LITERATURE REVIEWS

Ionizing radiation exposure in humans during X-ray procedures in dogs and cats: A systematic review

Exposición a la radiación ionizante en humanos durante procedimientos de rayos X en perros y gatos: una revisión sistemática

Exposição à radiação ionizante em humanos durante procedimentos de raios X em cães e gatos: uma revisão sistemática

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Abstract

Background: Ionizing radiation in veterinary medicine enhances diagnosis and treatment but poses risks to animals, pet owners, and clinical staff. Inadequate training in radiographic equipment increases the risk of unnecessary exposure and related hazards. **Objective:** To systematically gather and analyze the available evidence on ionizing radiation exposure in human individuals involved in X-ray diagnostic procedures performed in dogs and cats. **Methods:** An electronic search on four platforms, followed by a manual review of references from articles identified in the full-text screening, was conducted. References from six selected review articles (1997-2022) were also examined. Predetermined inclusion and exclusion criteria were strictly applied, with a focus on articles published in peer-reviewed journals. **Results:** A total of 5 articles met the definitive inclusion criteria. The relevant articles were published between 2007 and 2024. The levels were low (approximately 90% of the measurements showed doses below 0.005 mSv), with exposure peaks observed in critical anatomical areas such as the veterinary staff´s eyes and hands, particularly during procedures requiring proximity to the radiation field. **Conclusion:** Our results highlight the need to increase awareness of the need for proper training and the implementation of radiological protection measures to minimize the risks associated with ionizing radiation in veterinary practices. In addition, future research needs to incorporate a wider range of devices and techniques to develop safety protocols that safeguard staff and patients.
Keywords: *animal well-being; ionizing radiation; radiographic exposure; safety protocols; veterinary medicine; work safety.*

Resumen

Antecedentes: La radiación ionizante en medicina veterinaria mejora el diagnóstico y el tratamiento, pero representa riesgos para los animales, tutores y personal clínico. La formación inadecuada en el uso de equipos radiográficos aumenta el riesgo de exposición innecesaria y los peligros asociados. **Objetivo:** Reunir y analizar sistemáticamente la evidencia disponible sobre la exposición a radiación ionizante en personas involucradas en procedimientos de diagnóstico por rayos X realizados en perros y gatos. **Métodos:** Se realizó una búsqueda electrónica en cuatro plataformas, seguida de una revisión manual de referencias de artículos identificados durante la evaluación de texto completo. También se examinaron referencias de seis artículos de revisión seleccionados (1997-2022). Se aplicaron estrictamente criterios de inclusión y exclusión

predeterminados, centrándose exclusivamente en artículos publicados en revistas revisadas por pares. **Resultados:** Un total de 5 artículos cumplieron con los criterios definitivos de inclusión. Los artículos relevantes fueron publicados entre 2007 y 2024. Los niveles de exposición fueron bajos (alrededor del 90% de las mediciones mostraron dosis por debajo de 0.005 mSv), con picos de exposición observados en áreas anatómicas críticas como los ojos y las manos del personal veterinario, particularmente durante procedimientos que requieren proximidad al campo de radiación. **Conclusión:** Nuestros resultados destacan la necesidad de aumentar la concienciación sobre la importancia de la formación adecuada y la implementación de medidas de protección radiológica para minimizar los riesgos asociados con la radiación ionizante en las prácticas veterinarias. Además, investigaciones futuras deben incorporar una gama más amplia de dispositivos y técnicas para desarrollar protocolos de seguridad que protejan al personal y a los pacientes.
Palabras clave: *bienestar animal; exposición radiográfica; medicina veterinaria; protocolos de seguridad; radiación ionizante; seguridad laboral.*

Resumo

Antecedentes: A radiação ionizante na medicina veterinária melhora o diagnóstico e o tratamento, mas apresenta riscos para os animais, tutores e equipe clínica. O treinamento inadequado no uso de equipamentos radiográficos aumenta o risco de exposição desnecessária e os perigos associados. **Objetivo:** Reunir e analisar sistematicamente as evidências disponíveis sobre a exposição à radiação ionizante em pessoas envolvidas em procedimentos de diagnóstico por raios X realizados em cães e gatos. **Métodos:** Foi realizada uma busca eletrônica em quatro plataformas, seguida de uma revisão manual das referências de artigos identificados durante a triagem de textos completos. Referências de seis artigos de revisão selecionados (1997-2022) também foram analisadas. Critérios pré-definidos de inclusão e exclusão foram rigorosamente aplicados, com foco exclusivo em artigos publicados em revistas revisadas por pares. **Resultados:** Um total de 5 artigos atendeu aos critérios definitivos de inclusão. Os artigos relevantes foram publicados entre 2007 e 2024. Os níveis de exposição foram baixos (cerca de 90% das medições mostraram doses abaixo de 0,005 mSv), com picos de exposição observados em áreas anatômicas críticas, como os olhos e as mãos da equipe veterinária, especialmente durante procedimentos que exigem proximidade ao campo de radiação. **Conclusão:** Nossos

