy users through an electronic questionnaire.

The first study demonstrated a significant improvement in all behavior outcomes after the video training (vs before), and also found that sedation or anesthesia reduce the need for workers to be inside the radiography room manually restraining the animal; however, the overall frequency of optimal behaviors was still low. The second study found a low eyeglasses and hand shielding compliance among veterinary fluoroscopy users. Both studies demonstrated that workers with formal training in radiation safety are more likely to adopt behaviours that reduce their dose, such as PPE compliance.

In conclusion, this thesis work found that education and formal training on radiation safety increases behaviours that decrease worker dose and help to develop a radiation safety culture in the workplace. However, it also found a low compliance of protective eyeglasses and gloves among veterinary radiology and fluoroscopy users. Finally, sedation or anesthesia should be used more often during diagnostic radiography as it reduces the need for workers to be inside the radiography room, thus reducing their radiation exposure.

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DEDICATION

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"Nothing is impossible. Every chain is breakable. With You, we are victorious. We are more than conquerors, through Christ. You have overcome this world, this life. We will not bow to sin or to shame. We are defiant in Your name. You are the fire that cannot be tamed. You are the power in our veins. Our Lord, our God, our Conqueror"

(Chris Llewellyn & Gareth Gilkerson)

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LIST OF ABBREVIATIONS

ACVIM	American College of Veterinary Internal Medicine
ACVR	American College of Veterinary Radiology
ACVS	American College of Veterinary Surgery
NCRP	National Commission on Radiological Protection and Measurements
ICRP	International Commission on Radiological Protection
mSv	Millisieverts
ALARA	As Low As Reasonably Achievable
Z	Atomic number
DNA	Deoxyribonucleic acid
Sv	Sievert
Gy	Gray
γ-rays	Gamma rays
IAEA	International Atomic Energy Agency
UV	Ultraviolet
UVB	Ultraviolet B
CT	Computed tomography
ICR	International Congress of Radiology
ICRU	International Commission on Radiation Units and Measurements
USA	United States of America
ALARA	As low as reasonably achievable
^{60}Co	Cobalt 60
WCVM	Western College of Veterinary Medicine
PPE	Personal Protective Equipment
kV	kilovoltage
mA	milliAmperes

1. INTRODUCTION AND LITERATURE REVIEW

In veterinary medicine, workers are frequently in the x-ray room while radiographs or fluoroscopy are being taken to provide restraint and positioning of the animal.[1-6] While at this time there is no recommendation for veterinary workers to use leaded eyeglasses in the National Council on Radiation Protection and Measurements (NCRP) 2004 and 1991 Health Canada published guidelines, these were written prior to the 2012 report of the International Commission on Radiological Protection (ICRP) that examined new data on the risk of cataracts.[7-9] The ICRP report reduced the radiation induced cataracts absorbed acute dose threshold from 2 mSv to 0.5 mSv (Millisieverts) and the recommended occupational exposure dose limit to the eyes from 150 mSv to 20mSv per year, over an average of five years, but not exceeding 50 mSv in one year. This dose limit is the same as the rest of the body.[9]

Compliance with regulations regarding radiation safety is extremely important for veterinary workers in order to minimize their exposure to radiation and to follow the principle of ALARA (As Low As Reasonably Achievable taking into account economic and social factors).[10] There is limited data available on the distance between workers' eyes and the source of radiation, as well as on the use of leaded eye protection in veterinary hospitals.[11-13] Increasing distance between the eyes and the radiation source and wearing leaded protective shielding can greatly reduce the radiation dose to the eyes.[14]

If state and provincial regulatory bodies follow these recommendations and decrease the occupational dose limit to the lens, which is likely, leaded eye shielding may soon be required for workers who remain in the room during exposures.

A 2018 study of worker dose during small animal radiography reported unshielded eye doses of 2.29mSv and 3.04mSv to two restrainers in a two months period, during which 778 exposures were acquired.[15] With the rapidly growing availability of digital radiography and fluoroscopy increasing the amount of diagnostic or interventional X-ray use and the exposed veterinary population, the risks to health due to ionizing radiation side effects also are increasing.

In light of the anticipated regulatory changes to the occupational lens dose limit resulting from the ICRP recommendations, these studies highlight the need for a change in worker behaviors that affect dose to the lens.

Currently available radiation safety training courses generally involve hours of training with a large volume of scientific and regulatory content aimed at veterinarians or veterinary technologists in a supervisory role, with very limited time, if any, dedicated to reducing dose to the lens of the eye. Training course developers who are not familiar with veterinary workplaces may overlook the challenges of manually restraining animals for radiographs.

Current literature on the use of PPE by veterinary workers during diagnostic radiographic imaging is based mainly on self-reported surveys in radiography;[1, 4,11,13,16-18] just one study used direct observation,[12] but no study has evaluated veterinary workers behaviors among fluoroscopy users or has objectively evaluated the effect of a radiation safety video training on veterinary worker behaviors.

1.1 History of X-rays

The X-ray was discovered by Wilhelm Conrad Roentgen in 1895 and his finding became public at a lecture when he performed the first radiograph of an anatomy professor’s hand, (Rudolf Albert von Kölliker's). The following year, the first X-ray medical diagnostic usage was reported in the journal Lancet in January 1896. This report described the use of X-ray to locate a fragment of a knife from the spinal column of a paralyzed sailor, who recovered his leg’s movement after the fragment removal.[19] In the same year the first therapeutic use was done to treat a hairy mole and within a few years, X-ray was being used for cancer treatment.[19]

This technology spread throughout Europe and North America, and early reports of side effects and hazard signs started to appear in the following years.[19] The pioneer biological effect described was the radioactive element radium that caused a skin erythema followed by an ulceration that took several weeks to heal. It was later denominated “radium burn”.[19] The increased rate of cancer was the major side effect of radiation in early X-ray workers; leukemia and skin carcinoma were the two most common cancers.[19] Moreover, in 1897, the first radiation-associated cataract experiment was performed,[20] which later was corroborated by other studies,[21] including ones on from atomic bomb survivors.[22-30] Current radiation medical modalities include diagnostic imaging, disease staging and treatment.[31]

1.2 Physics of X-Rays

X-ray is one type of electromagnetic radiation. The characteristics that distinguish X-rays are their wavelength and frequency. X-rays have a shorter wavelength and higher frequency than other types of electromagnetic radiation, such as radio waves, microwave, infrared, visible light and ultraviolet (UV).[19,32] While X-rays are produced in the electrosphere (extranuclear), γ-rays (gamma rays), another type of electromagnetic ionizing radiation, are produced by an unstable nuclei. Both have shorter wavelength and higher frequency than other types of electromagnetic radiation.[19]

Another way to describe X-rays is as a stream of photons, or small packages of energy. The higher the wave frequency and shorter the wavelength, the higher the energy of the photon.[19] When the photon transfers enough energy to eject an electron from the outer shell of an atom or molecule orbit, this is termed ionization and the radiation types that are capable of producing this process are called ionizing radiation.[19] Diagnostic X-rays are generated in a vacuum tube when high-speed electrons are emitted from the cathode, by an electric field, to the anode (target). When the electrons strike the anode (usually made of tungsten) they produce heat (99% of the dissipated energy). The remaining 1% of energy is dissipated when the electrons pass by near an atom, making them slow down and stop producing Bremsstrahlung photons; another part is dissipated when the electrons hit a bound orbital electron of an atom (in the inner shells) ejecting this electron. When the vacancy is filled by an outer orbital electron, it changes energy level and emits a photon (characteristic X-rays).[32,33]

1.3 Energy Absorption

An image can be produced by X-rays because a percentage are absorbed by the matter (the patient), while others are scattered and others pass through the matter unchanged[32] and hit the phosphor plate or digital image receptor, creating an image.[33] Since different types of body tissues have different absorption capabilities, the amounts of photons that pass through to the plate or receptor will vary, producing the radiographic image with a broad spectrum of shades of grey.[32] The absorption of photons depends on two factors: the composition of the matter and the energy of the photon.[19]

Photoelectric absorption and Compton scattering are the predominant phenomenon by which X-rays interact with matter in diagnostic imaging (due to the energy range of the photons).[34] Compton scatter radiation is generated when photons interact with the electrons of atoms, most likely with the outer layer electrons, transferring part of the energy and ejecting the electron (fast-moving charged particles). With the ejected electron, a scattered photon is emitted with a lower level of energy compared to the original photon since part has been transferred to the ejected electron. This event results in an ion (atom with an unpaired electron), an ejected electron and a scattered photon. These scattered photons are scattered from the patient towards the worker and are the main source of radiation exposure to workers restraining an animal.[34] The photoelectric effect results in absorption of the X-ray, without scatter. One important feature that increases the probability of photoelectric occurrence is the atomic number (Z) of the material. For this reason, wearing protective lead (a high Z material) equipment of 0.25-mm or 0.5-mm thickness attenuates respectively over 90% and 99% of X-rays, thus providing a high level of protection for the worker.[35]

1.4 Biological Damage

X-rays or γ-rays do not directly disrupt molecules causing biological or chemical damage, rather they produce fast-moving electrons that cause the damage.[19] They are therefore termed indirectly ionizing radiation.[19] Other important concepts are direct and indirect actions.[19] Direct action is when organic molecules, such as deoxyribonucleic acid (DNA), are directly targeted by the radiation and become ionized.[19] However, when the radiation produces free radicals (molecule or atom with an unpaired electron in the outer shell), which cause the biological damage, it is called indirect action of radiation.[19] Since water composes 80% of the cells, indirect is the predominant mechanism for biological damage.[19]

The major biologic injury of X-ray is chromosomal DNA damage that may lead to cell killing or mutation and carcinogenesis.[19] After DNA damage, cellular death primarily recurs when cells attempt to divide.[19] However, if the cells with impaired chromosomes survive mitosis, they are likely to maintain DNA errors after the mitosis, which is the first step toward cancer.[19]

When a small radiation dose is given, the risk of tissue damage is close to zero.[19] But above a certain level denominated threshold dose, this probability sharply rises to 100%.[19] This is termed deterministic effect, and the dose is related with the severity of the effect, (e.g. cataracts).[19] Another process that can happen after tissue irradiation is the stochastic effect.[19] If a somatic cell is irradiated, it increases the probability of cell damage that may lead to certain diseases, such as cancer.[19] Moreover, the severity of disease is not related to the dose.[19] Nevertheless, there is not a threshold dose below which this event will not happen; it may happen regardless the amount of absorbed dose, but the chance increases with the dose.[19]

1.5 Radiation Associated Diseases

Cancer associated with radiation exposure in pre-1950s workers was demonstrated in cohort studies. These studies highlighted a marked increase in risks of several types of cancer in radiation technologists such as skin cancer,[36,37] breast cancer[38,39] and leukemia.[40]

Many workers and scientists suffered from radiation injuries caused by chronic radiation exposure and even early death due the lack of knowledge and understanding of the need for radiation protection measures.[41] For instance, Marie Curie developed cataracts and died from anaplastic anemia after years working with radium and polonium (radioactive elements).[42] In the name of persons like the scientist Marie Curie, a memorial to the X-ray martyrs with workers' names from various countries was built at St. George's Hospital in Hamburg, Germany, in 1936.[43]

1.5.1 Radiation Induced Cataracts

Cataracts are defined as any opacity of the lens, which may lead to blindness.[44] This disease is considered an important health condition because it is the major cause of blindness around the world, so the identification of risk factors is highly desirable. But it is challenging to identify risk factors due the interactions between them, being different from the linear cause-effect relationship such as age and the disease.[45] Well studied risk factors are age, diabetes mellitus, corticosteroids, infections, trauma, nutritional deprivation and sunlight exposure (specially UVB, a non-ionizing radiation).[46]

The lens is considered a radiosensitive tissue,[47] especially the epithelial cells.[48,49] Epithelial cells suffer from aberrant proliferation and migration in a process termed epithelial to mesenchymal transition.[49] This process is present during cataractogenesis and posterior capsule opacification.[49]

Cataracts were one of the first lesions associated with ionizing radiation in the end of 1800's.[20] Some scientists suffered from this disease, like Marie Curie, who had four operations for cataracts in the beginning of the 20th century,[42] or nuclear physicists who developed incipient cataracts at a relatively young age for this condition.[50] However, the robust evidence in human beings came decades later from atomic bomb survivors who developed posterior subcapsular opacities.[22-30]

Radiation-induced lens opacity starts in the center of the posterior subcapsular lens region and appears as a dot on the ophthalmic examination. Over time, the opacity enlarges, and vacuoles and small granules appear in the adjacent areas surrounding it. With the continuous progression of the lesion to around 3 to 4 mm in diameter, the center becomes relatively clear, giving a doughnut-shaped feature.[19,51] Simultaneously, vacuoles and granular opacity also may emerge in the anterior subcapsular region in the central area.[19] There is not a pathognomonic ophthalmic lesion caused by ionizing radiation,[19,45,52,53] but this sequence of events associated with the history of radiation exposure is highly suggestive of radiation induced cataracts.[19,52] Evidence has been found that not only posterior subcapsular cataracts were overrepresented in populations exposed to ionizing radiation, but also cortical[45,53,54] and nuclear cataracts.[55] But posterior subcapsular opacities are still considered the major *footprint* of radiation induced cataracts.[56]

Some studies found that radiation used for medical purposes may lead to cataracts or other ophthalmopathy.[53,57] For example, diagnostic X-rays such as computed tomography (CT) head scans have been associated with the increased incidence of cataracts.[53] Radiation therapy may also increase the risk of cataract development[45,57,58] as well as other forms of ophthalmologic lesion such as optic nerve damage or retinopathy.[57] In children, the risk of cataracts seems to be even more significant.[30,58-64]

After the atomic bomb, the first studies to display a acute threshold dose for radiation induced cataracts estimated to be 1.5 Sv to 2 Sv.[28,65] However, the authors used the data collected just 19 years after the bombing,[25,51] while the latent periods can take up to 35 years.[66] The report from International Atomic Energy Agency (IAEA) suggests the dose to cause significant cataracts that would lead to vision impairment is between 2 and 10 Gy,[67] while a practical threshold acute dose to induce obvious lenticular opacity would be 0.5 Sv,[64] and a chronic low dose exposure over several years is estimated to be at least 0.15 Gy/year.[67] Further studies proposed lower threshold dose when an increased risk of cataracts was found after head CTs.[53]

More recently in the past two decades, epidemiological studies and reanalysis challenged the doses from early studies with a more robust data and suggested much lower doses can induce cataracts. Firstly, a study with 295 astronauts receiving low doses of space radiation (average of 45mSv of high linear energy transfer radiation) presented incidence of early cataracts.[68] Secondly, according to Chen, et al., 2001, 114 individuals exposed to chronic low dose to gamma ray (5 mSv/year for 10 years), who lived in a building contaminated with a radioactive element (^{60}Co) in

Taiwan, presented a higher risk of mild cataracts, especially young individuals. Thirdly, airplane pilots exposed to cosmic radiation presented an increased risk of developing nuclear cataracts.[55] Fourthly, the reanalysis for atomic bomb survivors suggested a dose threshold of 0.6 Sv for cortical cataracts and 0.7 Sv for posterior subcapsular cataracts, and both these doses were not significantly different from 0 Sv.[63] Finally, 25% of Chernobyl clean-up workers that received a low dose in a fractionated manner for about one year (most receiving 0.5 Gy of low linear energy transfer) presented posterior subcapsular or cortical lens opacity.[54] These epidemiological studies led to the new dose limit recommendations in the 2012 ICRP report, and increased the interest of researchers on eye dosimetry[69] and radiation induction cataracts.[70]

1.6 Radiation Protection

In 1904, Antoine L. G. Béclère was the first scientist to advocate for radiation protection measurements to protect physicians from X-rays, especially protection of the hands by wearing lead gloves during radiological procedures.[71] Even with early reports of harmful effects caused by X-rays, it was not until 1925 that the first International Congress of Radiology (ICR) proposed the first standards.[71] The Second ICR congress in 1928 invited several countries, and two commissions were set up after World War II: the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU).[19] Canada and most of Europe follow ICRP recommendations, although regulations around radiation protection and exposure fall under Provincial Occupational Health and Safety Act jurisdiction in Canada (see section 2.7).[19] In 1946 the United States of America (USA) set up the National Council on Radiation Protection and Measurements (NCRP).[19] But only in 1959, the first European managerial concerning the protection of workers against ionising radiation was released.[71] These committees evaluate the available data, formulate concepts, suggest risk estimates, recommend dose limits and protection measurements for safe practices, but they do not have jurisdiction to enforce laws.[19]

Since ionizing radiation may cause hazardous effects, unnecessary exposure should be avoided, and any exposure must be controlled and monitored.[19] The aim of radiation protection is to reduce radiation exposure to as low as reasonably achievable (ALARA),[10,19,72] taking into account economic and social factors,[10,72] a concept introduced by ICRP in 1950's (also called optimization).[72] It advocates three measures to reduces radiation exposure dose: shielding, distance and time of exposure.[72]

Given the common use of manual restraint of small animals, which decreases the distance between the worker and the source of ionizing radiation, the use of leaded equivalent personal protective equipment by veterinary workers becomes important in preventing occupational exposure.[12]

Another simple way to reduce the scatter radiation is to collimate the X-ray beam. A collimator restricts the primary beam to the area of exam interest.[33]

1.7 Legislation

In Canada, occupational radiation exposure is legislated at the provincial or territorial levels. For instance, Saskatchewan legislation requires enforcement of ALARA principles by employers but, does not specify the protective clothing or covers used by the workers.[73,74] Occupational workers, including veterinary, can receive up to 50mSv/year and a maximum of 100mSv in a period of 5 years (20mSv/year as an average). Currently, the specific equivalent dose limit regarding eye lenses is 150 mSv/year in Saskatchewan.[73,74]

At the federal level, Health Canada guidelines (as well as the USA's NCRP), recommend that veterinary workers always use at least 0.5 mm of lead or equivalent apron, thyroid shield and gloves that fully enclose from the wrists to the finger when manually restraining an animal for radiographic procedures.[7,8] They also recommend inspection of this equipment through an annual radiographs or whenever damage is suspected.[1,7,8] These are recommendations that Provincial governments may or may not use to make their own laws. Furthermore, Health Canada and NCRP guidelines were based on reports prior to most new cataracts epidemiological studies already described[54,55,62,63,68] and the ICRP Report 118, 2012.

