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Restrainer exposure to scatter radiation in practical small animal radiography measured using thermoluminescent dosimeters

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ABSTRACT: This study was aimed at estimating restrainer exposure to scatter radiation in veterinary radiography using thermoluminescent dosimeters (TLDs) in different positions, and at different anatomic regions. A prospective study was conducted to measure exposure dose of two restrainers: A (cathode side) and B (anode side), and an observer C (at a 1-meter distance from the X-ray table) over two months. Protective devices included panorama mask, thyroid shield and arm shield. TLDs were placed on the inside and outside of the protective gear at five different anatomic sites (eye, thyroid, breast, gonad and arm). The study data consisted of 778 exposures, 82 patients (78 dogs, four cats), a mean kVp of 58.7 and a mean mAs of 11.4. The doses (outside the shield/inside the shield, in mSv) measured by restrainers A, B and C were eye (3.04/0.42), (2.29/0.17), (0.55/0.01), thyroid (2.93/0.01), (1.97/0.01), (0.19/0.01), breast (1.01/0.04), (0.73/0.01), (0.32/0.01), gonad (0.07/0.01), (0.01/0.01), (0.16/0.01) and arm (2.81/1.43), (1.17/0.01), (0.08/0.01), respectively. This study describes the extent of occupational radiation exposure in small animal radiography. The exposure dose for eyes outside lead protection showed the highest value in all participants. With lead protection, the reduction in the exposure dose of eyes was significant (A: 86%, B: 93%, C: 98%), and the highest reduction was 99% in the thyroid region. These results suggest the necessity of radiation shields in manual restraint, particularly for eye protection.

Keywords: veterinary radiography; thermoluminescent dosimeter; radiation exposure; eye protection

In the past decades, digital radiographic imaging systems have replaced screen-film imaging systems because of the convenience of image acquisition and post-processing steps, leading to increased recognition of overexposure (Shepard et al. 2009). Strictly, a radiographic study should be performed under sedation or anaesthesia to avoid unnecessary exposure of restrainers. However, manual restraint has been used widely in veterinary practice. Due to the resulting ambiguous understanding of radiation exposure, operators tend to be unaware of the risks of excessive radiation exposure. In small animal radiography, personnel are exposed to radiation from the primary beam and to scatter radiation. Scatter radiation is the principle source of radiation and the primary reason for wearing lead protective devices (Williams 1997). Previous studies investigating scatter radiation dose levels received by a restrainer in small animal radiography revealed the risk of cumulative doses of scatter radiation exposure and the effectiveness of lead protective devices (Barber and McNulty 2012; Canato et al. 2014). Several studies have identified radiation-associated risks in X-ray examinations (Wagner

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et al. 1994; Lindell 1996; Nikolic et al. 2000; Vano et al. 2008; Dendy and Heaton 2011). Radiation exposure studies performed with medical staff and even pet owners have also been reported (Seifert et al. 2007; Hausler et al. 2009; Martin 2009; Olgar et al. 2009). There are two types of adverse effects associated with X-ray radiation. Deterministic effects have a threshold that is dependent on exposure dose; radiation-induced cataracts are an example of deterministic effects (Merriam and Worgul 1983). In contrast, stochastic effects are independent of radiation dose and have no threshold. Various types of cancer can be examples of stochastic effects. In small animal X-ray examination, drugs such as anaesthetics are typically used for restraint; however, manual restraint of animals is often necessary under certain circumstances, such as hip dysplasia (Barber and McNulty 2012). Legislation on animal restraint varies throughout the world, and there is still controversy regarding specific aspects of manual restraint (Barber and McNulty 2012). Several previous studies were performed to identify the intensity of radiation exposure during manual restraint in animal X-ray examination, but they were conducted in circumstances that were far from the practical situation (Barber and McNulty 2012; Canato et al. 2014). The primary purpose of this study was to measure the practical intensity and distribution of occupational exposure to scatter radiation received by a manual restrainer during small-animal radiography and to identify the risk of scatter radiation exposure.