resultados destacam a necessidade de aumentar a conscientização sobre a importância do treinamento adequado e da implementação de medidas de proteção radiológica para minimizar os riscos associados à radiação ionizante nas práticas veterinárias. Além disso, pesquisas futuras devem incorporar uma gama mais ampla de dispositivos e técnicas para desenvolver protocolos de segurança que protejam a equipe e os pacientes.
Palavras-chave: *bem-estar animal; exposição radiográfica; medicina veterinária; protocolos de segurança; radiação ionizante; segurança do trabalho.*

Introduction

On a cold November night in 1895, German physicist Wilhelm Röntgen discovered an unknown type of ray, which he named X-rays (Röntgen, 1898). Initially, these rays sparked significant interest and fascination, with circles and fairs presenting them as attractions, allowing the public to view their bones through a fluorescent screen (Morton and Hammer, 1896). The first medical application of X-rays in humans was to examine broken bones and internal body structures. Small vehicles adapted for X-rays to locate bullets or broken bones in soldiers during World War I could forget petite injuries. The radiation used by surgeons was continuous and assisted by a fluorescent screen, enabling precise identification of the anatomical location where the bullet or object was embedded (Quinn, 1995). Information about the first veterinarian to use this technology is unclear. Names such as Maximilian Von Prittwitz, Friedrich Wilhelm Zinn, and Richard Eberlein are mentioned, but there is a lack of evidence.

Despite the technological advancements it represented, the risks of radiology in humans became evident through the martyrs of radiology —a term used to describe early scientists, including Marie and Pierre Curie, who died owing to a lack of protection from X-rays. In this sense, ionizing radiation has become (and still is) a significant public health concern, and the failure to understand or ignore the consequences of exposure without proper protective measures can result in symptoms such as vomiting and nausea in cases of acute exposure. Over time, this may lead to cataracts, thyroid damage, and, with prolonged exposure, breast cancer, leukemia, lung cancer, and irreversible DNA damage. The maximum recommended effective dose for occupationally exposed workers is 20 mSv (millisieverts) per year, excluding doses from medical exposures (ICRP, 2007).

The use of ionizing radiation in veterinary medicine has allowed significant advances in the diagnosis and treatment of animal diseases. However, exposure to this radiation presents a potential risk not only to veterinary patients but also to pet owners and clinical staff involved in their care (EUR-Lex, 1996). In veterinary practice, training on the proper use of radiographic equipment is often insufficient, increasing the likelihood of unnecessary exposure and the associated risks (Consejo de Seguridad Nuclear, 2012).

Despite the growing use of radiographs and other imaging methods that rely on ionizing radiation, awareness of radiation exposure levels among veterinary clinicians remains limited. In human medicine, numerous studies have highlighted the critical importance of radiation protection, emphasizing both regulatory frameworks and the perceptions of healthcare professionals regarding occupational exposure (Arias, 2006; González, 2018; Batista *et al*., 2019; Valenzuela-Medina & Hidalgo-Rivas, 2021). However, in veterinary practice, awareness and training in radiation safety remain limited, which increases the likelihood of unnecessary exposure and underscores the need to strengthen protection protocols for veterinary staff and pet owners. This gap in knowledge is concerning given the increasing use of these technologies in veterinary clinics and hospitals (ICRP, 2007).

Given the limited information on this topic, our aim was to systematically gather and analyze the available evidence on ionizing radiation exposure (amount) to human individuals involved in X-ray diagnostic procedures performed in dogs and cats.

Materials and methods

This systematic review was planned, executed, and reported in accordance with PRISMA guidelines (Page *et al*, 2021). The research question, search strategy, criteria for study inclusion and exclusion, and checklists for relevance screening, baseline characterization, methodological evaluation, and data extraction from relevant primary studies were all based on a preestablished, pretested protocol.

Search strategy

Our specific research question focused on determining the amount of ionizing radiation used during X-ray diagnostic procedures in dogs and cats. Consequently, this was the study topic that required identification and assessment. The initial search was conducted on May 21, 2024.