As previously explained, in 2012, the ICRP reduced the estimated radiation induced cataracts threshold absorbed dose and equivalent dose to the eye lens, to the same dose limit as the rest of the body.[9] In 2019, the Nuclear Energy Agency Committee created the Expert Group on the Dose Limit for the Lens of the Eye in order to discuss regulations toward equivalent dose limit of the eye lens for occupational exposures, based on the latest ICRP report. Japan and some European countries have already started to enforce the new ICRP dose limits or are planning a transitional phase prior to fully implementing these limits. Canada has representatives from Health Canada and Canadian Nuclear Safety Commission participating in this meeting[75] so, we expect changes in regulations shortly.

1.8 Occupational Radiation Exposure in Veterinary Medicine

The greatest source of occupational radiation exposure for veterinary workers comes from medical use of therapeutic and diagnostic X-rays,[11,76] such as computed tomography (CT), fluoroscopy and radiography, with the last one being the modality most available in veterinary practices.[11] Animal radiological examination has two subgroups: small animal (mainly represented by dogs and cats) and large animals (mainly represented by horses).[5]

Veterinary patients commonly need a worker to manually position the animal during the X-ray exposure,[1-6,13,17,18] similar to orthopedic pediatrics radiograph[5]. Diagnostic radiography is performed by 90 to 95% of veterinarians and the majority of imaging is done by manually restraining the animal.[2,4,6,77] In Western Canada 95% of the animals were manually positioned.[6] This finding agrees with Mayer, et al., 2018, who found 92% of manual restraint in small animal radiograph at the Western College of Veterinary Medicine (WCVM). Wiggins et al., 1989 found that 83% of small animal veterinarians in California perform manual restraint during radiographs[2] and another study reported that 64% of American pregnant female veterinarians are exposed to X-rays due radiological procedures in the workplace.[78] Moreover, veterinarians in Western Australia spend on average 3 hours per day on radiological work.[77] A study found that most animals were manually restrained even when they were sedated or anesthetized, and concluded that sedation or anesthesia would not change the exposure of workers.[1] In contrast, Mayer et al., 2018, reported that the number of workers inside the radiology room was significantly lower when the animals were sedated or anesthetized compared to when they were not.

Prior to the 1940's and 50's, diagnostic X-rays were not commonly used in veterinary practices,[79] so reports of radiation-induced cancer in veterinary workers before that period were rare. In the 1960's and 70's, studies suggested a higher risk of developing certain types of cancer among veterinarians due to the carcinogenic effect of X-ray exposure,[1,80-82] such as hematopoietic and lymphatic cancers.[83,79] The lack of personal protective equipment (PPE) use in the same period,[81] helps to support the claim that radiation exposure contributed to cancer risk. Due the demographic shift from a majority of males to a majority of female veterinarians, risks to the embryo and fetus have become a greater concern.[4,78,79,84-88]

Because of the lack of physical sensation and markedly delayed health side effects, the risk of ionizing radiation exposure may be perceived as less important by the workers.[77] This idea is corroborated by some studies which found that veterinarians do not perceive ionizing radiation as one of the most concerning hazards in their profession,[11,16] although in more recent years, Jeyaretnam et al., 2000 found that 24% of veterinarians in Western Australia believe radiation is the most important occupational health and safety issue.[77]

The usage of personal protective equipment varies according to the type and decade that the research was done. For instance, between the 1960's to 80's, studies reported high rates of poor radiological protection practices and behavior among veterinarians.[81,90,91]. Regarding testing PPE for leaks, just 24.1% of apron and gloves were tested for leaks.[11]

Lead aprons have a broad use as a safe practice in recent studies, varying from 86% to 100%,[3,4,11,12] which is quite different from early surveys seven decades ago which found 25% of workers rarely used apron and many workplaces had just one apron, even when more than one worker was restraining the animal.[1] In the 1980's, some studies revealed a low use of thyroid shield protection varying from 0% to 1.2%,[11,16] but more recent studies suggested thyroid shield use has dramatically improved, varying from 83% to 100%.[3,12,92] Leaded glove use varies widely, ranging from 43.6% to 96.6%[3,11-13] and in one study evaluating specifically equine veterinarians, just 8% used gloves.[92] A major issue regarding surgeons' behavior was the unprotected hands and forearm while manual restraining the animal during radiography procedures.[90] Most studies have not evaluated leaded eyeglass use or availability as part of the PPE for veterinary workers exposed to occupational ionizing radiation,[1,3,4,11,81,90-92] but those which have found a very low percentage of workers were using protective eyeglasses when taking radiographs, varying from 0% to 3%[11,12] and in one study, some workplaces did not even had protective eye shield available to workers.[11,13]

Film badge dosimeters (personnel radiation dose monitoring devices) have a wide range of frequency of use, varying from 49.2% to 85% among veterinarian workers in USA and Canada,[2,3,11,12,92,93] however, in one study done in the late 80's, veterinary staff were commonly sharing the badge dosimeters and therefore not receiving accurate individual dose reports.[11]

1.9 Radiation Safety Training

Although most veterinary students in the USA worked in a veterinary practice prior to, or concurrent to, entering veterinary college,[6] the majority have not received any radiation safety training.[11] In a study, just 34.5% of all workers operating radiograph machines had received some type of radiation safety training and just 26.6% of the practices had a written safe operating procedure.[11] In a survey done in California, only 6% veterinary students had never manually restrained a patient for a radiographic procedure prior to entering college.[6]

Some evidence also suggested that the university from which the workers have obtained their degree was an important factor on their safety behavior.[16] In Western Canada, veterinarians who graduated after 1990 presented a higher chance to perform radiographs and manually restrain the animals (88% and 96% respectively) than veterinarians who graduated before 1990 (66% and 89% respectively).[6] The same study found that veterinarians who graduated after 1990 were 3.2 times more likely to report accidental X-rays exposure than ones graduating before 1990.[6]

The country of origin may also affect radiation safety attitudes; a worldwide survey found out that US interventional human cardiologists gave less consideration to ALARA principles and using personal or patient protective equipment than the rest of the world. It also showed that

Americans cardiologists are less concerned about radiation exposure to themselves and to the patient than European cardiologists.[94]

Some complex and comprehensive training in radiation safety has been tried in human medicine.[96] Dauer et al., 2006, studied a training intervention which included five different approaches, achieving a 12.7% improvement in nurses' behavior and knowledge. A more recent publication suggested training as a form of reducing radiation exposure to the patient and consequently to the workers. After a 90-minute minicourse for interventional cardiologists, the median overall dose area product (radiation dose in Gy, divided by area in cm^2) was reduced by 48.4% due to better parameters adjustment on the fluoroscopy machine and also a shorter fluoroscopy time.[95]

1.10 Safety Culture

The lack of safety culture can increase the chances of occupational health issues.[97] One way to define safety culture within an enterprise is "a set of individual and group values, attitudes and behaviour patterns, which determine the safety level of its employees' behaviours".[97] Another important term is attitude, which "denotes opinions, feelings and reactions manifested by a person relative to other people, objects, events and phenomena; an attitude may be positive, negative or ambivalent".[97] The last important term to highlight is risky behaviours, which are "those noncompliant with behaviours in safety regulations".[97]

To change a safety culture is not an easy task and requires not only change for the individual, but also for the organization and sometimes the whole industry.[97] Even in high risk hazard professions, such as coal miners, most workers and supervisors have a low positive attitude regarding safety standards.[97] But some experiences with long term behavioral modification programs are positive; accidents were decreased by 50% in a Polish coal mine after two years of implementation of safety training.[97]

Actions to improve implementation of safety can be summarized in 5 points. First, the alignment of the vision and the actions, to establish the connection between the idea and the final action at multiple levels.[98] Second, implementation of gradual small changes that complement one another, forming a greater change.[99] Third, the involvement of leaders in multiple hierarchical levels, up to the head of the department, increases effectiveness of the safety training and long term cultural change.[99] Fourth, fostering employees' engagement and fifth, promotion of staff collaborative relationships.[99]

2. OBJECTIVES

According to the authors' knowledge, no study has evaluated radiation safety behaviors among veterinary fluoroscopy users or has objectively evaluated the effect of a radiation safety video training module on veterinary workers performing diagnostic radiography.

The first objective of our study was to develop an open access training intervention. The second objective was to test the effectiveness of the training video in improving radiation safety behaviors during diagnostic radiography in a veterinary teaching hospital. To achieve this objective, we compared the use of protective shielding, head and body position, before and after the video training was completed by workers and to evaluate the number of people inside the radiological room. We examined potential risk factors for these radiation safety behaviors, including study type, worker categories, sedation, anesthesia, species, weight, and material restraint.

The objective of this cross-sectional survey study was to describe the radiation safety behaviors of veterinary specialists performing fluoroscopic procedures, including frequency of use of personal protective equipment. We also examined potential risk factors for these radiation safety behaviors, including knowledge of radiation risk, employer requirement that workers wear personal protective equipment, and training on machine parameters.

We hypothesized that the percentage of veterinary workers wearing properly protective gloves and eye shielding while performing diagnostic radiography will be significantly higher after a video training module than before the training. And regarding other behaviors, our hypotheses were that workers performing diagnostic radiography will use an optimal body and head position more frequently and would decrease the number of workers inside the radiology room during exposure after the video training (vs before). We also hypothesized poor radiation safety behaviors toward eye and hand protection among veterinary fluoroscopy workers, similar to the workers performing diagnostic radiography. Finally, we have hypothesized that the higher the worker knowledge, the better the PPE compliance.

3. MATERIALS AND METHODS

3.1 Impact of a Video Training Module on Worker Use of PPE, Head and Body Position During Small Animal Radiography at a Veterinary Teaching Hospital

The study was a prospective, observational design. The sample was comprised of workers from the Veterinary Medical Center at the Western College of Veterinary Medicine, University of Saskatchewan, who were involved in taking an after-hours radiograph of a small animal during a 17-week period between March 2 and June 30, 2019. After-hours was defined as after 5:00 p.m. and before 8:00 a.m. on weekdays, and 24 hours a day on weekends and holidays. This study was determined to meet the requirements for exemption status by the University of Saskatchewan Behavioral Ethics Board (BEH ID 36). All decisions for subject inclusion or exclusion were made by an analytical epidemiologist and an American College of Veterinary Radiology board-certified radiation oncologist.

3.1.1 Worker Training Video

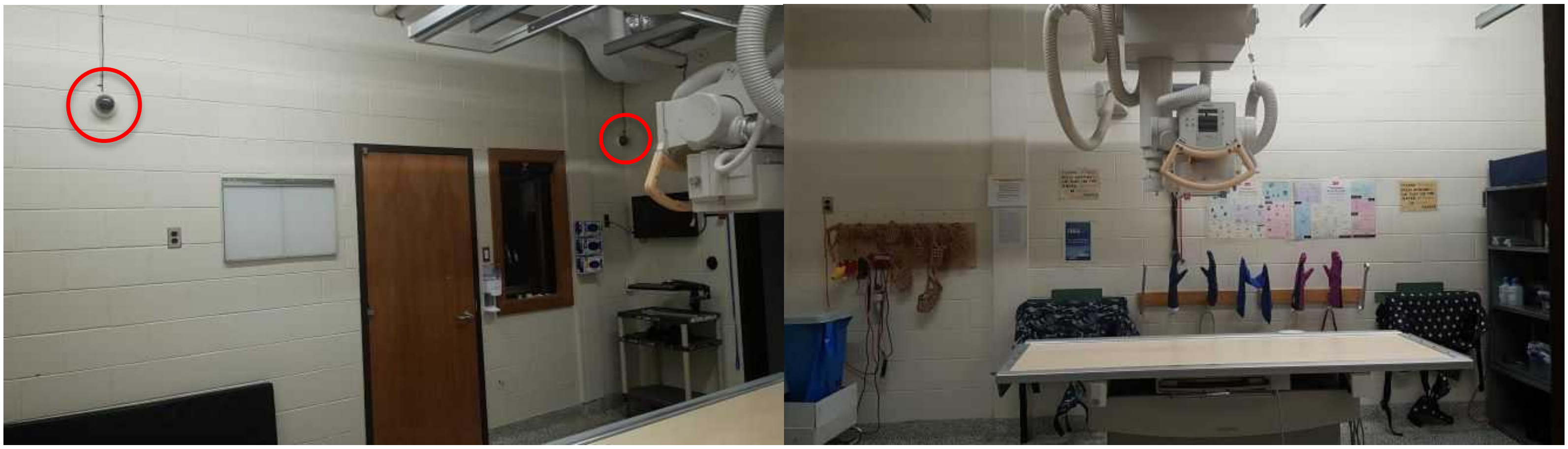
A 7-minute worker training video describing correct use of worker shielding equipment and optimal radiation safety behaviors during small animal radiography was developed by the authors with the University of Saskatchewan Teaching and Learning Media Production unit (https://vimeo.com/380783835/a5c2da35f2). The video was created in English and then translated into French, Spanish and Portuguese. The video included sections on body and thyroid protection, hand protection and eye protection. Veterinarians in the Department of Small Animal Clinical Sciences, veterinary students at the Western College of Veterinary Medicine and staff members of the Veterinary Medical Centre were enrolled by the University radiation safety officer in a mandatory course administered through Blackboard Learn. The course consisted of the training video and a 5-question multiple choice quiz based on the video contents and was released to the workers on April 4, 2019. The date and time of course completion was recorded for each worker.

Figure 3.1. This still shot captured from the video training module shows 2 workers performing a thoracic radiograph and wearing all recommended PPE (protective eyeglasses, leaded apron, thyroid shield and gloves), standing in an optimal body position (leaning backward), and looking straight at the animal's area to be radiographed.

3.1.2 Data Recording

Two motion-triggered video cameras were positioned to observe worker behavior and use of personal protective equipment. Cameras recorded color video, were equipped with night vision, and operated 24 hours a day in the main radiology imaging room. Leaded personal protective equipment available in the radiology room included aprons with and without attached thyroid shields, thyroid shields, gloves, and standard and fit-over eyeglasses. All video recordings were examined by a single investigator (the graduate student).