MATERIAL AND METHODS

This prospective study was approved by the Institutional Animal Care and Use Committees (IACUC) of Chonbuk National University and was conducted in Chonbuk Animal Medical Center over the course of two months (from May 2016 to July 2016). A veterinary digital X-ray machine (HF-525 PLUS, Ecoray, Seoul, Republic of Korea) with digital detector (Rayence, Gyeonggi-do, Republic of Korea) was used, and all patients that underwent X-ray examination with this machine were included. The levels of kVp and mAs were adjusted according to the size of the patient. All the participants were aware of the risks of X-ray exposure and they gave their consent for participation in this study. The lead equivalent (PbEquiv) protective devices used

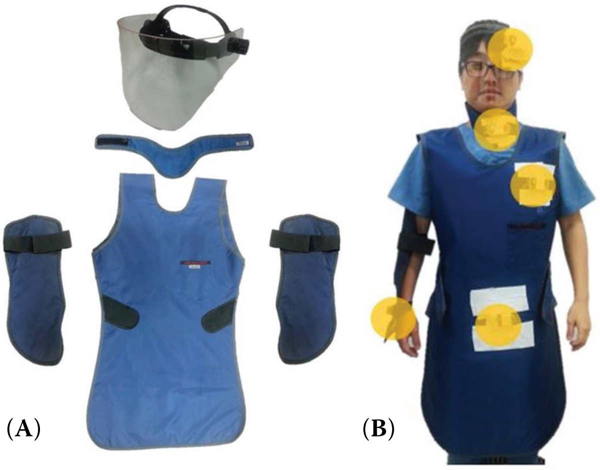

Figure 1. Picture (**A**) shows the lead protective devices, which were a lead mask, thyroid shield, apron and hand shield. Picture (**B**) shows the locations where the TLDs were fixed on the body

were a mask (PbEquiv of 0.1 mm), thyroid shield (PbEquiv of 0.35 mm), apron (PbEquiv of 0.35 mm) and hand shield (PbEquiv of 0.35 mm) (Figure 1). Thermoluminescent dosimeters (TLD, UD-802AS, Panasonic Co., Japan), commonly used devices for personnel monitoring, were used to measure cumulative exposure dose (Figure 2). To identify the distribution of scatter radiation exposure, TLDs were fixed on five locations of the lead protective devices representing five different body parts: mask for eye, thyroid shield for thyroid, apron for breast and gonad and hand shield for hand. TLDs were also attached inside and outside of the protective gear to identify the exposure reduction achieved by the lead protection (Figures 1 and 2). Two manual restrainers and an observer participated in the radiographic examination, and their positions were controlled (Figure 3). Though the ALARA principle suggests that only persons necessary should be in the X-ray room, two to three restrainers are re-

Figure 2. (**A**) shows a TLD used in this study for measuring the cumulative equivalent dose, and (**B**) shows how TLDs were attached inside and outside of the lead apron

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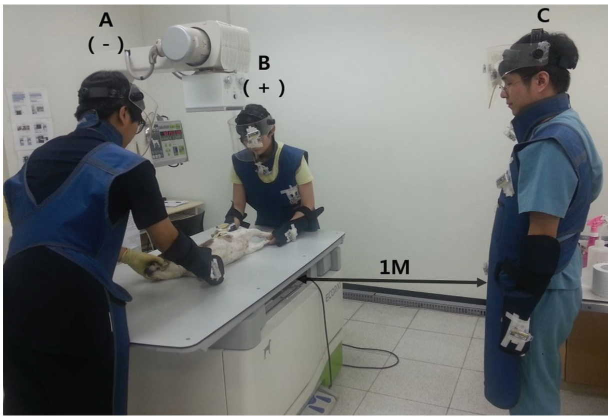

Figure 3. The restrainers (A and B) were positioned at the cathode and anode aspects, respectively, when restraining the patient, and the observer was positioned at a distance of 1 m from the X-ray table

quired to hold the animal patients efficiently in our domestic situation. Therefore, besides the measurement over essential restrainers holding animals the front and the rear, radiation exposure of the third person should be measured.

Restrainer A was positioned at the cathode aspect and restrainer B was positioned at the anode aspect. The observer was positioned 1 m from the X-ray table for comparison with the restrainers. After performing this procedure for two months, the TLDs were collected and submitted to a company (Orbitech Co., Republic of Korea) specialising in TLD analysis of cumulative equivalent dose with an automatic TLD reader machine (UD-716AGL, Panasonic Co., Japan).

RESULTS

A total of 778 radiographs were collected from 82 patients (78 dogs, four cats) over two months. Some cases that deviated from the controlled circumstances for the study were excluded, such as when more than two restrainers were needed or when the restrainers could not maintain their designated positions. The mean body weight of the patients was 5.61 kg, and the mean kVp and mAs were 58.7 and 11.4, respectively. The equivalent doses to the eye represented the highest exposure in all participants, followed by the thyroid in the restrainers. Restrainer A recorded generally higher exposure in all body parts than the doses measured by the B and C restrainers (Table 1). The effective doses of the breast were highest among the different body parts in all participants, and restrainer A recorded higher effective doses than restrainer B and the observer for all body parts.