We searched four databases (OVID®/MEDLINE, PubMed®, SciELO, and Redalyc). The topic was divided into components, and the following search pattern was used to locate relevant studies: (amount* OR quantit* OR total OR sum OR value* OR accumulation OR measure* OR magnitude OR count) AND ("ionizing radiation" OR "ionizing beams" OR "ionizing emissions" OR "ionizing energy" OR "ionizing particles" OR "ionizing rays" OR radiation) AND (X-ray* OR radiography OR radiology) AND (pet OR pets OR dog OR dogs OR canine* OR cat OR cats OR feline*).

Eligibility screening

The inclusion criteria were restricted to original articles published in peer-reviewed journals and written in English, Portuguese, French, German, or Spanish. Neither the publication year nor the country of origin served as exclusion factors.

The initial citation selection process involved two authors evaluating the titles for their potential relevance to the study topic. Citations deemed potentially relevant were then screened by two authors based on their abstracts, following the inclusion and exclusion criteria established during the title review phase. The full texts of the remaining citations were subsequently thoroughly reviewed by two authors to ensure that they contained data pertinent to the research question. Kappa coefficients were calculated at each of the three selection stages to evaluate interauthor agreement. A detailed review of the materials, methods, and results sections of each full text was conducted, and any disagreements were resolved by consensus.

As a final step, two authors performed a manual search of the references cited in the articles identified during full-text screening—a process known as snowballing —to identify additional relevant sources. Additionally, references from selected review articles were examined via the same approach (Thrall, 1997; Arias, 2006; González, 2018; Batista *et al.,* 2019; Valenzuela-Medina and Hidalgo-Rivas, 2021).

Data extraction

Following the compilation of all relevant publications, a descriptive summary was provided for each of the resulting publications that considered the information on the study objective, methods, results, conclusions, practical implications, and limitations. In addition, an extraction of quantitatively relevant data was performed.

Results

The electronic search, which combines results from all search engines and, after deduplication, yielded 244 eligible citations possibly associated with the subject of this systematic review. The citations to be reviewed were published between 1972 and 2024. After the titles were read, 212 studies were considered unrelated (agreed upon by two authors). The final number of citations by title screening was 32 (retained by at least one reviewer). After the abstracts of the articles were read, 22 were excluded (by both authors), and 10 original articles remained for the full-text review. Five articles were completely reviewed by full-text and kept for data extraction after five articles were dismissed during this phase. The snowballing strategy was then applied through the reference lists of the definitive articles, and no citations or selected review articles were retained. The final number of articles that met the eligibility criteria and were therefore included in the qualitative synthesis was five. The file containing the systematic process for collecting and selecting citations is available upon request to the authors. Figure 1 describes the protocol and the selection of relevant articles.