Figure 3.2. The two motion-triggered video cameras used to capture the video used for data collection, inside the radiology suite of the Veterinary Medical Center – Western College of Veterinary Medicine – University of Saskatchewan

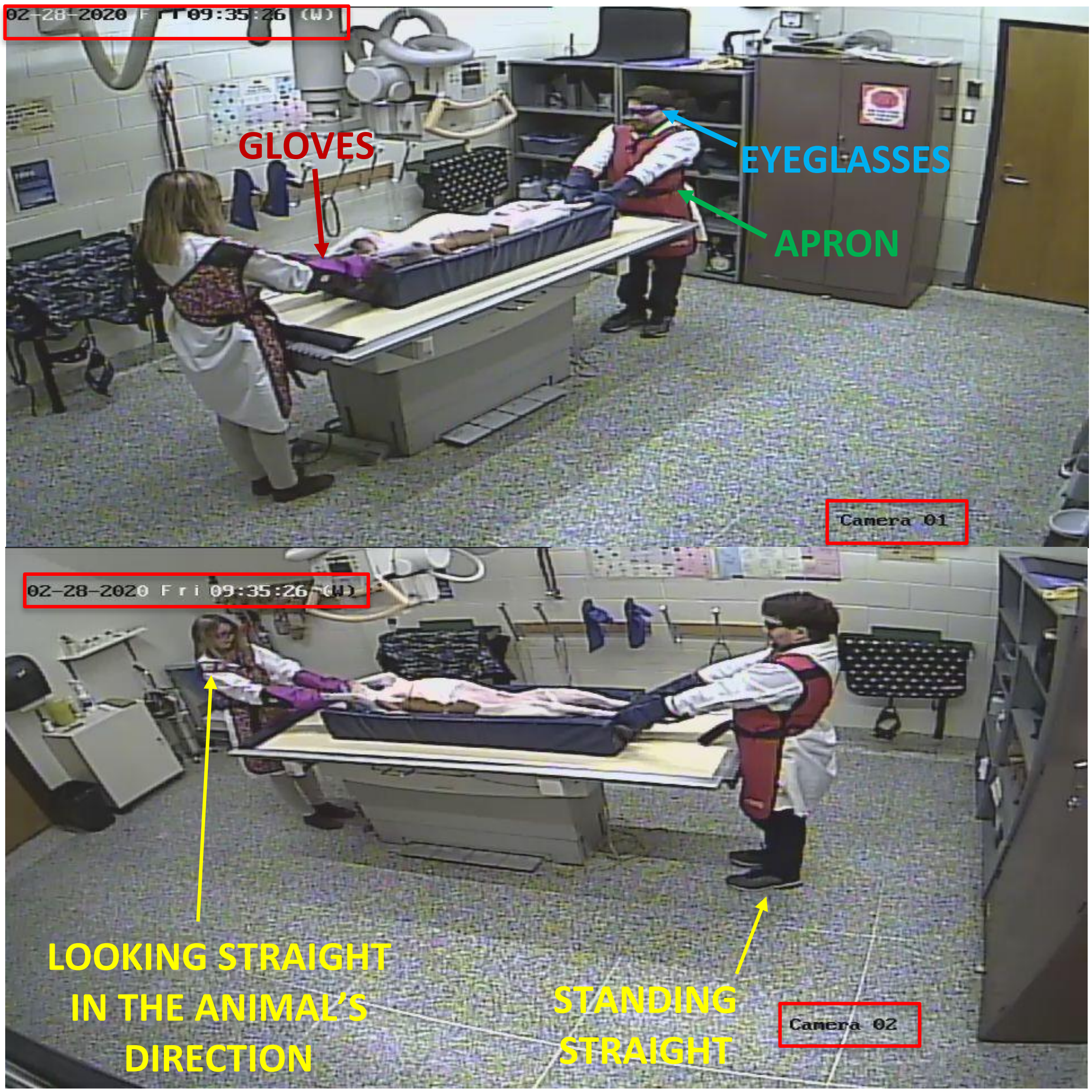


Data collected for each radiographic study included type of radiographic study (thorax, abdomen, front limb, hind limb, hip, spine, full body), species, weight, administration of sedatives prior to imaging, appearance of sedation (no voluntary movement by the animal), and if the animal was under general anesthesia (presence of an inserted endotracheal tube). A radiographic study was considered a set of radiographic images, including one or more views, of a single anatomical location of the same animal.

For each x-ray exposure, the number of workers in the room at the time of exposure, use of manual restraint, use of material restraint (ropes or sandbags used to restrain animal), the number of exposures sent to the Picture Archiving and Communications System (PACS), the presence of visible gloves or human body parts on the image and the number of spectators in the room at the time of exposure were recorded. Workers were considered to be spectators if they were in the room during the exposure with no contact with animal or cassette.

For each exposure-worker observation, worker completion of video training module and use of personal protective equipment including a lead apron, a securely closed thyroid shield, gloves and eyeglasses was summarized. Glove use was categorized as gloves used correctly (gloves worn on both hands with hands fully inserted into gloves) or gloves used incorrectly (no gloves worn, or gloves worn in any way other than what was considered to be correct use). Data were also collected on worker body position (leaning forward versus standing straight or leaning back) and head position (facing patient directly versus head turned to side). Workers were categorized as a veterinary technologist, Doctor of Veterinary Medicine (DVM), or DVM student.

Figure 3.3. Views from the two cameras inside the radiology suite: 2 workers simulating a thoracic radiograph and demonstrating optimal behaviour during manual restraint: wearing required PPE (protective eyeglasses, leaded apron, thyroid shield and gloves), standing in an optimal body position (straight or leaning backward), and looking straight to the animal's area to be radiographed while wearing eyeglasses. On the upper left side of each picture the date and time is visible, and on the bottom right side the identification of the camera is visible. The upper image represents camera 1 and the bottom picture represents camera 2.



3.1.3 Data analyses

All data analyses were completed by an analytical epidemiologist using commercial software (Stata SE version 16, StataCorp, College Station, TX).

Radiation safety behaviors were summarized for each unique x-ray exposure-worker observation, for all x-ray exposures with at least 1 worker in the room. Examined behaviors included use of lead gloves, use of lead eyeglasses, optimal head position at the time of exposure, and optimal body position at the time of exposure. Head position was considered optimal if the worker was facing patient directly if wearing lead eyeglasses or turned their head to the side if not wearing lead eyeglasses, and body position was considered optimal if the worker was standing straight or leaning back (versus leaning forward). Potential risk factors considered for these behaviors included: training video completion (before or after), study type (thorax, abdomen, front limb, hind limb, hip, spine or full body), worker category (non-radiology technologist, DVM or DVM student), species (canine, feline or exotic), patient weight (< 10 kg, 10-25 kg, > 25 kg), sedation and anesthesia. Apron and thyroid shield use were not examined as they were worn for all exposure-worker observations.

Generalized estimating equations were used to evaluate the differences between categories accounting for repeated measures for individual workers. The model included a logit link function, assumed a binomial distribution and an autoregressive(1) correlation structure to account for the order of the observations. Results were reported as odds ratios (OR) with 95% confidence limits (CI). Initially the associations between each risk factor and behavior were examined using bivariate or unconditional analysis. A multivariable model was built using stepwise, manual backwards elimination. Variables with $p \leq 0.20$ were considered in building the final model but only retained if $p \leq 0.05$. Any variable that when removed from the model changed the effect estimates for other factors of interest by more than 20% was also retained as a confounder. Risk factors that were very highly correlated were examined in separate models.

The number of workers in the room at the time of exposure was recorded for all exposures. Potential risk factors considered for the number of workers in the room during an exposure included: study type (thorax, abdomen, front limb, hind limb, hip, spine or full body), worker category (non-radiology technologist, DVM or DVM student), species (canine, feline or exotic), patient weight, sedation, anesthesia and use of material restraint. Training video completion was not examined as a risk factor because exposures with 0 workers in the room were included in this analysis. The model was built as above with generalized estimating equations adjusting for repeated measures within the same animal using a log link function and assuming a Poisson distribution. The effect estimate was exponentiated and reported as relative difference (RD) in counts with 95% CI.

3.2 Radiation Safety Practices Among Veterinary Fluoroscopy Users

3.2.1 Subject preparation

This study was approved by the University of Saskatchewan Behavioral Ethics Board (BEH ID 1580). An electronic questionnaire developed in SurveyMonkey (Enterprise, Ottawa, ON, Canada) (Appendix B) was distributed to American College of Veterinary Internal Medicine-Cardiology (ACVIM-Cardio) diplomates (n = 362) and residents (n = 106), American College of Veterinary Internal Medicine-Small Animal Internal Medicine (ACVIM-SAIM) diplomates (n = 1531) and residents (n = 358), American College of Veterinary Radiology (ACVR) diplomates (n = 725) and residents (n = 218) and American College of Veterinary Surgery (ACVS) diplomates (n = 763) and residents (n = 211) regarding radiation safety behaviors, including frequency of use of personal protective equipment and knowledge of risks of ionizing radiation. The study invitation and questionnaire link were distributed to ACVIM-Cardio, ACVIM-SAIM and ACVR members through the professional colleges' electronic diplomate and resident mailing lists. The invitation and link were distributed through the closed Facebook groups for ACVS diplomates and residents, as an electronic mailing list was not available. The initial invitation was followed with a one-week reminder.

3.2.2 Questionnaire

The questionnaire (Appendix B) initially asked respondents if they had been the operator of an X-ray unit for a small animal fluoroscopic procedure in the last year, and only respondents who answered yes were able to complete the remainder of the questionnaire. Respondents were asked how often they were involved in small animal fluoroscopic procedures, what type of fluoroscopic procedures they were involved in (cardiac, gastrointestinal, hepatobiliary, orthopedic, respiratory, urinary, vascular, other), the location of the viewing monitor relative to their position, what personal protective equipment their employer required them to wear (apron, thyroid shield, gloves, eyeglasses), and for which locations they had been assigned a personal dose monitoring device (dosimeter). Respondents were asked how often they wore an apron, gloves, thyroid shield, eyeglasses, body dosimeter, ring dosimeter and how often they used radiation attenuating hand cream or a lead shielding curtain during the X-ray exposure time (always, > 75% of the time, between 50% and 75% of the time, < 50% of the time, or never). Respondents were also asked what type of gloves (gauntlet type gloves, radiation attenuating surgical gloves) and eyeglasses (with or without side shielding) they used, if they used a dosimeter to estimate eye dose, and for what percentage of procedures an unshielded body part was visible on an acquired image.

Respondents were then asked whether they had received formal training regarding fluoroscopy machine parameters that reduce radiation exposure, and how often they adjusted these parameters during procedures to reduce their dose. Respondents were also asked to describe their knowledge of the risks of ionizing radiation, to identify the annual occupational dose limits to whole body and lens of the eye recommended by the International Commission on Radiological Protection (ICRP), whether they knew their last reported whole body and lens dose, and if they believed that radiation exposure increases the risk of cancer and cataracts. Finally, respondents were asked to select the 3 most important reasons for not wearing eyeglasses during a fluoroscopic procedure, with reason 1 being most important. Eight reasons were available: (1) eyeglasses interfere with performing my task, (2) eyeglasses are uncomfortable, (3) eyeglasses are not required by my employer, (4) not enough eyeglasses for all workers, (5) I am not concerned about the adverse health effects of ionizing radiation, (6) my coworkers do not wear eyeglasses, (7) eyeglasses are unhygienic, (8) eyeglasses do not fit properly.

3.2.3 Data analysis

All data analyses were completed by an analytical epidemiologist using commercial software (Stata SE version 16, StataCorp, College Station, TX).

Examined radiation safety outcomes included frequency of use of personal protective equipment (gloves, eyeglasses), lead shielding curtain, dosimeters (ring and body), and frequency of adjusting machine parameters to reduce radiation exposure. Potential risk factors considered for radiation safety outcomes were respondent knowledge of radiation risk (self-assessed and ability to correctly identify ICRP recommended dose limits), employer requirement that workers wear personal protective equipment, belief that radiation exposure can cause cataracts, professional college (ACVIM Cardiology, ACVIM Small Animal Internal Medicine, ACVR Diagnostic Imaging, ACVS), resident versus diplomate, age (≤ 45 years versus > 45 years), gender, practice type (private versus academic) and country (United States versus Canada). Training on machine parameters to reduce radiation exposure was only considered for frequency of adjusting machine parameters to reduce dose. Frequency of apron and thyroid shield use were not examined because > 95% of respondents always wore these types of shielding. As well, belief that radiation causes cancer was not considered as a risk factor because > 95% of respondents believed that radiation causes cancer.

The respective associations between risk factors of interest and frequency outcomes were assessed by means of appropriate nonparametric tests because each of those outcomes was reported on a 5-point ordinal scale. The Kruskal-Wallis test was used with post hoc protected Wilcoxon rank sum tests to identify significant pairwise comparisons. Outcomes were then recoded into 3 groups (never, inconsistent, always) and multivariable ordinal logistic regression models were built using stepwise, manual backwards elimination to identify final models and account for potential confounders. Interactions were not examined. Only variables with $p \leq 0.10$ in the nonparametric analysis were considered in building the final model. A p-value ≤ 0.05 was considered significant.

4. RESULTS

4.1 Impact of a Video Training Module on Worker Use of PPE, Head and Body Position During Small Animal Radiography at a Veterinary Teaching Hospital

Data were collected from 374 radiographic studies (1478 exposures) of 310 animals: 75.2% (233/310) dogs, 21.0% (65/310) cats and 3.9% (12/310) exotics; 54.1% (144/266) males, 45.5%

(121/266) females, and 0.4% (1/266) unknown; 75.2% (200/266) intact, 22.2% (59/266) neutered and 2.6% (7/266) unknown. Of the radiographic study types included, 38.5% (144/374) were of the thorax, 39.3% (147/374) of the abdomen, 5.3% (20/374) of the front limb, 7.0% (26/374) of the hind limb, 5.3% (20/374) of the hip, 1.9% (7/374) of the spine, and 2.7% (10/374) of the full body. Animals were not sedated or anesthetized for 69.5% (260/374) of studies, had sedatives administered prior to imaging or the appearance of sedation for 25.4% (95/374), and were under general anesthesia for 5.1% (19/374). Thus, the exposure-worker events were done with the animals under sedation or general anesthesia in 10.6% (188/1769) and 1% (17/1769) of the times, respectively.

Manual restraint of the animal was used for 78.3% (1158/1478) of exposures, material restraint was used during 12.0% (177/1478) of exposures, both were used in 1.2% (18/1478) of exposures, and neither was used in 11.0% (163/1478) of exposures. Of the 1478 exposures, 80.7% (1193/1478) were sent to PACS for diagnostic interpretation.

For 21.7% (321/1478) of exposures there was no worker present in the radiology room during the exposure, for 26.0% (385/1478) of exposures there was 1 worker present, for 50.7% (750/1478) of exposures there were 2 workers present, and for 1.5% (22/1478) of exposures there were 3 workers present. A worker was present in the room as a spectator for 3.6% (53/1478) of exposures. Gloves were visible on the radiographic image in 1.1% (13/1158) of exposures with at least 1 worker present, and in no instance were unshielded human body parts visible on an exposure.

At least 1 worker was present in the room for 78.3% (1158/1478) of exposures. For these 1158 exposures, individual worker observations were summarized as 1769 unique imaging exposure-worker observations (for example, 1 imaging study with 2 workers present would count as 2 unique imaging exposure-worker observations).

An apron with a securely closed, attached thyroid shield was worn for 100% (1769/1769) of exposure-worker observations. 74.2% (1313/1769) of observations demonstrated incorrect glove use. Of the incorrect use observations, most of the time workers were not wearing gloves on either hand (80.6%, 1058/1313), and 13.4% (176/1313) of incorrect use observations showed workers wearing a glove on one hand only. For 6.0% (79/1313) of incorrect glove use observations, workers laid a glove on top of one or both hands during the exposure while wearing just one glove or no gloves.

The behaviours of 53 workers were observed: 32% (17/53) DVMs, 34% (18/53) veterinary technologists, and 34% (18/53) DVM students. None of the veterinary technologists were dedicated to the Radiology service and none of the DVMs were radiologists.

4.1.1 Factors associated with personal protective equipment use, and head and body position

In unconditional analysis, correct glove use was significantly more likely for workers after completing the video training module, when imaging a hip or spine (versus a thorax), if they were a DVM student (versus a technologist), and if the patient weighed between 10 - 25 kg (versus < 10 kg) (Appendix A.1). Correct glove use was significantly less likely for workers when imaging a front limb (versus a thorax). Species, sedation, and anesthesia were not significantly associated with correct glove use ($p \geq 0.24$). In final multivariable analysis, workers wore gloves correctly significantly more frequently after completing the video training module (OR 2.09), when imaging hip or spine (versus a thorax), if they were a DVM student (versus a technologist) (Table 4.1).