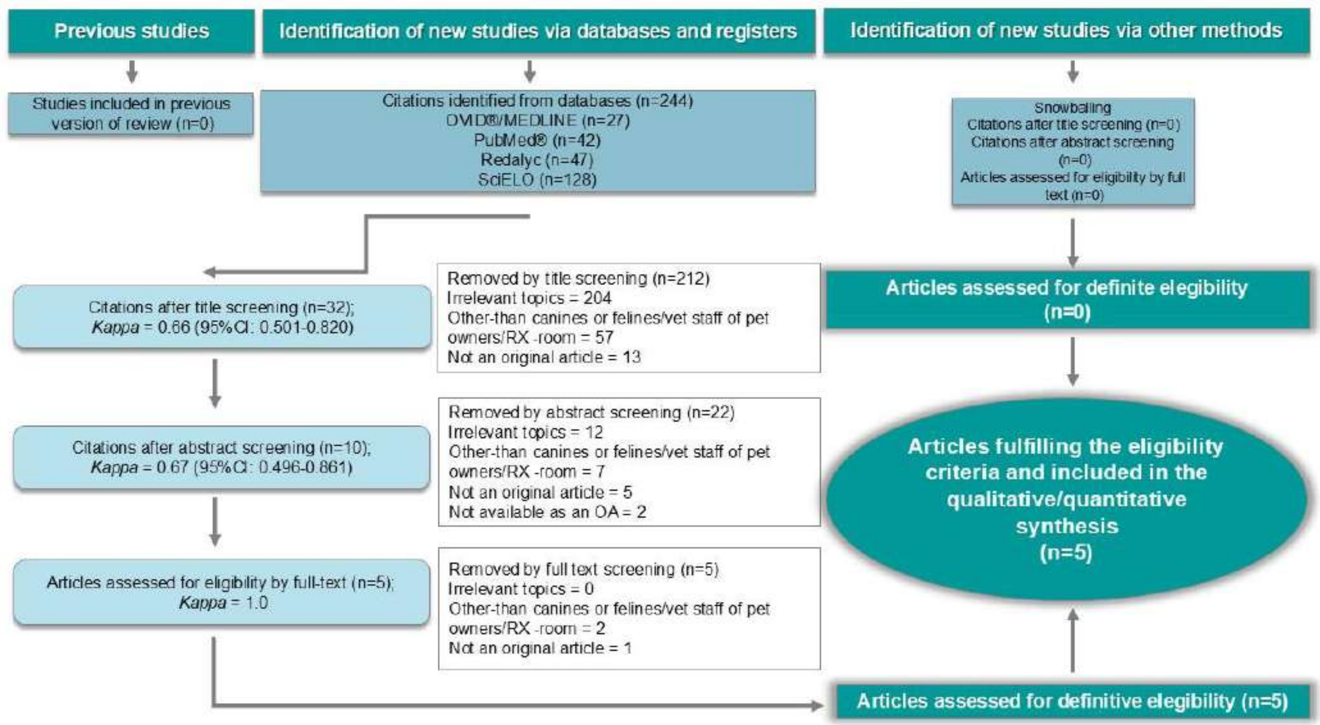

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow chart (Page *et al.,* 2021), which describes the progress of the citations through the systematic review. OA=open access.

The relevant articles were published between 2007 and 2024; three were written in English, and two were written in German, all of which were published in four different journals. The United States, Germany, and China were the countries where the studies were conducted. The radiation exposure levels were low (approximately 90% of the measurements showed doses below 0.005 mSv), with exposure peaks observed in critical anatomical areas such as the veterinary staff´s eyes and hands, particularly during procedures requiring proximity to the radiation field. Previous studies also measured radiation exposure in people—pet owners and veterinary staff—but did not report the specific number for each population (Seifert *et al.,* 2007; 2008). Table 1 presents the quantitative information extracted from the relevant articles. Below is a descriptive summary of each of the five resulting articles.

Table 1. Quantitative information extracted from the relevant articles (n=5).

Ref.	Procedures and population	Anatomical place/operator	Total amount of radiation from the equipment	Exposure time (in sec)	Radiation exposure (in mSv)	Imaging technique
Seifert *et al.* (2007)	Measurements in veterinary staff during 278 X-ray examinations in dogs (n=278) and cats (n=46)	Eye lens	60 kV – 91 mA	Not reported	0.0443	Conventional radiography
		Thyroid			0.0483	
		Chest (beneath the lead apron)			<0.005	
		Hands (under gloves)			0.004 (right hand) and 0.0053 (left hand)	
		Gonads (beneath the lead apron)			<0.005	
		Lower legs			<0.002	
Seifert *et al.* (2008)	Measurements in pet owners during 278 X-ray examinations in dogs (n=278) and cats (n=46)	Eye lens	60 kV – 91 mA	Not reported	0.013	Conventional radiography
		Thyroid			0.009	
		Chest (under the lead apron)			0.0023	
		Hands (under gloves)			0.014 (both hands)	
		Gonads (under the lead apron)			0.0021	
		Lower legs			0.0020	
Hersh-Boyle *et al.* (2019)	Measurements in veterinary staff during 360 fluoroscopic procedures in dogs and cats*	Interventional radiology–trained clinicians	Not reported	11.85 (50.57-85.10)	16.10 (0.44-617.50)	Fluoroscopy
		Orthopedic surgeons		1.71 (0.05-22.20)	2.38 (0.14-74.33)	

		Soft tissue surgeons		2.10 (0.30-23.70)	4.07 (0.15-131.50)	
		Internists		5.60 (1.50-12.20)	25.24 (3.58-185.79)	
		Cardiologists		10.45 (0.02-47.80)	25.82 (0.33-287.45)	
Chen *et al.* (2019)	2,224 X-ray procedures in 472 animals**; dogs (n=369) and cats (n=84)	Inside plain radiography room	61 kV (48-95) - 10.1 mA (3.2-51.2)	Not reported	1.1 - 9.6	Conventional radiography and computed tomography environment
		Outside plain radiography room			0.99 ± 0.23 (controlled area) and 0.28 ± 0.21 (uncontrolled area)	
Villamizar-Martínez and Losey (2024)	Measurements in veterinary staff (one person), after intraoral radiographs in dogs (n=20) and cats (n=10) - 10 radiographs per patient	Eye	60 kV - 2.5 mA	0.15 (in X rays to cats) and 0.15-0.2 (in X rays to dogs)	0.001	Intraoral dental radiography (handheld unit)
		Left hand			<0.01	
		Right hand			<0.01	
		Thyroid			<0.01	
		Left breast			<0.01	
		Right breast			0.0002	
		Left ovary			0.0003	
		Right ovary			<0.01	
		Testicle			<0.01	

*Exposure time and radiation exposure are presented as total (for 4 years).

**Other animals were included (7 turtles, 4 rabbits, 3 parrots, 2 hedgehogs, 2 sharks, and 1 honey badger), but dogs and cats accounted for the largest proportion (96%). The total exposure time and amount of radiation exposure are presented (for 1 year).

Seifert et al. (2007)

This study aimed to assess radiation exposure for pet owners during X-ray procedures to ensure their safety. The authors used a thermoluminescent dosimeter (TLD)-100H, which is sensitive to low radiation levels, to measure exposure. Fifty dosimeters were calibrated, 45 of which were used for field measurements across various X-ray procedures on dogs and cats. Measurements were taken at several body locations, including the eyes, thyroid, chest, hands, gonads, and lower legs. The results revealed that most doses were less than 0.0025 mSv per X-ray, with the highest recorded dose being 0.0052 mSv in the right hand. Most doses were consistently low, indicating minimal exposure for pet owners. Nearly half of the doses measured at certain body sites were zero, reflecting minimal radiation in many cases. Although any radiation exposure carries potential health risks, the study revealed that exposure levels were generally low. With most equivalent doses below 0.002 mSv and the maximum dose only reaching 0.0042 mSv, continuous monitoring for each X-ray is deemed unnecessary, although it remains a legal requirement. These findings suggest that pet owners can safely be present during X-rays with proper protection measures in place. Veterinary practices should ensure effective radiation safety protocols and consider the use of sensitive dosimeters for accurate measurements. Despite the low degree of risk, training pet owners about radiation safety remains important. Limitations include the potential unavailability of TLD-100H in some practices and the question of whether continuous monitoring is practical given the low exposure levels. The scope of this study was also limited, potentially affecting its applicability to all veterinary scenarios.

Seifert et al. (2008)

This study assessed radiation exposure for veterinary staff during radiographic procedures for dogs and cats, with the aim of enhancing radiation protection measures. Measurements were taken for 13 different X-ray procedures on dogs and four on cats, which were selected on the basis of their frequency and potential exposure risk. Dogs were categorized by weight, influencing the radiographic settings. TLD-100H, calibrated with a reference dose of 0.00780 mSv, was used to measure radiation at various anatomical sites. The results revealed that the maximum dose exceeded 0.0040 mSv, with 0.00443 mSv recorded for the lens of the eye and 0.00483 mSv recorded for the thyroid gland. However, the median and mean doses at most measurement sites were less than 0.005 mSv per radiograph, with the eye lens showing a mean dose of 0.0060 mSv. More than 95% of the doses at the chest, hands, gonads, and lower legs were less than 0.002 mSv. The use of modern radiographic equipment and digital storage technology has resulted in high-quality images with relatively low radiation doses. The study concluded that radiation exposure for staff holding animals during X-ray procedures is relatively low, making manual restraint acceptable when proper safety measures are followed. Continuous monitoring of radiation exposure is essential for ensuring the safety of veterinary staff. The radiation level is influenced by the type of animal, its weight, and the specific procedure used, highlighting the need for optimized safety protocols. Advancements in technology have improved safety by reducing radiation doses. The findings support regulatory efforts to enhance safety standards and emphasize the importance of using updated equipment, providing staff training, and considering both manual restraint and sedation methods. Future research should explore the impact of different animal types, sizes, and sedation techniques on radiation exposure to refine safety guidelines. Limitations of the study include a limited number of procedures, a focus on specific body parts, calibration variations, and environmental factors such as background radiation. The study also did not explore the potential benefits of sedation compared with manual restraint.

Hersh-Boyle et al. (2019)