Correct glove use was significantly less likely for workers when imaging a front limb (versus a thorax).

Table 4.1. Final Multivariable Model of the Associations Between Risk Factors of Interest and Whether or Not Lead Gloves Were Used Correctly Summarized for 1158 Exposures From 296 Imaging Studies Completed on 265 Animals by 53 Workers (1769 Unique Imaging Exposure-Worker Events)

	FREQUENCY[a]	**aOR**[b]	**95% CI**[c]	**P VALUE**
Gloves used correctly	0.26 (456/1769)			
After Training				
Not used correctly	0.18 (131/729)	Reference category		
Used Correctly	0.31 (325/1040)	2.09	1.68 – 2.59	< 0.001
Study Type				< 0.001
Thorax	0.26 (186/717)	Reference category		
Abdomen	0.25 (215/855)	0.93	0.76 – 1.14	0.50
Front limb	0.18 (12/68)	0.31	0.15 – 0.60	0.001
Hind limb	0.27 (17/64)	0.77	0.45 – 1.32	0.34
Hip	0.55 (18/33)	3.07	1.57 – 6.00	0.001
Spine	0.67 (8/12)	4.90	1.56 – 15.4	0.006
Full body	0 (0/20)	Non-estimable		< 0.001
Worker category				< 0.001
Technologist	0.23 (239/1042)	Reference category		
DVM	0.22 (119/536)	0.88	0.69 – 1.12	0.30
DVM student	0.51 (98/191)	2.67	1.88 – 3.80	< 0.001

[a]Relative frequency
[b]OR Odds ratio, calculated adjusting using logistic regression adjusted for repeated measures within individual workers.

[c]95% confidence interval

In unconditional analysis, use of eyeglasses was significantly more likely for workers after completing the video training module (Appendix A.2). Study type, worker category, species, weight, sedation, and anesthesia were not significantly associated with use of eyeglasses ($p \geq 0.15$). In final multivariable analysis, wore eyeglasses significantly more frequently after completing the video training module (OR 1.85) (Table 4.2).

Table 4.2. Final Multivariable Model of the Associations Between Risk Factors of Interest and Whether or Not Lead Eye Shielding Was Used Summarized for 1158 Exposures From 296 Imaging Studies Completed on 265 Animals by 53 Workers (1769 Unique Imaging Exposure-Worker Events)

	FREQUENCY[a]	**aOR[b]**	**95% CI[c]**	**P VALUE**
Eye shielding worn	0.03 (56/1769)			
After training use of eye shielding				
No	0.008 (6/729)	Reference category		
Yes	0.05 (50/1040)	1.85	1.23 – 2.78	0.003

[a]Relative frequency
[b]OR Odds ratio, calculated adjusting using logistic regression adjusted for repeated measures within individual workers.
[c]95% confidence interval

In unconditional analysis, optimal head position was significantly more likely for workers after completing the video training module, when imaging an abdomen (versus a thorax) and if the patient weighed > 25 kg (versus < 10 kg) (Appendix A.3). Optimal head position was significantly less likely if workers were a DVM (versus a technologist), and if the patient was a cat or an exotic (versus a dog). Sedation and anesthesia were not significantly associated with optimal head position (p-values 0.14 and 0.44, respectively). In final multivariable analysis, optimal head position was significantly more likely for workers after completing the video training module (OR 1.27), when imaging an abdomen (versus a thorax) and if the patient weighed > 25 kg (versus < 10 kg) (Table 4.3). Optimal head position was significantly less likely if workers were a DVM (versus a technologist).

Table 4.3. Final Multivariable Model of the Associations Between Risk Factors of Interest and Whether or Not Head Position was Optimal[a] Summarized for 1158 Exposures From 296 Imaging Studies Completed on 265 Animals by 53 Workers (1769 Unique Imaging Exposure-Worker Events)

	FREQUENCY[b]	aOR[c]	95% CI[d]	P VALUE
Head Position Optimal	0.35 (611/1769)			
After Training				
Not optimal	0.30 (222/729)	Reference category		
Yes (optimal)	0.37 (389/1040)	1.27	1.03 – 1.58	0.03
Study Type				0.003
Thorax	0.31 (222/717)	Reference category		
Abdomen	0.39 (333/855)	1.43	1.16 – 1.77	0.001
Front limb	0.26 (18/68)	0.65	0.36 – 1.19	0.17
Hind limb	0.38 (24/64)	1.11	0.65 – 1.90	0.70
Hip	0.24 (8/33)	0.68	0.31 – 1.50	0.34
Spine	0.42 (5/12)	1.12	0.34 – 3.68	0.85
Full body	0.05 (1/20)	0.22	0.03 – 1.75	0.15
Worker category				< 0.001
Technologist	0.39 (406/1042)	Reference category		
DVM	0.26 (141/536)	0.61	0.47 – 0.79	< 0.001
DVM student	0.34 (64/191)	0.83	0.58 – 1.18	0.30
Weight				0.02
< 10 kg	0.31 (254/822)	Reference category		
10 – 25 kg	0.34 (126/369)	1.03	0.79 – 1.35	0.81
> 25 kg	0.41 (227/560)	1.38	1.09 – 1.74	0.007

[a]Head position was considered optimal if the worker was facing patient directly if wearing lead eyeglasses or turned their head to the side if not wearing lead eyeglasses

[b]Relative frequency
[c]OR Odds ratio, calculated adjusting using logistic regression adjusted for repeated measures within individual workers.
[d]95% confidence interval

In unconditional analysis, optimal body position was significantly more likely for workers after completing the video training module, if the patient weighed 10 – 25kg or > 25 kg (versus < 10 kg), and if sedation or anesthesia were used (Appendix A.4). Optimal body position was significantly less likely if the patient was a cat or an exotic (versus a dog). Study type and worker category were not significantly associated with optimal body position (p-values 0.51 and 0.53, respectively). In final multivariable analysis, optimal body position was significantly more likely for workers after completing the video training module (OR 1.85), if the patient weighed 10 – 25kg or > 25 kg (versus < 10 kg), and if sedation or anesthesia were used (Table 4.4).

Table 4.4. Final Multivariable Model of the Associations Between Risk Factors of Interest and Whether or Not Workers Stood Straight or Leaned Backwards (Optimal Body Position) Summarized for 1158 Exposures From 296 Imaging Studies Completed on 265 Animals by 53 Workers (1769 Unique Imaging Exposure-Worker Events)

	FREQUENCY[a]	**aOR[b]**	**95% CI[c]**	**P VALUE**
Standing Straight or Leaning Back	0.32 (569/1769)			
After Training				
No	0.24 (178/729)	Reference category		
Yes	0.38 (391/1040)	1.85	1.48 – 2.23	< 0.001
Weight				< 0.001
< 10 kg	0.25 (205/822)	Reference category		
10-25 kg	0.37 (136/369)	1.43	1.09 – 1.87	0.01
> 25 kg	0.40 (224/560)	1.77	1.39 – 2.26	< 0.001
Sedation				
No	0.30 (467/1581)	Reference category		
Yes	0.54 (102/188)	2.54	1.86 – 3.49	< 0.001
Anesthesia				
No	0.32 (558/1752)	Reference category		
Yes	0.65 (11/17)	3.57	1.22 – 10.47	0.02

[a]Relative frequency
[b]OR Odds ratio, calculated adjusting using logistic regression adjusted for repeated measures within individual workers.
[c]95% confidence interval

4.1.2 Factors associated with number of workers in the room for each exposure

In unconditional analysis, there were significantly more workers in the room when imaging an abdomen (versus a thorax) and if the patient weighed 10 – 25kg or > 25 kg (versus < 10 kg) (Appendix A.5). There were significantly less workers in the room when imaging a front limb, hind limb, hip, spine or full body (versus a thorax), if the patient was a cat or an exotic (versus a dog), and if sedation, anesthesia or material restraint were used. In final multivariable analysis, there were significantly more workers in the room if the patient weighed > 25 kg (versus < 10 kg) (Table 4.5). There were significantly less workers in the room if the patient was an exotic (versus a dog), and if sedation, anesthesia, or material restraint were used.

Table 4.5. Final Multivariable Model of the Associations Between Risk Factors of Interest and Number of Workers in the Room Summarized for 1478 Exposures From 374 Imaging Studies Completed on 310 Animals.

	NUMBER OF EXPOSURES	MEDIAN (5th, 95th PCTL[a])	aRD[b]	95% CI[c]	P[d]
Species					0.01
Canine	1167	2 (0, 2)	Reference category		
Feline	263	1 (0, 2)	0.94	0.82 – 1.08	0.41
Exotic	48	1 (0, 1)	0.55	0.38 – 0.82	0.003
Weight					0.01
≤ 10 kg	728	1 (0, 2)	Reference category		
> 10 - 25 kg	289	2 (0, 2)	1.12	0.99 – 1.27	0.07
> 25 kg	452	1 (0, 1)	1.19	1.06 – 1.33	0.003
Sedation					
No	1107	2 (0, 2)	Reference category		
Yes	371	0 (0, 2)	0.44	0.38 – 0.52	< 0.001
Anesthesia					
No	1410	2 (0, 2)	Reference category		
Yes	68	0 (0, 2)	0.26	0.16 – 0.41	< 0.001
Material Restraint					
No	1301	2 (0, 2)	Reference category		
Yes	177	0 (0, 1)	0.14	0.09 – 0.22	< 0.001

[a]Percentile

[b]Relative difference in counts calculated adjusting using Poisson regression adjusted for repeated measures within individual workers with generalized estimating equations.
[c]95% confidence interval
[d]P-value

4.2 RADIATION SAFETY PRACTICES AMONG VETERINARY FLUOROSCOPY USERS

The overall survey response rate was 5.6% (240/4272). By professional college, the response rates were as follows: 18.4% (86/468) ACVIM-Cardio, 2.1% (39/1889) ACVIM-SAIM, 10.1% (95/943) ACVR and 2.1% (20/974) ACVS. Of the respondents who completed a questionnaire, 17.9% (43/240) had not been involved in taking a radiograph of a small animal in the last year, and their questionnaire was terminated after the first question. Eighty-two percent (197/240) of workers who completed a questionnaire had operated an X-ray unit for a small animal fluoroscopic procedure in the last year, and these workers completed the remainder of the questionnaire. Characteristics of these 197 workers are described in Table 4.6. Not all respondents completed every question and therefore the denominator of some the reported fractions is less than 197.

Table 4.6. Characteristics of members of the American College of Veterinary Internal Medicine (ACVIM) - Small Animal Internal Medicine, American College of Veterinary Internal Medicine - Cardiology, American College of Veterinary Radiology (ACVR), and American College of Veterinary Surgery (ACVS) who completed a questionnaire on radiation safety practices during small animal fluoroscopic procedures (n = 197 respondents).			
Variable		**N**	**%**
Professional College*	ACVIM (Cardiology)	79	42
	ACVIM (Small Animal Internal Medicine)	28	15
	ACVIM (Cardiology and Small Animal Internal Medicine)	3	2
	ACVR (Diagnostic Imaging)	69	36
	ACVS	14	7
Position*	Diplomate	145	75
	Resident-in-Training	48	25
	Both Resident-in Training and Diplomate	3	2
Practice Type	Private Practice	88	45
	Academic Institution	108	55
	Other	1	< 1
Gender	Female	117	59
	Male	77	39
	Prefer Not to Say and Other	3	2
Age	24 – 44 years	144	73
	45 – 65 years	51	26
	> 65 years	2	1
Country	United States of America	160	81

	Canada	23	12
	Other	14	7

*Four participants indicated that they were neither a Resident-in-Training nor a Diplomate, and did not select a professional college, and therefore the number of participants in these 2 categories was 193.

Twenty-one percent (41/197) of respondents were involved as an operator in less than 1 fluoroscopic procedure a month, 60.4% (119/197) in 1-4 fluoroscopic procedures a month, 17.8% (35/197) in 5-10 fluoroscopic procedures a month,< 1% (1/197) in 11-15 fluoroscopic procedures a month, < 1% (1/197) in 16-20 fluoroscopic procedures a month, and no workers in > 20 fluoroscopic procedures a month. The percentage of time spent on different types of fluoroscopic procedures for all respondents, and for each professional college, is presented in Table 4.7. The

Table 4.7. Percentage of time spent on different fluoroscopic procedures reported by American College of Veterinary Internal Medicine - Small Animal Internal Medicine, American College of Veterinary Internal Medicine - Cardiology, American College of Veterinary Radiology, and American College of Veterinary Surgery Diplomates and Residents-in-Training (n = 193 respondents).

Procedure Types	**Professional College**				
	All Respondents	**ACVIM (Cardiology)**	**ACVIM (Small Animal Internal Medicine)**	**ACVR**	**ACVS**
Cardiac	42%	95%	3%	2%	< 1%
Gastrointestinal	16%	< 1%	12%	39%	0
Hepatobiliary*	2%	2%	2%	< 1%	7%
Orthopedic	6%	0	0	2%	65%
Respiratory	17%	1%	23%	36%	7%
Urinary	15%	< 1%	58%	17%	14%
Vascular	1%	< 1%	2%	1%	< 1%
Other	1%	< 1%	< 1%	2%	6%

*Including portocaval shunt attenuation

location of the viewing monitor relative to the operator of the fluoroscopic unit was straight ahead for 24.9% (48/193) of respondents, at 45 degrees for 63.7% (123/193) of respondents, and at 90 degrees for 11.4% (22/193) of respondents. Ninety-eight percent (194/197) of respondents were required by their employer to wear aprons during fluoroscopic procedures, 96.4% (190/197) were required to wear thyroid shields, 27.9% (55/197) were required to wear gloves and 24.9% (49/197) were required to wear eyeglasses.

Frequency of use of personal protective equipment (apron, gloves, thyroid shield and eyeglasses), use of a mobile or fixed lead shielding curtain and presence of an unshielded body part on at least one acquired image per procedure is described in Table 4.8.

Sixty-five percent (129/197) of respondents never wore radiation attenuating hand cream during the x-ray exposure time, < 1% (1/197) always wore hand cream, and 34% (67/197) did not have radiation attenuating hand cream available. For the 80 respondents who had gloves available and at times wore gloves, 87.1% of the time gauntlet type gloves were used, and 12.9% of the time radiation attenuating surgical gloves were used. Of the 77 respondents who had eyeglasses available and at times wore eyeglasses, 75.3% (58/77) used eyeglasses without lead side shielding most often, and 24.7% (19/77) used eyeglasses with lead side shielding most often.

Sixty-four percent (126/196) of respondents were assigned a whole body dosimeter, 33.7% (66/196) a thyroid dosimeter, and 70.4% (138/196) an extremity dosimeter. Frequency of whole body and extremity dosimeter use is reported in Table 4.3. Eleven percent (22/197) of respondents used a dosimeter to estimate the annual equivalent dose to their eyes, 74.1% (146/197) did not use a dosimeter to estimate eye dose, and 14.7% did not know if a dosimeter was used to estimate their eye dose. When asked about the last reported whole body effective dose from occupational radiation exposure, 19.6% (19/197) of respondents knew their last reported whole body effective dose, 38.6% (76/197) did not know the dose but could easily look it up, 16.8% (33/197) had a rough idea of the dose, 21% (42/197) did not know the dose and did not know how to look it up easily, and 13.7% (27/197) did not receive reports on their whole body effective dose. When asked about the last reported equivalent dose to the lens of the eye from occupational radiation exposure, 2.0% (4/196) of respondents knew their last reported equivalent lens dose, 15.8% (31/196) did not know the dose but could easily look it up, 2.0% (4/196) had a rough idea of the dose, 21.4%

(42/196) did not know the dose and did not know how to look it up easily, and 58.7% (115/196) did not receive reports on their equivalent lens dose.

Fifty percent (98/197) of respondents had received formal training from their hospital regarding fluoroscopy machine parameters that reduce radiation exposure, while 50.3% (99/197) had not. Seventy-two percent (142/197) of respondents reported that they at times adjusted the fluoroscopy machine parameters for the purpose of reducing their radiation exposure, and frequency of machine parameter adjustment is described in Table 4.8. Of these 142 respondents, 34.5% (49/142) adjusted pulse rate frequency (pulses per second), 54.9% (78/142) adjusted frame-rate frequency (frame rates per second), 88.7% (126/142) adjusted collimation, and 23.2% (33/142) adjusted the mA and/or kV settings.