This study aimed to evaluate radiation exposure during fluoroscopic procedures in dogs and cats, with a focus on both the animals and the veterinary staff involved. A total of 360 procedures were conducted. Only cases with available dose reports from the C-arm units were included, and procedures with single images or without dose reports were excluded. Radiation data were collected from four different C-arm units, with each unit's technology affecting the total radiation emitted. The procedures were categorized into vascular (n=43), respiratory (n=66), cardiovascular (n=62), orthopedic (n=37), urinary (n=148), and gastrointestinal (n=4) types. Vascular procedures had the highest median radiation exposure (137 mSv) and fluoroscopy time (35.83; 5.63-85.13). The veterinary staff trained in interventional radiology had the highest median radiation exposure (16.10 mSv), followed by cardiologists and internists. The median fluoroscopy time was 35.80 minutes, with vascular procedures also associated with longer fluoroscopy times. Compared with the continuous mode, the pulsed fluoroscopy mode significantly reduced the fluoroscopy time (by 76%) and radiation dose (by 64%), suggesting a safer approach. The study concluded that fluoroscopic procedures expose both patients and veterinary staff to significant radiation, especially during vascular procedures. Future research should include real-time dosimetry to measure actual doses and improve safety protocols. These findings highlight the need for better veterinary staff training and the development of safety protocols to minimize risks. The limitations of this study include the use of C-arm unit data as a surrogate for the actual radiation dose, the variability among different C-arm units, and the lack of control over the experience of veterinary staff. These factors could affect the accuracy of the results and underscore the need for more precise measurement techniques and further research.

Chen et al. (2019)

This study aimed to evaluate radiation exposure in various areas of a veterinary clinic, including plain radiography and computed tomography (CT) rooms, as well as control rooms and corridors, via TLDs. A total of 122 TLDs were deployed: 42 in the plain radiography room, 68 in the CT room, and 12 in offices and an ultrasound room to measure background radiation. Each point of measurement had two TLDs to ensure accuracy. The TLDs were calibrated and read with a Harshaw 3,500 reader, and a solid detector was also used for X-ray dose assessment. The findings revealed considerable variability in radiation doses across different radiographic protocols, with some protocols showing doses up to 22 times higher than others. Annual dose estimates for both controlled and uncontrolled areas were well below the limits set by the National Council on Radiation Protection and Measurements (NCRP), indicating effective radiation safety measures. In the CT room, higher doses were observed at the gantry opening angle than at the sides. Most doses were less than 0.005 mSv per radiograph, with the highest being 0.0060 mSv for the eye lens. This study underscores the effectiveness of current safety protocols but suggests that continued monitoring and optimization of imaging protocols are necessary to further reduce radiation exposure. This highlights the importance of proper equipment positioning and the use of advanced technologies to minimize exposure. The study also highlights the need for improved training on radiation safety and awareness of exposure risks. Limitations include the study's restricted generalizability due to varying equipment and protocols, potential overestimation of annual dose estimates, lack of longitudinal data, and limited focus on nonworker exposure. Future research should address these limitations and explore the impact of different protocols and equipment on radiation exposure.

Villamizar-Martínez and Losey (2024)

This study aimed to evaluate the radiation exposure of veterinary staff during the acquisition of full-mouth intraoral radiographs in dogs and cats via a handheld X-ray unit. The study involved 30 animals (10 domestic short-haired cats, 10 small dogs <10 kg, and 10 medium–large dogs >20 kg). Radiation measurements were conducted via nine dosimeters placed on critical anatomical areas of the veterinary staff, including the thyroid, breasts, ovaries, testicles, hands, and eyes. The study revealed that the backscatter radiation levels recorded for most dosimeters were minimal, with deep dose equivalent (DDE), lens dose equivalent (LDE), and shallow dose equivalent (SDE) values mostly below the detection limit of the dosimeters (<0.01 mSv). Notably, only certain areas, such as the right breast, left ovary, and eye, presented radiation exposures exceeding 0.01 mSv. Veterinary staff handling larger dogs resulted in the highest recorded dose of 0.1 mSv in the eye region, whereas exposure from handling cats was significantly lower (<0.01 mSv). These findings suggest that handheld X-ray units are generally safe, as the radiation levels are well below the permissible annual occupational dose limits. Although handheld X-ray units for dental radiography are effective and safe, there is a need to improve protective measures to reduce backscatter radiation, particularly in sensitive areas such as the eyes, ovaries, and breasts. The optimal position of the X-ray unit, perpendicular to the patient, was highlighted as a critical factor in minimizing radiation exposure. Therefore, training veterinary staff in proper positioning techniques can further increase safety. The results underscore the importance of employing personal protective equipment, such as lead aprons and safety glasses, to mitigate unnecessary radiation exposure. The study's limitations include the small sample size of radiographic exposures, which may impact the reliability of the results. In addition, the study did not assess patient radiation doses, leaving a gap in the comprehensive understanding of radiation impact. The potential for increased exposure in typical veterinary settings, where more than 10 radiographs might be taken per patient, needs further investigation. Variability in techniques and positioning among different practices also limits the generalizability of the findings.