Table 4.8. Frequency of shielding use and other radiation safety behaviors reported by American College of Veterinary Internal Medicine - Small Animal Internal Medicine, American College of Veterinary Internal Medicine - Cardiology, American College of Veterinary Radiology, and American College of Veterinary Surgery Diplomates and Residents-in-Training (n = 197 respondents) involved with performing small animal fluoroscopic procedures.

Shielding or behavior	**Frequency**					**Not available**
	Always	**> 75%**	**50%-75%**	**< 50%**	**Never**	
Apron	197 (100%)	0	0	0	0	0
Thyroid shield	191 (97%)	5 (3%)	0	0	1 (< 1%)	0
Gloves	39 (20%)	10 (5%)	4 (2%)	27 (14%)	95 (48%)	22 (11%)
Eyeglasses	41 (21%)	11 (6%)	7 (4%)	19 (10%)	79 (40%)	40 (20%)
Lead curtain used*	26 (13%)	4 (2%)	7 (4%)	20 (10%)	76 (39%)	64 (32%)
Body part in primary beam	4 (2%)	0	2 (1%)	63 (32%)	128 (65%)	—
Adjust machine parameters†	48 (24%)	24 (12%)	31 (16%)	39 (20%)	55 (28%)	—
Wear body Dosimeter	162 (82%)	18 (9%)	3 (2%)	4 (2%)	5 (3%)	5 (3%)
Wear extremity Dosimeter	105 (53%)	19 (10%)	2 (1%)	8 (4%)	19 (10%)	44 (22%)

*Participants were asked how often they use a lead shielding curtain (fixed or mobile) during the X-ray exposure time.
†Participants were asked how often they adjust the parameters on the fluoroscopy machine for the purpose of reducing their radiation exposure. — = Not applicable.

Twenty-three percent (45/197) of workers described their knowledge of the risks of ionizing radiation as excellent, 47.2% (93/197) described their knowledge as good, 23.4% (46/197) described their knowledge as fair, and 6.6% (13/197) described their knowledge as poor. Twenty-one percent (41/197) of respondents correctly identified the annual occupational effective dose limit (averaged over 5 years) recommended by the ICRP, and 7.6% (15/197) correctly identified the annual occupational equivalent dose limit for the lens of the eye recommended by the ICRP. Ninety-seven percent (190/196) of respondents believed that radiation exposure increases the risk of cancer, 1.5% (3/196) did not believe that radiation exposure increases the risk of cancer, and 1.5% (3/196) did not know if radiation exposure increases the risk of cancer. Eighty-nine percent (175/197) of respondents believed that radiation exposure increases the risk of cataracts, no respondents did not believe that radiation exposure increases the risk of cataracts, and 11.2% (22/197) did not know if radiation exposure increases the risk of cataracts.

The most important reasons respondents selected for not wearing eyeglasses during fluoroscopic procedures are listed in Table 4.9.

Table 4.9. The three most important reasons participants did not wear radiation attenuating eyeglasses when operating a fluoroscopic unit (reason 1 most important); 116 respondents were asked this question; respondents who always wore eyeglasses (n = 40), or who did not have eyeglasses available (n = 41) were not asked this question).

	Number of workers selecting the reason
Reason 1 (*n* = 76 respondents)	Eyeglasses are not required by my employer (*n* = 29) Eyeglasses are uncomfortable or do not fit properly (*n* = 17) Eyeglasses interfere with performing my task (*n* = 16) Not enough eyeglasses for all workers (n = 6) I am not concerned about the adverse health effects (n = 5) My coworkers do not wear eyeglasses (n = 3)
Reason 2 (*n* = 60 respondents)	Eyeglasses are uncomfortable or do not fit properly (*n* = 19) Eyeglasses interfere with performing my task (*n* = 10) Not enough eyeglasses for all workers (n = 10) Eyeglasses are not required by my employer (*n* = 9) My coworkers do not wear eyeglasses (n = 8) I am not concerned about the adverse health effects (n = 4)
Reason 3 (*n* = 52 respondents)	Eyeglasses are uncomfortable or do not fit properly (*n* = 20) My coworkers do not wear eyeglasses (n = 8) Not enough eyeglasses for all workers (n = 7) Eyeglasses are not required by my employer (*n* = 7) Eyeglasses interfere with performing my task (*n* = 6)

	I am not concerned about the adverse health effects (n = 3) Eyeglasses are unhygienic (n = 1)

4.2.1 Factors associated with radiation safety behaviours

Unconditional associations between risk factors of interest and frequency of radiation safety behaviors are provided in Appendix A.6. The final multivariable model of the associations is presented in Table 4.10.

In final multivariable analysis, respondents wore gloves significantly more frequently if their employer required that gloves be worn (OR 28.19). Members of ACVIM Small Animal Internal Medicine, ACVR Diagnostic Imaging and ACVS wore gloves significantly more frequently than members of ACVIM Cardiology (OR 8.57, OR 108 and OR 9.93, respectively). In final multivariable analysis, respondents wore eyeglasses significantly more frequently if their employer required that eyeglasses be worn (OR 28.73). Respondents who correctly identified the ICRP body dose limit used a lead curtain significantly more frequently (OR 4.37), while members of ACVS used a lead curtain significantly less frequently than members of ACVIM Cardiology (OR 0.81).

In final multivariable analysis, members of ACVS wore a body dosimeter significantly less frequently than members of ACVIM Cardiology (OR 0.11). Respondents who rated their knowledge of radiation risks as good or excellent wore a ring dosimeter significantly more frequently than respondents who rated their knowledge as poor (OR 4.20 and OR 8.19, respectively). Respondents from Canada wore a ring dosimeter significantly less frequently than those from the United States (OR 0.27).

In final multivariable analysis, respondents who had received training on machine parameters adjusted machine parameters to reduce their dose during procedures significantly more frequently than respondents who had not received training (OR 2.69). Diplomates adjusted machine parameters to reduce their dose during procedures significantly more frequently than residents (OR 2.43). Members of ACVS adjusted machine parameters to reduce their dose during procedures significantly less frequently than members of ACVIM Cardiology (OR 0.18).

Table 4.10. Final multivariable model of the associations between risk factors of interest and frequency of radiation safety behaviors reported by veterinarians involved with performing small animal fluoroscopic procedures (n = 197 respondents).

OUTCOME	Odds Ratio	95% CI*	P VALUE
Use of gloves			
Employer requirement that shielding be worn	28.19	9.47-83.95	< 0.001
Professional college			
ACVIM† Cardiology	Reference category		
ACVIM Small Animal Internal Medicine	8.57	1.58-46.62	0.013
ACVR‡ Diagnostic Imaging	108	20.67-573.01	< 0.001
ACVS§	9.93	1.47-67.23	0.019
Use of eyeglasses			
Employer requirement that shielding be worn	28.73	12.68-65.09	< 0.001
Lead curtain use			
Correctly identified ICRP body dose limit	4.37	1.94-9.86	< 0.001
Professional college			
ACVIM Cardiology	Reference category		

ACVIM Small Animal Internal Medicine	1.49	0.49-4.57	0.49
ACVR Diagnostic Imaging	4.24	1.81-9.94	0.001
ACVS	0.81	0.14-4.56	0.81
Body dosimeter use			
Professional college			
ACVIM Cardiology	Reference category		
ACVIM Small Animal Internal Medicine	0.43	0.15-1.24	0.12
ACVR Diagnostic Imaging	2.46	0.75-8.11	0.14
ACVS	0.11	0.03-0.39	0.001
Ring dosimeter use			
Self-reported knowledge of radiation risk			
Poor	Reference category		
Fair	2.10	0.56-7.90	0.27
Good	4.20	1.22-14.48	0.02
Excellent	8.19	1.99-33.75	0.004
Country (Canada versus United States)	0.27	0.10-0.78	0.02

Adjust machine parameters to reduce dose			
Training on machine parameters	2.69	1.59-4.54	< 0.001
Diplomate versus resident	2.43	1.31-4.51	0.005
Professional college			
ACVIM Cardiology	Reference category		
ACVIM Small Animal Internal Medicine	0.59	0.27-1.28	0.18
ACVR Diagnostic Imaging	0.56	0.31-1.01	0.054
ACVS	0.18	0.06-0.53	0.002

*95% confidence interval
†American College of Veterinary Internal Medicine
‡American College of Veterinary Radiology
§American College of Veterinary Surgery

5. DISCUSSION

5.1 Impact of a Video Training Module on Worker Use of PPE, Head and Body Position During Small Animal Radiography at a Veterinary Teaching Hospital

This work resulted in an effective tool that can be incorporated into radiation safety programs to reduce ionizing radiation exposure of workers during small animal diagnostic radiography. While the study hypotheses were supported by the video training significantly improving the frequency of use of gloves and eyewear as well as optimization of head and body position, the overall improvement remained suboptimal.

Our results are in agreement with previous studies that found that veterinary patients are usually restrained manually by workers for radiography.[1-6,13,17,18] and the use of manual restraint for just over three-quarters of exposures is consistent with the frequency of manual restraint previously reported in veterinary medicine.[4,13,17,18] Interestingly, the percentage of animals restrained manually was lower in this study than in a 2018 study[12] at the same workplace, which found that 92% of exposures involved manual restraint. This is likely due to the efforts of the radiology service to employ hands-free techniques whenever possible, although the impact of that effort is expected to be lower for after-hours radiography given that after-hours workers are not part of the radiology service.

The after-hours worker population was comprised of DVMs, technologists and DVM students with primary responsibilities outside of medical imaging. The DVMs, technologists and DVM students hired by the clinic receive an orientation in radiation safety at the start of their employment, and DVM students are oriented at the start of their senior rotations and receive a 50-minute lecture on radiation safety in their second year. However, after-hours workers do not work alongside dedicated radiology technologists, who lead by example and direct workers to use shielding and maximize distance to the patient, and there is also no direct supervision by radiology technologists or faculty during after-hours.

A multicenter study examining the effect of a 90 minute radiation safety minicourse on dose to patient found that after the training there was a 48.4% reduction in the median overall dose area product[95] While this study showed significant reduction in dose, the population targeted by the training was very homogeneous, composed only of cardiac interventionalists, and this result was for just one type of procedure (coronary angiography). This decreases the external validity and assumptions that similar training would have a similar result for different categories of specialists, performing different procedures. In contrast, our population was more heterogeneous, and involved the full range of diagnostic radiography of different regions, increasing the external validity and assumptions for our study.

Workers had body parts in the primary beam for 1.1% of the exposures, a finding comparable to a previous study which found that protective radiological glove were visible in 1.7% of exposures.[12] It is important to highlight that leaded or leaded equivalent shields effectively attenuate scatter X-rays, but not primary beam X-rays which have a higher energy level.[14] So, even if shielding is worn, and body parts such as bones are not visible on the radiographic image, the absorbed dose to the worker is much higher when a body part is in the primary X-ray beam.

5.1.1 Protective apron and thyroid shield

Protective aprons and thyroid shields were always worn by the workers, and therefore not examined for risk factors. This finding is consistent with the current literature which reveals that lead aprons are worn by 86% to 100% of workers during radiography,[4,11-13,17] and thyroid shields by 88% to 100% of workers.[12,13,17] The characteristic we believe was the main contributor to the thyroid shield high frequency use in the current study was that all aprons available at this workplace have a protective thyroid shield attached This finding agrees with Mayer et al., 2018, where 50% of workers suggested that a leaded apron with the thyroid shield attached would improve its usage.

5.1.2 Protective gloves and eyeglasses use

The frequency of glove use was significantly higher after workers completed to the video training: the frequency increased from 18% (131/729) before training to 31% (325/1040) after training (P<0.01). This is a lower frequency than the previous reports that varied ranging from 43.6% to 96.6%.[11-13,17] A similar percentage of radiation safety behavior change was found in a study of oncology nurses using ionizing radiation by Dauer et al., 2006, who reported a 12.7% improvement of knowledge and attitude regarding radiation safety. However, our training was based on a 7-minute video, while the intervention for the nurses in the Dauer study was a comprehensive training with 5 different approaches, including video training and an evaluated through a self-reported questionnaire.

But, performing radiographic exams afterhours is considered a risk factor for lack of protective gloves use.[12] Mayer et al., 2018 conducted a study in the same workplace as ours and found just 5% of workers afterhours were using protective gloves properly compared to 77% in regular hours.[12] Some reasons that afterhours glove use may be lower than during regular working hours include are unsupervised or low supervision work, absence of a radiology technician or veterinarian, higher incidence of emergency cases which may not allow sedation or anesthesia.

Protective eyeglasses were worn for less than 1% of observations before the video training. This result is consistent with the literature, which shows a frequency varying from 0% to 3%.[11-13] While we found a significant (P<0.01) improvement in the frequency of eyeglasses use, the overall use even after the training was still very low (5% of observations). In a previous study, 42% (8/19) of veterinary workers suggested that making eyeglasses more readily available would increase use.[12] Since in the workplace in our study, eyeglasses are stored in a different location than gloves and aprons, this may have contributed to the low use even after training. We suggest storing the eyeglasses together with the protective aprons/gloves, in a place where workers can readily visualize the eyeglasses when they are putting on the apron and gloves, as this may increase use.

In addition to lack of availability, another reason for poor compliance in use of eyeglasses reported by workers in previous studies was discomfort or lack of proper fit.[12,13,101] We therefore suggest use of a strap that wraps around the head to improve fit, as the fairly heavy eyeglasses tend to slide down the face/nose. Employers should ensure that workers know what PPE is required to be worn, that adequate numbers of properly fitting PPE are readily accessible, and that workers are trained how to use it; as a previous study[13] found that workers wore hand shielding significantly more frequently if required to do so by their employer, and workers in the same study suggested that making eye protection mandatory would increase its use.

5.1.3 Number of Workers in the Room, Head Position and Body Position Optimization

Use of sedation decreased radiation exposure of the workers. Workers were less likely to lean forward towards the source of scattered radiation when sedation or anesthesia was used. Small patient size (<10 Kg) was found to be a significant risk factor for workers not to optimize body or head position. This is likely due to the difficulty in holding small animals, especially when wearing thick, unwieldy gloves.

In addition, about two-thirds of workers looked straight towards the animal during the exposure, which is the optimal head position when eyeglasses are worn. Workers look straight to the animal to check if the animal is still quiet and in position before and during the exposure. If workers wear eye shielding more frequently, then this current practice would increase the head position optimization.

Moreover, our findings agree with Mayer et al., 2018, as both studies found that less workers are in the room during the radiographic exposure for sedated or anesthetized animals. While sedation can be used to avoid the need for manual restraint, it has also been suggested that with appropriate hands-free techniques and restraint devices, approximately 75% of non-sedated patients can be imaged without workers in the room.[100] Training on hands-free techniques is available through: https://handsfreexrays.com/. Moreover, there were fewer workers in the room at the time of exposure when material restraint was used, such as sandbags or ropes. This finding agrees with hands-free techniques and restraint devices can help to avoid manual restreaint.[100]

The significant increase in number of workers in the room if the patient weighed > 25 kg (versus < 10 kg) may be explained by the increased distance between the thoracic and the pelvic limbs, which could be difficult to hold by one person. The significantly decreased number of workers in the room if the patient was an exotic (versus a dog) may be explained by the small size of the animal (e.g. rabbits, guinea pigs and birds) and the necessity on sedate or anesthetize most of them.

5.1.4 Legislation

Since Health Canada and the Canadian Nuclear Safety Commission are already discussing regulation and legislation for eye lens dose for occupational exposures,[75] implementation of mandatory protective eyeglasses will likely happen in the near future. This is in line with the initial intention of this study which was to anticipate protective measures due to potential future legislation changes. The earlier we start to change the radiation safety culture and philosophy regarding eye protection, the earlier we will succeed in protecting veterinary workers.