Discussion

This systematic review describes the current literature on systematically gathering and analyzing the available evidence on the amount of ionizing radiation exposure of human individuals involved in X-ray diagnostic procedures performed in dogs and cats (veterinary staff and pet owners). These values depend on factors such as body mass, use and maintenance of equipment, training and experience, infrastructure of the X-ray rooms, use of radiographic security implements, and regulation of equipment. Exploring such factors will provide starting points for future research aimed at understanding the risk of exposure in the field of veterinary medicine. This review identified five studies published between 2007 and 2024, considering that this topic has only recently been explored. In addition, we aimed to identify knowledge gaps and opportunities for future research.

The medical imaging modalities in veterinary medicine that involve ionizing radiation include computed tomography, nuclear medicine, conventional radiography, and fluoroscopy. There has been an increase in the use of computed tomography and ionizing radiation diagnostic aids in animals (Linet *et al.,* 2012). Small animal practices are the most common form of X-ray use (90%), followed by large animal practices (77%) and other practices (52%) (Wiggins *et al*., 1989). Therefore, studying radiation exposure during radiographic and other radiological procedures in veterinary medicine is crucial, especially given the increasing use of portable X-ray units. In addition, the need to hold the animal in a specific position for the radiograph increases the likelihood of exposure (Lee *et al.,* 2004; Sadight *et al.,* 2014; Gregorich *et al.,* 2018). This demands effective management of radiological safety in daily clinical practice, ensuring adherence to biosafety protocols, such as the use of personal protective equipment (lead aprons, lead gloves, and thyroid shields), to minimize exposure to scatter radiation, a secondary type of radiation, which occurs when the beam intercepts an object, causing the X-rays to disperse. For example, from a technical and procedural perspective, it is suggested that in periapical dental radiographs, owing to the position of the patient, the X-ray equipment is positioned according to the needs of the plate, which may result in certain parts of the veterinary staff´s body receiving more exposure than others (Villamizar-Martinez and Losey, 2024).

In addition to the limited number of veterinary studies, evidence from human medicine has consistently demonstrated how insufficient training and weak enforcement of radiation protection protocols translate into measurable occupational risks (Arias, 2006; González, 2018; Batista *et al*., 2019; Valenzuela-Medina & Hidalgo-Rivas, 2021). Despite the increasing use of radiographic and fluoroscopic techniques in parallel with veterinary practice, the systematic implementation of protective measures remains uncommon. This gap suggests that future efforts should focus not only on documenting exposure levels but also on developing and enforcing structured educational programs and regulatory policies specifically tailored to veterinary environments.

The ionizing radiation to which patients, veterinary staff, or other individuals are exposed to be expressed as an *effective dose*, reflecting the tissue's sensitivity to a radiation-induced genetic defect or cancer —also known as a stochastic effect. The equivalent dose is calculated based on the amount of radiation absorbed by a specific tissue or organ, whereas the biological effectiveness of that radiation is determined by its type and energy (Linet *et al.,* 2012). The annual effective dose of ionizing radiation attributable to medical exposure in humans has increased from 0.53 mSv in 1980 to 3.0 mSv in 2006. The increase in exposure, along with the increased cancer risk identified for human patients, is also possible and potentially greater in veterinary settings (Bolus, 2013).

Veterinarians and related personnel are constantly exposed to anesthetic gases, pesticides (particularly insecticides), zoonotic infectious agents, and carcinogens (including ionizing radiation) (Fritschi, 2000). The adverse effects of ionizing radiation in both humans and animals, although still limited to animals, include alopecia, erythema, immature dysplastic glomeruli, ocular sequelae (such as severe keratitis, conjunctivitis, keratoconjunctivitis sicca, cataracts, and uveitis), and an increased incidence of diabetes mellitus (Benjamin *et al.,* 1998; von Zallinger and Tempel, 1998).

The specific risks of X-ray exposure inherent to veterinary practice have not been quantified. However, studies in human medical specialties include findings among dentists and dental nurses, who present a 13-fold greater risk of thyroid cancer, melanoma, and colorectal cancer, and among general surgeons and orthopedic surgeons, who use fluoroscopy, which is associated with increased risks of skin cancer, thyroid cancer, or leukemia (Wingren *et al.,* 1997).

In both contexts, biosafety training is essential and is more commonly provided in academic institutions than in private practices for human medicine. Such training has proven to be insufficient in veterinary practice (EUR-Lex, 1996; Lee *et al.,* 2004; Sadigh *et al.,* 2014; Gregorich *et al.,* 2018).