5.1.5 Training module

The length of the video was around 7 minutes. We tried to keep training module short since the average engagement time for any video is 6 minutes.[102] We advocate that all staff involved directly or indirectly with radiation medical procedures should be instructed about ionizing radiation health risk and the standard procedures to minimize it.[14] This training module agrees with several recommendations by ICRP report 117 which addressed worker PPE compliance. The intent of the video training was to increase awareness among veterinary workers of the risks involving ionizing radiation and to improve the behavior that could minimize their own exposure.[103]

The training module incorporated realistic and feasible training, presenting clinical situations and solutions from the view of the veterinary worker in a typical veterinary radiography environment.[103] In addition, examples of optimal and bad practices were shown in the training video module, and in the evaluation tool administered after watching the video.[103] The training was specific for the manual restrainer of a patient for a radiograph examination.[103]

We agree that every veterinary residency program that deals with ionizing radiation should have their own particular radiation safety training so it will be specific to that field and not overlook challenges associated with any particular specialty. We also suggest that every veterinary internship program should include radiation safety training, especially because interns are often responsible for much of the afterhours shift, which is considered a negative risk factor for PPE compliance.[12]

Radiation safety should be introduced at the beginning of every veterinary worker's career and continue throughout their lifetime to reinforce optimal behaviours and safety culture,[103] and training should be updated as the technology changes. Due to the different job categories that this training video was developed for, including workers with no professional training, we chose to keep the video at a layperson level. As a result, the video did not include some important measures that can be used to decrease worker dose, such as beam collimation and technical settings. These measures will need to be addressed in other training.

5.1.6 Improving Radiation Safety Training Programs

The goal of this training module was to raise the risk perception so veterinary workers would comply with behaviours that decrease the dose to their eyes and other body parts (hands, wrists), and avoid unnecessary exposures. While the video training significantly improved personal protective equipment use and worker positioning and is therefore worth using, it is apparent that a one-time intervention alone is not enough to achieve optimal radiation safety behavior. This was not unexpected as personal protective equipment (PPE) compliance is impacted by environmental factors such as availability of PPE and organizational factors such as communication of expectations, feedback and enforcement, in addition to individual factors such as knowledge and perception of risk.[105]

The degree to which the risk associated with hazards are perceived is also important. It is well known that some types of hazards, for example, car accidents do not raise much public concern despite high risk of injury or death. Some hazard communication specialists have attempted to answer why this happens and have identified some features that help to decrease or increase public concern.[106] Applying the same concepts[106] to our study, we can find some features that help explain why the training did not increase workers risk' perception making the overall result in behaviour change low.

First, the risk of something familiar tends to be underestimated.[106] Radiographs are the most common imaging examination in veterinary medicine,[11] and have been used for over 100 years.[19] Therefore perception of risk may be low because most workers are already familiar with radiographic examination and X-rays.

Second, since cataracts and cancer may develop after many years to decades, they raise less concern than if the same number of people would develop cataracts or cancer in a short period of time.[106] A routinely used example is that people are more concerned about airplane accidents (that cause deaths in a short period) than car accidents (that cause significantly more deaths but in a longer period of time).[106] Third, the radiograph is assumed to be a benefit for the animal's health and consequently wellbeing.[106] This plays a role because despite the possible future risk to the worker of developing a disease due to X-ray exposure, it represents a benefit for the patient. So, when the benefit to others is deemed worthy, people are capable of altruistic acts which justify a risk to themselves.[106] So, after-hour workers may prioritize immediate risks to themselves (e.g. being bitten) and their critically ill patients over long term risks[106], such as ionizing radiation exposure, and choose to restrain without shielding to hold patients more securely and acquire diagnostic quality images more quickly and without sedation. Fourth, the workers involved in the exam are in control of the procedure.[106] Some of them are there because they were asked to do the exam; however, they are still the ones who are implementing the exam, which decreases the risk perception.[106]

Finally, if workers have never suffered from a certain hazard in the workplace, they may feel that the safety measures are unnecessary.[106] These factors may have contributed to the low overall result this educational training video module had on worker behaviour change .

Safety professionals are more aware of the hazards; therefore, they tend to see the risks differently than workers. There are many strategies to circumvent the lack of workers' risk perception and to scale-up response. It is necessary to prove and emphasize that the risk of a hazards justify the implementation of safety behavior. We have to demonstrate how vulnerable workers are towards hazards and how fortunate they are not to be affected. [107] Studies have shown that the closer involvement of supervisors or middle managers, up to the head of the hierarchy, can increase effectiveness of safety culture and is sometimes critical.[98,99,108,109] In addition, the behaviour improvement found after the intervention in our study could decrease over time since engagement of higher level workers is critical for the cultural change to endure through time.[98]

We also did not have prior engagement of workers, which may in part explain the long timeframe for most workers to watch the training module (one month) and the low PPE and suboptimal behaviour compliance after the video training module. The literature recommends fostering employees' engagement to increase effectiveness of safety culture program.[99,110] Other industries face the same situation, even those professions with higher hazard risks such as coal mining, where most supervisors and workers do not have a positive attitude regarding safety procedures and standards.[97] Our program was delivered online to supervisors and employers, without any supervision or previous engagement, which might help to explain the low overall result.

Some ways to engage staff are frequent informal workplace meetings and repeated messaging in other formats. 'Toolbox talks' refer to brief, informal, small group safety meetings, common in many industries.[111] This form of training can use a participatory approach to involve workers in problem-solving, and has been shown to raise safety awareness, increase knowledge retention, and improve safety behaviors.[111] Repetition of the video training message could be achieved through signage in the radiology room, follow-up viewings of the video or quizzes on the video content.

Finally, workers should be aware of the consequence for failure to use required PPE. Methods other than enforcement should be preferentially used to improve safety behaviors; discipline only has a role when other methods have failed. As cancer is a stochastic effect of radiation, with no dose threshold, any reduction in radiation dose will result in a lowered risk of occupationally related cancer over the lifetime of a worker.[72]

The best optimization of protection is achieved when workers are not in the room during an exposure, and federal guidelines recommend that the workers avoid regular manual restraint for radiography. However, given that most veterinary clinics do not practice hands-free radiography at this time, training on appropriate behavior during restraint is needed.

5.1.7 Limitations

A limitation of this study is the assumption that there were no or minimal variables that changed worker radiation safety behaviors over the study period other than the training intervention. For instance, some workers knew about the study during data collection phase, but we cannot predict how many knew and to what extent this knowledge affected their behaviours. Ideal study design would have included a control group that received no training intervention, to examine the contribution of factors other than the intervention to the changes in behavior. Our reasons for not using a control group included the small size of the study population, the possibility of workers who had received training influencing the behavior of workers who had not received training, and the possibility of workers in the control group viewing the video, given the unsupervised, online access. Other than checking that the post-video quiz was complete with a score equal to or greater than 80%, we were not able to assess whether a worker was actively involved with training video when it played. Due to the large number of workers and their diverse schedules, it was not possible to deliver the training video in a supervised environment. Some workers may have played the video without watching it, and this may have decreased the measured effect of the video.

The students' rotation across services or veterinarians' and technicians' rotation on afterhours shift are also limitations since the same individual may assist with a radiographic procedure before their training, but then the same individual may not appear after their training. Another limitation is the lack of information regarding the duration of effect of the training video. If we started to change the local radiation safety culture, we may see long-term improvement in behaviors. However, if the training was not sufficient, we might see no change or worsening in radiation safety behavior over time. A year-long study could help to evaluate long term effects of the training. Moreover, yearly staff turnover (4th year DVM students, interns, and 3rd year residents) is a challenge, since every year the workplace must offer the training for the first time to a large proportion of the workers. Though performed in a consistent manner by a single observer, the evaluation of head and body position on an image is by nature a subjective process. As well, the awareness by the evaluator that workers had undergone training can also be a potential source of bias.

We may have seen a greater improvement in behaviours if we had incorporated other measures that potentially could had contributed to increasing the overall results, such as signage in the radiology room reminding workers to use shielding. However, since the intervention (video training) was not delivered over a short period of time, it would have been difficult to determine if the behavior changed after all measures were applied or just one of them. A way to circumvent this would be to evaluate pre-intervention, train staff with all interventions, and then perform the post-intervention evaluation. Finally, the study population was from a teaching hospital, which may not represent the behavior of a private practice environment.

5.2 Radiation Safety Practices Among Small Animal Veterinary Fluoroscopy Users

The X-ray exposure is usually higher for fluoroscopy procedures than for diagnostic radiography because the exposure times are usually longer.[112] This increases the potential for high doses not just to the patient, but also occupational doses, especially during interventional fluoroscopy procedures.[113,114] The only study found by the authors which evaluated veterinary fluoroscopy, investigated just dose and time of the procedures, but did not observe workers' radiation safety behaviour .[115] To the author's knowledge, this study is the first to report radiation safety behaviors among veterinary specialists performing fluoroscopy. Despite the potential for high radiation doses to the operator associated with fluoroscopic procedures, we found that frequency of hand and eye protection, and other dose-reducing practices, were suboptimal.

In this study, optimal use of aprons and close to optimal use of thyroid shields were achieved. Both were consistent with the current literature, where the use rate of lead aprons varies between 86% to 100%[4,11-13,17] and the use rate of thyroid shields varies between 88% to 100%.[12,13,17] Operator dose can be substantially reduced by use of shielding: lead curtains, aprons and thyroid shields can reduce operator dose to specific body regions by 90% to over 99%[35], depending on the lead equivalence and incident X-ray energy.[103]

Protective gloves were inconsistently used. Just 20% of respondents always used gloves and 21% of respondents used gloves at times, presenting a lower rate when compared to diagnostic radiography practices reported in the literature, which range from 43.6% to 96.6%.[11-13, 17] In addition, among protective gloves users, 12.9% of the time radiation attenuating surgical gloves were used; this result is higher than human interventional radiologists who wore attenuation surgical glove in only 1% of the procedures.[101]

Since an operator's hands may receive a much higher dose than their trunk[116] not shielding hands may increase the hazard risk. While gauntlet-type gloves are not suitable for interventional procedures when fine manipulation of equipment and sterility are needed, flexible radiation-attenuating gloves or radiation-attenuating hand cream have been reported to reduce scatter dose to the hand by 15-70%.[103,117]

Possible reasons for the low frequency of use of any type of gloves by operators in this study include lack of awareness of the hand shielding options available and belief that hand shielding is not needed due to high occupational dose limits for extremities.

Surgical attenuation gloves decrease operators' dexterity[118] and depending on the level of attenuation may not effectively reduce the dose to the hand.[119] Both arguments also may explain the low use of this type of hand shielding in our study. The need for a high level of dexterity and tactile sensation during interventional cardiac procedures is likely a reason for our finding that all other specialties were significantly more likely to use gloves than cardiologists. Operators who do not wear hand shielding for this reason could consider a radiation-attenuating hand cream worn under their surgical gloves. A commercially available, bismuth oxide cream reduced radiation dose by about 40%, and did not interfere with tactile sensitivity or ability to perform interventional cardiac procedures.[120]

As about one-third of our respondents reported placing a body part in the primary beam at times, a rate much higher compared to the diagnostic radiography where protective radiological gloves were visible in 1.7% of the images.[12] But unlike the current survey, no body parts were seen during the radiography exposure.[12] Hands in the fluoroscopy X-ray field could be difficult to avoid in some interventional procedures due the small size of some patients. However, it is important to highlight that hand shielding is designed to reduce the dose to operators from scattered radiation and the level of attenuation will be reduced if hands are exposed to the higher energy, primary beam.[14,103] Therefore, primary beam X-rays should be avoided, especially in fluoroscopy procedures which has the potential for higher radiation dose.

Another negative effect of placing a hand wearing an attenuating glove in the primary beam is that the presence of attenuating material within the primary beam may automatically trigger machine adjustments which increase the x-ray dose.[103] This increases dose not just to the hands but also to the operator's body and lens. In addition, the gloves may give a false sense of protection which may result in increasing the exposure time in the primary beam, which may mitigate the protection that the glove is meant to provide.[103]

The percentage of fluoroscopy operators always wearing eye shielding in this study was higher than reported for diagnostic radiography, which varies from 0% to 3%.[11-13], however the overall frequency of use was still suboptimal, and one-fifth of respondents did not have access to eye shielding. This result was better than human fluoroscopy technologists who consistently wore lead eyeglasses for just 5% of the procedures.[121] However, the frequency of leaded eyeglasses was much higher, 54%, for human interventional radiologists in another study.[101]

The top reasons for not wearing eyeglasses given by respondents included the recognized problems of poor fit and interference with performance of tasks. The lack of comfort and proper fit were stated by human radiologists as the major reason for not wearing eyeglasses.[101] Flynn et al., 2017 concluded that is difficult to find alternative PPE sizes and that these products were rarely advertised or properly size labeled, sometimes just presenting as "standard". It is recommended that different types of eyeglasses be tried out by workers prior to purchase to ensure comfort and good fit.[122] These findings suggests that multiple sizes PPE available for workers could potentially increase the use rate by increasing the PPE fit, especially regarding gloves and eyeglasses, which have a high suboptimal use.

Seventy five percent of the eyeglasses used by fluoroscopy workers did not have a side shielding. This is an important factor because the eye shielding may not fully protect the workers' eye lens, especially since 62% of the respondents viewed a monitor that was at a 45-degree angle in relation to the operator. Therefore, the operator is at 45 degrees angle compared to the patient, which is the source of scatter radiation, and that could increase the radiation dose to the unprotected area of the lateral portion of the eye. ICRP recommends that all lead eye wear should have side shields (Figure 5.4.) to protect against radiation coming from the sides.[103]

Figure 5.4. Glasses with side shield (left) and without side shielding (right).

We found that employer requirement that eye (and hand) shielding be worn resulted in a dramatic increase in use; respondents who reported that their employer required them to use the shielding were about 28 times more likely to do so.

Over two-thirds of specialists reported that they never used a lead curtain or did not have one available for use. The ICRP recommends use of radiation shielding screens wherever feasible to reduce operator exposure.[103] The significantly more frequent use of lead curtains by radiologists compared to cardiologists in this study is again likely due to the difference in procedures performed by these two specialties.

The use of radiation attenuating surgical drapes can significatively reduce the radiation dose exposure to workers with minimal additional dose to the patient[123] and could be considered for veterinary interventional procedures for which lead screens or lead curtains are not feasible. While attenuation drapes may reduce the dose to all workers in the room, the ones who benefit the most are the operators, as they must stay close to the patient during the procedure and in many cases are not able to hide behind a lead screen or step away from the patient during exposure.

While shielding effectively reduces operator dose, shielding cannot protect all parts of the operator's body and therefore other measures to reduce dose are important. Machine parameters that can be adjusted to reduce operator dose include, but are not limited to, pulse rate, frame rate, beam collimation, tube voltage (kilovoltage, kV) and tube current (milliAmperes, mA). These parameters can dramatically reduce operator dose,[123,124] however over one-quarter of our respondents never adjusted machine parameters to reduce their dose. Use of pulsed fluoroscopy, in which the beam is composed of a series of short x-ray pulses, may reduce operator dose by over 50%, depending on the method used to achieve the pulsed mode.[123,124] A study of fluoroscopic procedures at two veterinary institutions found higher median radiation exposures for any given median fluoroscopy time at the institution that performed most procedures using continuous mode, compared to the institution that used only pulsed mode.[125] A lower frame rate (the number of images recorded per second) will also reduce operator dose but can compromise image quality.[126] The lowest frame rate needed to achieve the diagnostic or therapeutic intent should be used. Since scattered radiation increases linearly with increasing field size, the x-ray beam should be collimated to the smallest size needed to show the required image.[103] Reducing kV and mA to the lowest settings to provide an adequate image for the purpose of the procedure rather than an optimum image quality will also reduce operator dose.[126] Almost 90% of our respondents who adjusted machine parameters reduced the field size to reduce their dose, however the remaining parameters were modified less frequently. Diplomates were twice as likely to adjust machine parameters to reduce their dose than residents, possibly due to more training and experience with maximizing dose reduction while achieving acceptable image quality for the purpose of the procedure. We found that machine parameters were adjusted to reduce dose significantly more frequently if respondents had received training on how to do so; this type of training is a potentially modifiable factor that could be implemented to reduce operator exposure at all veterinary workplaces using fluoroscopy. This finding agrees with the literature which also found that workers who had formal radiation safety education presented a better knowledge, therefore presenting higher compliance in safety attitudes.[101,110,127]

Body and ring dosimeters frequency use rate were comparable with the literature, varying from 49.2% to 85% among veterinary workers in the USA and Canada;[2,3,11,12,92,93] when compared to human pediatric anesthesiologists, dosimeters were worn by 13% of physicians and never used by 52% of physicians, and just 28.5% of practices had dosimeters as mandatory part of the PPE.[128] We found that two measures of respondent knowledge about radiation safety, correct identification of the ICRP recommended annual effective dose and self-reported knowledge of radiation risk, improved radiation safety behaviors (frequency of lead curtain and ring dosimeter use). Based on our findings of suboptimal radiation safety practices among veterinary fluoroscopy users, we recommend formal incorporation of radiation safety into residency training programs, particularly for the specialties performing interventional procedures.