Epidemiological studies in human medicine have reported an increased lifetime cancer risk associated with the increasing use of medical imaging, particularly due to increased ionizing radiation exposure. Individual factors, such as lifestyle (e.g., smoking, diet, and exercise) and family history (i.e., genetics), should also be considered. Awareness of these risks remains low in both medical and veterinary practice and has not been explored thus far (Sadigh *et al.,* 2014).

Although the recorded doses in relevant studies were low, with 97% of the measurements showing levels below 0.005 mSv, exposure peaks were noted in critical anatomical areas such as the eyes and hands of veterinary staff, particularly during procedures requiring close proximity to the radiation field. Procedures such as fluoroscopy and the infrastructure in which they are performed are influential factors in radiation exposure. Comparisons between different institutions highlighted variations in practices and technologies, which impact exposure levels (Hersh-Boyle *et al.,* 2019).

One of the most important observations herein was that scatter radiation doses were lower in cats than in dogs, possibly due to the lower tissue density in the heads of felines. This variability in exposure highlights the importance of adapting imaging protocols to the specific characteristics of each species, as well as the need for continuous training of veterinary staff on how to optimize equipment and positioning during procedures. On the other hand, the perpendicular positioning of the X-ray device was identified as the safest, whereas oblique orientations increased exposure, indicating that training in radiographic techniques could be a key factor in reducing radiation exposure. In addition, procedures such as fluoroscopy and the infrastructure in which they are performed are influential factors in radiation exposure. The comparison between different institutions highlighted how practices and technologies vary, affecting exposure levels. This is consistent with findings in human medicine, where veterinary staff training and experience are linked to radiation exposure levels. It is suggested that veterinary staff trained in interventional radiology tend to be exposed to higher doses due to the complexity of the procedures they perform (Hersh-Boyle *et al.,* 2019).

This systematic review identified important gaps in the literature that warrant further research. Issues such as determining adequate protection for patients (dogs and cats, in this case), veterinary staff, and owners present during radiographic procedures to minimize X-ray exposure effects on sensitive tissues such as the eyes (a topic extensively studied in human radiology); identifying the specific characteristics of facilities, equipment, and personnel in veterinary practice that ensure minimal ionizing radiation exposure; understanding factors that affect biosafety in veterinary medicine, particularly considering the necessity of positioning the patient manually; establishing standardized equipment for each procedure and protocols that adjust equipment parameters before patient use for the biosafety of both parties, according to the conditions of each veterinary setting; and defining radiographic limits for veterinary staff and patients. Specifically, the need for real-time radiation dose measurement and the development of veterinary-specific standards has become apparent, as there are currently no adequate regulations in this area. Expanding the scope of research is recommended, which is currently limited, to account for a broader variety of devices and techniques, aiming to establish safety protocols that protect both personnel and patients in any environment.

Our review has strengths. We adhered to a formal process based on a clearly defined research question, which was previously reported and endorsed by experts in health-related systematic reviews. To identify relevant studies, we conducted a comprehensive literature search across various databases and sources, including general-purpose databases, search engines, journals, and conference proceedings, with information spanning back to 1949. We imposed no geographic, language, or temporal restrictions, which helped reduce bias. Furthermore, the data extracted from the initial searches were rigorously defined. One author developed a matrix of findings that was subsequently reviewed by a second author to ensure consistency, considering the differences in quality and methodologies among the relevant studies. For limitations, we did not fully explore gray literature. To address this, we used snowballing approaches.

Conclusion

Current evidence on radiation exposure in veterinary practice remains limited, constrained by small sample sizes and the focus on specific devices. Despite these limitations, our review addressed the proposed research question and found that radiation doses were generally low, with nearly 90% of measurements below 0.005 mSv. Nonetheless, exposure peaks were consistently observed in sensitive anatomical regions, particularly the eyes and hands of veterinary staff during procedures requiring proximity to the field of radiation. These findings underscore the need for further research to quantify radiation exposure not only among veterinary professionals but also among animal patients and pet owners. Establishing standardized best practices in veterinary radiology at a global level is imperative. X-ray exposure should not be considered trivial; it represents a public health concern that requires robust evidence to guide effective policies, protective measures, and training strategies.

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Conflicts of interest

The authors declare no conflicts of interest regarding the work presented in this report.

Author contributions

Adrián C. Arcila Giraldo: Conceptualization, Investigation, Data curation, Writing – original draft, Writing - review & editing. Nathalia M Correa Valencia: Methodology, Investigation, Data curation, Writing – original draft, Writing - review & editing.

Use of artificial intelligence (AI)

During the preparation of this work, the authors used OpenAI ChatGPT (October 2023 version, https://chat.openai.com/) in order to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Data availability

The data sets used in the current study are available from the corresponding author on request.

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