In our study, workers reported a higher frequency of glove and eyeglasses compliance rate when they were mandatory. This result agrees with other authors.[96,104,129] This supports the important role of the employer engagement and enforcement regarding employee PPE compliance. In addition, 10% and 20% of practices did not provide protective gloves and eyeglasses, respectively, a finding that was present in previous veterinary literature.[11]

The International Commission on Radiological Protection recommends that the level of training in radiological protection be commensurate with the use of radiation, however, veterinary fluoroscopy is increasingly performed by non-radiologists, who may have minimal to no formal training in radiological protection.[103,125,130] While the American College of Veterinary Radiology qualifying examination study guide includes principles of radiation physics, radiation biology and radiation protection, no mention of these topics could be found by the authors in the residency training requirements available for other veterinary specialties including cardiology, small animal internal medicine and small animal surgery. Trainees likely receive some level of radiation safety orientation during their residencies, but there does not appear to be a formal requirement or examination of this knowledge other than for radiology trainees. Radiation safety training and increased awareness of factors influencing dose has the potential to reduce operator exposure through behavior modification.[131,132] We advocate that every specialty should develop their own radiation safety training.

We agree with Le Heron et al., 2010 that improving knowledge by providing training in radiation safety, standard working procedures, appropriate PPE, and monitoring devices should be done in order to provide adequate protection.[127] Our findings suggest that improving radiation safety education would help to improve the safety culture [4,95,96] in the workplace.

5.2.1 Limitations

In this study we limited examination of behaviors to reduce operator radiation exposure to use of personal shielding and adjustment of machine parameters, however there are many other measures that fluoroscopy operators can implement to reduce their exposure that we did not report. Sampling bias was introduced when members of ACVS were invited to participate using a different method (Facebook groups) than the other professional colleges; this was unavoidable since an electronic mail list was not available for ACVS members. This likely contributed to the low response rate for ACVS members. Nonresponse bias, in which people who participate in a study systematically differed from people who do not respond, is more likely when response rates are very low, such as for ACVIM-SAIM and ACVS. As with any self-reported safety behavior study, there was the potential for response bias; selective suppression of information about suboptimal radiation safety behaviors by respondents may have resulted in an underestimation of behaviors that increase dose to workers. As well, the surveyed population included specialists who perform a wide variety of fluoroscopic procedures, and the effect of procedure on the differences between members of the professional colleges could not be assessed.

5.3 Commonalities and Differences Between Both Studies

Both studies included in this thesis found a higher apron use frequency[4,11-13,17] and thyroid shield use frequency[12,13,17] comparable with the current literature. Both studies found a lower glove use frequency compared to the literature[11-13,17]

The rate of protective glove use in the fluoroscopy survey and in the observational study showed a lower frequency than the literature.[11-13,17] This difference on diagnostic radiograph may be explained because radiographic exams done afterhours is considered a risk factor for lack of protective gloves use.[12] Moreover, the difference among fluoroscopy users could be explained by the attenuation gloves decreasing operators' dexterity[118].

Veterinary workers manually restraining during radiographic procedures before the video training showed a rate of protective eyewear use comparable to the literature.[11-13] On the contrary, veterinarians that operate fluoroscopy demonstrated a higher frequency. This difference of the fluoroscopy survey from previous reports could be explained because other studies were evaluating mostly radiography machine veterinary users, and fluoroscopy users may be aware of the potential for higher doses associated with fluoroscopy. The survey results were consistent with the literature in that one of the top reasons for not wearing the eyeglasses was that the eyeglasses were uncomfortable / did not fit properly.[101] This also helps to explain the low protective eyeglasses compliance in the video training study.

Our findings for both studies agree that a higher knowledge base and training improve the overall radiation risk awareness and safety behavior. Similar results were found by other authors.[96,104,129] However, our findings agree with Dauer et al., 2006 that despite the training, knowledge and risk awareness improvement, the overall effectiveness of attitudes and behaviors after the video training intervention was still low.

The observational training study found 1.1% of radiological gloves in radiographic image, and the fluoroscopy survey found one third of body parts in the image at times. The operators sometimes have to work very close to the radiological fields especially in small patients during the exposure which justify the difference.

WCVM required workers to use protective gloves and eyeglasses before the start of this study, yet workers in afterhours duty were using them respectively 18% and 0.8% of the exposure-worker events prior to the training. This result agrees with Mayer et al., 2018 study performed in the same workplace, where the employer required protective gloves and 88% of workers were told by their employer to wear it, therefore being aware of the safety policy. And despite of the awareness of the mandatory glove use, just 5% of workers worn protective gloves after-hours compared to 77% in regular working hours. However, both studies contradict the survey study and reports in the literature that found workers use PPE more frequently when it is mandatory. The majority of workers in regular hours in this hospital use protective gloves[12] and currently the majority also use eyeglasses (besides this was not measured in this study). The Hawthorne effect, (often defined as workers changing their behaviours when they know they are being studied or observed), may also play a role in these findings.[134] Another possible reason for the low compliance is low risk perception of this risk among non-radiology technologists or veterinarians. Another possibility is that enforcement policies differed between regular and after hours. We suggest that employers' PPE requirement may be a positive component, but other measures should be implemented especially for after-hour workers working with no or low supervision, because requirement alone may not be as effective.

6. CONCLUSIONS AND FUTURE DIRECTIONS

In conclusion, this thesis indicated that education and formal training on radiation safety increases the behaviours that decrease workers' dose, helping to develop a radiation safety culture in the workplace. In addition, sedation or anesthesia should be used more often as it reduces the need for workers inside the radiography room and overall radiation exposure.

The survey study provided pioneer and valuable information regarding the radiation safety behaviours of veterinary specialists performing fluoroscopic procedures and potential risk factors for these radiation safety behaviors, that can help to guide the behaviours veterinarians should improve.

Our studies demonstrated a significant improvement in 4 behaviours after the video training (wearing protective eyeglasses and protective gloves, increasing distance from the body and head eye region to the radiation source) and showed that workers with more knowledge and formal training are more likely to present behaviours that reduce radiation exposure; therefore decreasing the probability of cataracts or other radiation associated diseases such as cancer.

However, the studies also indicate a low compliance with protective eyeglasses and gloves recommendations among veterinary radiology and fluoroscopy users. In order to increase use of these types of shielding and to comply with anticipated future regulation updates, changes are needed in the radiation safety culture.

To improve overall risk perception, PPE compliance and behaviours of veterinary workers to reduce radiation exposure, we recommend that workplaces consider the following measures: gradual implementation of multiple interventions that complement one another to achieve a greater change, repetition of the safety message through signage in the radiology room and follow-up viewings of training fostering employees' engagement, promoting staff collaborative relationship and involvement of leaders in multiple hierarchical levels. It is also important to provide comfortable PPE in different sizes, use straps on eyeglasses to increase fit, and to keep all PPE readily available in the same location. Employers should also make all PPE a requirement in the workplace (including lead gloves and eyeglasses). Finally, incorporating feedback from workers will achieve a better understanding of the workers' perspective which may help to improve future training.

There is a call for radiation safety culture implementation and improvement in all health areas and veterinary medicine must engage in this challenge as human medicine is doing, to have a safer workplace environment.

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APPENDIX

Appendix A.1. Unconditional Associations Between Risk Factors of Interest and Whether or Not Lead Gloves Were Used Correctly Summarized for 1158 Exposures From 296 Imaging Studies Completed on 265 Animals by 53 Workers (1769 Unique Imaging Exposure-Worker Events)

	FREQUENCY[a]	**uOR**[b]	**95% CI**[c]	**P**[d]
Gloves used correctly	0.26 (456/1769)			
After Training				
No	0.18 (131/729)	Reference category		
Yes	0.31 (325/1040)	1.50	1.25 – 1.80	<0.001
Study type				<0.001
Thorax	0.26 (186/717)	Reference category		
Abdomen	0.25 (215/855)	1.06	0.89 – 1.25	0.53
Front limb	0.18 (12/68)	0.43	0.26 – 0.71	0.001
Hind limb	0.27 (17/64)	0.95	0.61 – 1.47	0.83
Hip	0.55 (18/33)	3.08	1.68 – 5.66	<0.001
Spine	0.67 (8/12)	3.31	1.20 – 9.15	0.02
Full body	0 (0/20)	Non-estimable		0.004
Worker category				<0.001
Technologist	0.23 (239/1042)	Reference category		
DVM	0.22 (119/536)	1.15	0.55 – 2.40	0.72
DVM student	0.51 (98/191)	4.46	2.14 – 9.28	<0.001

Species				0.24
Canine	0.26 (374/1451)	Reference category		
Feline	0.27 (78/294)	0.90	0.72 – 1.11	0.32
Exotics	0.17 (4/24)	0.26	0.04 – 1.73	0.16
Weight (kg)				0.07
< 10 kg	0.25 (205/822)	Reference category		
10-25 kg	0.31 (113/369)	1.33	1.04 – 1.71	0.02
> 25 kg	0.23 (130/560)	1.06	0.84 – 1.33	0.64
Sedation				
No	0.25 (403/1581)	Reference category		
Yes	0.28 (53/188)	0.97	0.74 – 1.28	0.85
Anesthesia				
No	0.26 (448/1752)	Reference category		
Yes	0.47 (8/17)	1.28	0.36 – 4.57	0.70

[a]Relative frequency
[b]OR Odds ratio, calculated adjusting using logistic regression adjusted for repeated measures within individual workers.
[c]95% confidence interval
[d]P-value

Appendix A.2. Unconditional Associations Between Risk Factors of Interest and Whether or Not Lead Eye Shielding Was Used Summarized for 1158 Exposures From 296 Imaging Studies Completed on 265 Animals by 53 Workers (1769 Unique Imaging Exposure-Worker Events)

	FREQUENCY[a]	**uOR**[b]	**95% CI**[c]	**P**[d]
Eye shielding worn	0.03 (56/1769)			
After Training				
No	0.008 (6/729)	Reference category		
Yes	0.05 (50/1040)	3.13	1.73 – 5.68	<0.001
Study type				0.57
Thorax	0.03 (24/717)	Reference category		
Abdomen	0.02 (19/855)	0.79	0.54 – 1.14	0.21
Front limb	0.15 (10/68)	0.98	0.39 – 2.47	0.96
Hind limb	0.03 (2/64)	0.58	0.19 – 1.80	0.35
Hip	0.03 (1/33)	1.42	0.51 – 3.99	0.50
Spine	0 (0/12)	Non-estimable		0.99
Full body	0 (0/20)	Non-estimable		0.99
Worker category				0.98
Technologist	0.01 (14/1042)	Reference category		
DVM	0.07 (35/536)	0.86	0.18 – 4.07	0.85
DVM student	0.04 (7/191)	0.90	0.19 – 4.25	0.89
Species				0.18

Canine	0.03 (49/1451)	Reference category		
Feline	0.02 (7/294)	0.70	0.41 – 1.18	0.18
Exotics	0 (0/24)	Non-estimable		0.48
Weight (kg)				0.97
< 10 kg	0.04 (33/822)	Reference category		
10-25 kg	0.04 (15/369)	0.99	0.66 – 1.50	0.98
> 25 kg	0.01 (8/560)	0.96	0.66 – 1.40	0.82
Sedation				
No	0.03 (43/1581)	Reference category		
Yes	0.07 (13/188)	1.48	0.86 – 2.50	0.15
Anesthesia				
No	0.03 (54/1752)	Reference category		
Yes	0.12 (2/17)	1.24	0.11 – 13.4	0.86

[a]Relative frequency
[b]OR Odds ratio, calculated adjusting using logistic regression adjusted for repeated measures within individual workers.
[c]95% confidence interval
[d]P-value

Appendix A.3. Unconditional Associations Between Risk Factors of Interest and Whether or Not Head Position was Optimal Summarized for 1158 Exposures From 296 Imaging Studies Completed on 265 Animals by 53 Workers (1769 Unique Imaging Exposure-Worker Events)

	FREQUENCY[a]	uOR[b]	95% CI[c]	P[d]
Head Position Optimal	0.35 (611/1769)			
After Training				
No	0.30 (222/729)	Reference category		
Yes	0.37 (389/1040)	1.32	1.07 – 1.63	0.01
Study type				<0.001
Thorax	0.31 (222/717)	Reference category		
Abdomen	0.39 (333/855)	1.51	1.22 – 1.86	<0.001
Front limb	0.26 (18/68)	0.66	0.37 – 1.20	0.18
Hind limb	0.38 (24/64)	1.07	0.63 – 1.83	0.80
Hip	0.24 (8/33)	0.70	0.31 – 1.51	0.35
Spine	0.42 (5/12)	1.08	0.34 – 3.50	0.89
Full body	0.05 (1/20)	0.19	0.02 – 1.43	0.11
Worker category				0.07
Technologist	0.39 (406/1042)	Reference category		
DVM	0.26 (141/536)	0.56	0.33 – 0.93	0.03
DVM student	0.34 (64/191)	0.69	0.40 – 1.18	0.18
Species				0.008
Canine	0.36 (525/1451)	Reference category		

Feline	0.29 (85/294)	0.72	0.55 – 0.94	0.02
Exotics	0.04 (1/24)	0.10	0.01 – 0.93	0.04
Weight (kg)				<0.001
< 10 kg	0.31 (254/822)	Reference category		
10-25 kg	0.34 (126/369)	1.19	0.92 – 1.54	0.19
> 25 kg	0.41 (227/560)	1.57	1.24 – 1.97	<0.001
Sedation				
No	0.35 (552/1581)	Reference category		
Yes	0.31 (59/188)	0.78	0.56 – 1.08	0.14
Anesthesia				
No	0.35 (607/1752)	Reference category		
Yes	0.24 (4/17)	0.60	0.17 – 2.15	0.44

[a]Relative frequency
[b]OR Odds ratio, calculated adjusting using logistic regression adjusted for repeated measures within individual workers.
[c]95% confidence interval
[d]P-value

Appendix A.4. Unconditional Associations Between Risk Factors of Interest and Whether or Not Workers Stood Straight or Leaned Backwards Summarized (Optimal Body Position) Summarized for 1158 Exposures From 296 Imaging Studies Completed on 265 Animals by 53 Workers (1769 Unique Imaging Exposure-Worker Events)

	FREQUENCY[a]	uOR[b]	95% CI[c]	P[d]
Standing straight / Leaning Back	0.32 (569/1769)			
After Training				
No	0.24 (178/729)	Reference category		
Yes	0.38 (391/1040)	1.91	1.54 – 2.39	<0.001
Study type				0.51
Thorax	0.32 (233/717)	Reference category		
Abdomen	0.31 (263/855)	0.90	0.72 – 1.11	0.32
Front limb	0.40 (27/68)	1.31	0.80 – 2.22	0.31
Hind limb	0.41 (26/64)	1.44	0.85 – 2.42	0.17
Hip	0.30 (10/33)	0.86	0.40 – 1.81	0.68
Spine	0.25 (3/12)	0.97	0.29 – 3.23	0.96
Full body	0.35 (7/20)	0.92	0.32 – 2.65	0.87
Worker category				0.53
Technologist	0.32 (338/1042)	Reference category		
DVM	0.32 (169/536)	1.10	0.73 – 1.65	0.64
DVM student	0.32 (62/191)	0.82	0.51 – 1.33	0.42
Species				<0.001

Canine	0.34 (500/1451)	Reference category		
Feline	0.21 (62/294)	0.49	0.37 – 0.67	<0.001
Exotics	0.29 (7/24)	0.63	0.22 – 1.78	0.39
Weight (kg)				<0.001
< 10 kg	0.25 (205/822)	Reference category		
10-25 kg	0.37 (136/369)	1.61	1.24 – 2.09	<0.001
> 25 kg	0.40 (224/560)	1.85	1.46 – 2.34	<0.001
Sedation				
No	0.30 (467/1581)	Reference category		
Yes	0.54 (102/188)	2.82	2.07 – 3.84	<0.001
Anesthesia				
No	0.32 (558/1752)	Reference category		
Yes	0.65 (11/17)	3.80	1.32 – 11.0	0.01

[a]Relative frequency
[b]OR Odds ratio, calculated adjusting using logistic regression adjusted for repeated measures within individual workers.
[c]95% confidence interval
[d]P-value

Appendix A.5. Unconditional Multivariable Model of the Associations Between Risk Factors of Interest and Number of Workers in the Room Summarized for 1478 Exposures From 374 Imaging Studies Completed on 310 Animals

	NUMBER OF EXPOSURES	MEDIAN (5th, 95th PCTL[a])	aRD[b]	95% CI[c]	P[d]
Study Type					< 0.001
Thorax	589	2 (0, 2)	Reference category		
Abdomen	605	2 (0, 2)	1.16	1.06–1.27	0.002
Front limb	75	1 (0, 2)	0.69	0.54–0.88	0.003
Hind limb	85	1 (0, 2)	0.61	0.48–0.78	< 0.001
Hip	67	0 (0, 2)	0.41	0.30–0.57	< 0.001
Spine	20	1 (0, 2)	0.66	0.41–1.05	0.008
Full body	37	1 (0, 1)	0.40	0.25–0.62	< 0.001
Species					< 0.001
Canine	1167	2 (0, 2)	Reference category		
Feline	263	1 (0, 2)	0.83	0.74– 0.94	0.003
Exotic	48	1 (0, 1)	0.36	0.24– 0.55	< 0.001
Weight					0.001
< 10 kg	728	1 (0, 2)	Reference category		
10-25 kg	289	2 (0, 2)	1.23	1.09– 1.38	< 0.001
> 25 kg	452	2 (0, 2)	1.13	1.02– 1.25	0.024
Sedation					
No	1107	2 (0, 2)	Reference category		
Yes	371	0 (0, 2)	0.33	0.29– 0.39	< 0.001
Anesthesia					

No	1410	2 (0, 2)	Reference category		
Yes	68	0 (0, 2)	0.26	0.18– 0.39	< 0.001
Material Restraint					
No	1301	2 (0, 2)	Reference category		
Yes	177	0 (0, 1)	0.08	0.05– 0.12	< 0.001

[a]Percentile
[b]Relative difference in counts calculated adjusting using Poisson regression adjusted for repeated measures within individual workers with generalized estimating equations.
[c]95% confidence interval
[d]P-value

Appendix B. Radiation Safety Electronic Questionarie

UNIVERSITY OF SASKATCHEWAN

Radiation Safety Practices Among Veterinary Fluoroscopy Users

Participant Information and Consent

You are invited to participate in this survey study entitled 'Radiation Safety Practices among Small Animal Fluoroscopy Users'. Participation in this survey is voluntary, and you can decide not to participate at any time by closing your browser or choose not to answer any questions you don't feel comfortable with.

WHY IS THIS STUDY BEING DONE?

The objective of this study is to describe the radiation safety practices of veterinarians using fluoroscopy for small animal diagnosis and treatment.

WHAT DOES THE STUDY INVOLVE?

The questionnaire will take approximately 10 minutes to complete, and includes questions on general practices, use of personal shielding equipment, dose monitoring, and personal information.

WHAT ARE THE POTENTIAL RISKS OF PARTICIPATING IN THIS STUDY?

There are no known or anticipated risks to you by participating in this research.

WILL MY TAKING PART IN THIS STUDY BE KEPT CONFIDENTIAL?

No information disclosing your identity will be collected. Each participant will be identified only by a unique respondent ID generated by SurveyMonkey. The results of this study may be presented in a scientific meeting or published, and all data will be presented in summarized form.

HOW CAN I WITHDRAW FROM THIS STUDY?
Since survey responses cannot be linked to individual data, once your survey is submitted it cannot be removed.

WILL I BE INFORMED OF THE RESULTS OF THE STUDY?
The results of the study will be available after data has been collected and analyzed. To obtain these results once available please contact Dr. Niels Koehncke (Co-Investigator) at niels.koehncke@usask.ca

WHO DO I CONTACT IF I HAVE QUESTIONS ABOUT THE STUDY?
If you have any questions or desire further information about this study before or during participation, you can contact Dr. Monique Mayer (Principal Investigator) at monique.mayer@usask.ca or Dr. Niels Koehncke (Co-Investigator) at niels.koehncke@usask.ca

This research project has been approved on ethical grounds by the University of Saskatchewan Research Ethics Board. Any questions regarding your rights as a participant may be addressed to that committee through the Research Ethics Office ethics.office@usask.ca; (306) 966-2975. Out of town participants may call toll free (888) 966-2975.

By completing and submitting this questionnaire, **YOUR FREE AND INFORMED CONSENT IS IMPLIED** and indicates that you understand the above conditions of participation in this study.

Study Inclusion

For the following questions, 'operator' of a fluoroscopic machine is defined as a person operating the machine controls, or a person directly involved in the procedure and standing immediately adjacent to the machine operator. In the image below, both workers A and B would be considered operators, but worker C would not.

(If No – Survey Ends)

Question Title

1. In the last year, have you been the operator of an X-ray unit for a small animal fluoroscopic procedure?

- Yes
- No

General Practices

Question Title

2. On average, how many small animal fluoroscopic procedures are you involved in as operator per month?

- < 1
- 1-4
- 5-10
- 11-15
- 16-20
- > 20

Question Title

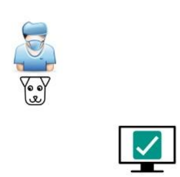
3. Approximately what percentage of your time as operator involves the following small animal fluoroscopic procedures? Please provide percentages that add up to 100, but omit the '%' sign from your answers.
(add up to 100, otherwise will go to the next page)

Cardiac
Gastrointestinal
Hepatobiliary (including portocaval shunt attenuation)
Orthopedic
Respiratory
Urinary
Vascular
Other

Question Title

4. When operating the fluoroscopic machine, which of the following configurations represents the most frequent position of the viewing monitor relative to you and the patient during the X-ray exposure time?

Monitor straight ahead



Monitor at 45° (left or right side)

Monitor at 90° (left or right side)

Question Title

5. Which of the following shielding does your employer require you to wear during fluoroscopic procedures? Please check all that apply.

- ☐ Apron
- ☐ Thyroid shield
- ☐ Gloves (with any radiation attenuating material e.g. lead or bismuth)
- ☐ Lead eyeglasses
- ☐ I don't know
- ☐ I am the employer

Question Title

6. How often do you wear a radiation shielding apron during the X-ray exposure time?

- ○ Always
- ○ > 75% of the time
- ○ 50% - 75% of the time
- ○ < 50% of the time
- ○ Never
- ○ Not available at my facility

Question Title

7. How often do you wear a thyroid shield secured closely around your neck during the X-ray exposure time?

- ○ Always
- ○ > 75% of the time
- ○ 50% - 75% of the time
- ○ < 50% of the time
- ○ Never

- Not available at my clinic

Question Title

8. How often do you use radiation attenuating hand cream during the X-ray exposure time?

- Always
- > 75% of the time
- 50% - 75% of the time
- < 50% of the time
- Never
- Not available at my clinic

Question Title

9. How often do you wear radiation shielding gloves (with any attenuating material, e.g. lead or bismuth) during the X-ray exposure time?

- Always
- > 75% of the time
- 50% - 75% of the time
- < 50% of the time
- Never
- Not available at my clinic

Body, Thyroid and Hand Shielding

Question Title

10. When you do wear radiation shielding gloves, approximately what percentage of your time do you wear the following types of gloves? Please provide percentages that add up to 100, but omit the '%' sign from your answers.

Gloves equivalent to 0.5mm of lead attenuation (e.g. typical radiology gloves)

Surgical gloves impregnated with radiation attenuating material (e.g. bismuth oxide)

Question Title

11. For approximately what percentage of fluoroscopic procedures is an unshielded part of your body (e.g. fingers) visible in at least one image acquired during the procedure?

- All procedures
- > 75% of procedures
- 50% - 75% of procedures
- < 50% of procedures
- No procedures

Question Title

12. How often do you use a lead shielding curtain (fixed or mobile) during the X-ray exposure time?

- Always
- > 75% of the time
- 50% - 75% of the time
- < 50% of the time
- Never
- Not available at my clinic

Eye Shielding

Question Title

13. How often do you wear lead eyeglasses during the X-ray exposure time?

- Always
- > 75% of the time
- 50% - 75% of the time

○ < 50% of the time

○ Never

○ Not available at my clinic

(if Question 13: > 75% of the time / 50% - 75% of the time / < 50% of the time / Never)

(SKIP: if Question 13 is Always / Not available at my clinic)

Question Title

*14. What are the three most important reasons you **DO NOT** wear lead eyeglasses during the X-ray exposure time?*

Reason 1 (most important)

Reason 2

Reason 3 (least important)

Drop down options for each question:

Eyeglasses interfere with performing my task

Eyeglasses are uncomfortable

Eyeglasses are not required by my employer

Not enough Eyeglasses for all workers

I am not concerned about the adverse health effects of ionizing radiation

My coworkers do not wear Eyeglasses

Eyeglasses are unhygienic

Eyeglasses do not fit properly

(if Question 13: Always / > 75% of the time / 50% - 75% of the time / < 50% of the time)

(SKIP: if Question 13 is Not available at my clinic)

Question Title

15. When you wear lead eyeglasses during the X-ray exposure time, which of the following design types do you wear most often?

Glasses with lead side shielding

Glasses without lead side shielding

Dose Monitoring

Question Title

16. For which of the following locations have you been assigned a personal dose monitoring device? Please check all that apply.

☐ Whole body

☐ Thyroid

☐ Hands (ring badge)

☐ Other (please specify)

Question Title

17. How often do you wear your assigned whole-body dosimeter during the X-ray exposure time?

- Always
- > 75% of the time
- 50% - 75% of the time
- < 50% of the time
- Never
- I have not been assigned a whole-body dosimeter

Question Title

18. How often do you wear your assigned hand dosimeter (ring badge) during the X-ray exposure time?

- Always
- > 75% of the time
- 50% - 75% of the time
- < 50% of the time
- Never
- I have not been assigned a hand dosimeter

Question Title

19. Do you use a personal dose monitoring device to estimate the annual equivalent dose to your eyes?

- Yes
- No
- I don’t know

Fluoroscopy Machine Parameters

Question Title

20. Have you received formal training from your hospital regarding fluoroscopy machine parameters that reduce radiation exposure?

- ○ Yes
- ○ No

Question Title

21. How often do you adjust the parameters on the fluoroscopy machine for the purpose of reducing your radiation exposure?

- ○ Always
- ○ > 75% of the time
- ○ 50% - 75% of the time
- ○ < 50% of the time
- ○ Never

Fluoroscopy Machine Parameters

(If Always to 50% YES / If Never, do NOT do this one0

Question Title

22. Which of the following machine parameters do you at times adjust for the purpose of reducing your radiation exposure? Please check all that apply.

- ☐ Pulse frequency (pulses per second)
- ☐ Frame-rate frequency (frame rates per second)
- ☐ Collimation
- ☐ mA and/or kV adjustment
- ☐ Other (please specify)

[ ]

Knowledge of Personal Dose and Radiation Risks

Question Title

23. How would you rate your knowledge of the risks of ionizing radiation?

- Excellent
- Good
- Fair
- Poor

Question Title

24. Do you know your last reported whole body effective dose from occupational radiation exposure?

- Yes, I know my exact reported dose
- I have a rough idea of my last reported dose
- I do not know, but I know how to look it up easily
- I do not know, and I don't know how to look it up easily
- I don't receive reports on my whole-body effective dose

Question Title

25. Do you know your last reported equivalent dose to the lens of your eye from occupational radiation exposure?

- Yes, I know my exact reported dose
- I have a rough idea of my last reported dose
- I do not know, but I know how to look it up easily
- I do not know, and I don't know how to look it up easily
- I don't receive reports on the equivalent dose to the lens of my eye

Question Title

26. What is the annual occupational effective dose limit (averaged over 5 years) recommended by the International Commission on Radiological Protection?

- 5 mSv (0.5 rem)
- 20 mSv (2 rem)
- 50 mSv (5 rem)
- 150 mSv (15 rem)
- 500 mSv (50 rem)
- I don't know

Question Title

27. What is the annual occupational equivalent dose limit for the lens of the eye recommended by the International Commission on Radiological Protection?

- 5 mSv (0.5 rem)
- 20 mSv (2 rem)
- 50 mSv (5 rem)
- 150 mSv (15 rem)
- 500 mSv (50 rem)
- I don't know

Question Title

28. Do you believe that radiation exposure increases the risk of cancer?

- Yes
- No
- I don't know

Question Title

29. Do you believe that radiation exposure increases the risk of cataracts?

- Yes
- No
- I don't know

Personal information

Question Title

30. Are you a resident in training?

- Yes
- No

(If 30 YES; SKIP if 30 is No)

Question Title

31. In which of the following areas are you a resident in training?

- Cardiology
- Diagnostic Imaging
- Small Animal Internal Medicine
- Surgery
- Other (please specify)

Question Title

32. Are you board-certified in one or more veterinary specialty area(s)?

- Yes
- No

(if 32 YES; SKIP if 32 is No)

Question Title

33. In which of the following areas are you board-certified?

- ☐ Cardiology
- ☐ Diagnostic Ima1ging
- ☐ Small Animal Internal Medicine
- ☐ Surgery
- ☐ Other (please specify)

Question Title

34. In which country is the veterinary clinic at which you primarily work located?

- ○ United States
- ○ Canada
- ○ Other (please specify)

Question Title

35. What type of practice do you primarily work at?

- ○ Academic institution
- ○ Private veterinary practice
- ○ Other (please specify)

Question Title

36. To which of the following age groups do you belong?

- ○ > 65 years of age

- 45 - 64 years of age
- 25 - 44 years of age
- 18 - 24 years of age

Question Title

37. To which gender identity do you most identify?

- Female
- Male
- Transgender
- Prefer not to say
- Other (please specify)

Appendix A.6. Unconditional associations between risk factors of interest and frequency of radiation safety behaviors reported by veterinarians involved with performing small animal fluoroscopic procedures (n = 197 respondents).

OUTCOME	RISK FACTOR	P-VALUE
Use of gloves	Self-reported knowledge of radiation risk	< 0.001
	Correctly identified ICRP[a] body dose limit	0.01
	Correctly identified ICRP eye lens dose limit	< 0.001
	Employer requirement that shielding be worn	< 0.001
	Belief that radiation exposure can cause cataracts	0.12
	Professional college	< 0.001
	Diplomate versus resident	0.90
	Age	0.56
	Gender	0.11
	Practice Type	0.03
	Country	0.98
Use of eyeglasses	Self-reported knowledge of radiation risk	0.17
	Correctly identified ICRP body dose limit	0.05
	Correctly identified ICRP eye lens dose limit	0.10
	Employer requirement that shielding be worn	< 0.001
	Belief that radiation exposure can cause cataracts	0.03
	Professional college	0.16
	Diplomate versus resident	0.38
	Age	0.18
	Gender	0.98
	Practice Type	0.08

	Country	< 0.001
Lead curtain use	Self-reported knowledge of radiation risk	0.002
	Correctly identified ICRP body dose limit	< 0.001
	Correctly identified ICRP eye lens dose limit	0.02
	Belief that radiation exposure can cause cataracts	0.08
	Professional college	< 0.001
	Diplomate versus resident	0.51
	Age	0.59
	Gender	0.25
	Practice Type	0.03
	Country	0.87
Body dosimeter use	Self-reported knowledge of radiation risk	0.05
	Correctly identified ICRP body dose limit	0.95
	Correctly identified ICRP eye lens dose limit	0.77
	Belief that radiation exposure can cause cataracts	0.09
	Professional college	< 0.001
	Diplomate versus resident	0.52
	Age	0.66
	Gender	0.97
	Practice Type	0.47
	Country	0.22
Ring dosimeter use	Self-reported knowledge of radiation risk	0.02
	Correctly identified ICRP body dose limit	0.40
	Correctly identified ICRP eye lens dose limit	0.22
	Belief that radiation exposure can cause cataracts	1.0

	Professional college	0.001
	Diplomate versus resident	0.35
	Age	0.17
	Gender	0.22
	Practice Type	0.94
	Country	0.01
Machine parameters adjust	Training on machine parameters	< 0.001
	Self-reported knowledge of radiation risk	0.43
	Correctly identified ICRP body dose limit	0.01
	Correctly identified ICRP eye lens dose limit	0.26
	Belief that radiation exposure can cause cataracts	0.62
	Professional college	0.02
	Diplomate versus resident	0.04
	Age	0.90
	Gender	0.33
	Practice Type	0.65
	Country	0.86

[a]International Commission on Radiological Protection