DISCUSSION

The eye recorded the highest exposure for all participants. This result is similar to the findings of a previous study conducted with portable X-ray devices (Canato et al. 2014). This can be explained by the interactions between the patient, the table top and the X-ray beam. The distribution of the scatter radiation might also be related to the positioning of the restrainers. Interestingly, restrainer A recorded a generally higher equivalent dose than the other restrainers for all body parts. This might be explained by the anode heel effect which occurs due to the geometry of the anode. Consequently, X-rays emitted towards the cathode are in general more intense than those emitted perpendicular to the cathode-anode axis. Another possibility regarding the two-month radiography history, is that more radiographs were focused on the cranial and rostral parts of the patients than on caudal parts (Table 2);

Table 1. Equivalent doses to the eye, thyroid, breast, gonad and hand inside and outside the lead protection (mSv) for two restrainers and an observer

Body parts	Restrainer A (–)		Restrainer B (+)		Observer C	
	outside lead protection	inside lead protection	outside lead protection	inside lead protection	outside lead protection	inside lead protection
Eye	3.04	0.42	2.29	0.17	0.55	0.01*
Thyroid	2.93	0.01*	1.97	0.01*	0.19	0.01*
Breast	1.01	0.04	0.73	0.01*	0.32	0.01*
Gonad	0.07	0.01*	0.01*	0.01*	0.16	0.01*
Hand	2.81	1.43	1.17	0.01*	0.08	0.01*

*The minimal value of the cumulative equivalent dose with TLD

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Table 2. Two-month X-ray examination history, the number of exposures and the sum of exposure doses according to the region of interest

	Region of interest	Number of exposures	Mean kVp	Mean mAs
Cranial parts	skull	64	67.8	11.8
	cervical spine	25	32.3	10.3
	thorax	342	25.3	4.6
	forelimb	83	71.0	12.3
	subtotal	514	38.3	7.0
Caudal parts	abdomen	121	71.4	13.1
	thoraco-/ lumbar spine	33	66.8	13.9
	pelvis	10	70.2	12.6
	hindlimb	100	64.8	12.6
	subtotal	264	68.3	13.0
Total		778	58.7	11.4

during exposure, restrainer A moves close to the X-ray beam centre to restrain the cranial part of the patients (Figure 4). This explanation is considered to be more convincing than the heel effect. The two-month exposure dose to the eye was 3.04 mSv; taking this value into account, the effective dose to the eye received for one year would be 18.19 mSv approximately. This value does not reach the recommended limit of 20 mSv of 2017 ICRP, (Stewart et al. 2012) but it is comparable. Considering fluctuation in the patient population and exposure times, it is impossible to ensure safety

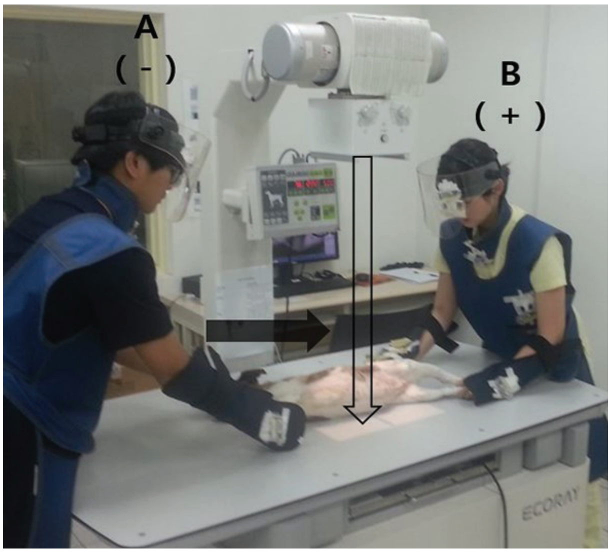

Figure 4. When restraining a patient, restrainer A naturally moves (filled arrow) to the X-ray beam centre (empty arrow) to hold the cranial region of the patient

from scatter radiation exposure. With lead protection, the exposure dose of the eye was significantly decreased by 92%; therefore, eye protection is effective and absolutely necessary in manual restraint. The scatter radiation exposure was significantly reduced by 91% on average by the presence of lead protective gear (Table 3). This result supports the effectiveness and importance of protection in manual restraint. The reduction rate for the hand was 49.11%, which was dramatically lower compared to other body parts. This result is considered to reflect direct exposure to the primary X-ray beam and to radiation emanating from close to the main beam. In principal, no body part should be exposed to the primary X-ray beam, but some part of the hand could be in the primary beam or very close to the main beam during the manual restraint of small-sized patients. Many institutions have their own regulations with respect to monitoring the radiation exposure of their personnel. Since the advantages of TLDs over other personnel monitors include their linearity of response to dose, their relative energy independence and their sensitivity to low doses, TLDs widely used in clinics were employed in this study. The measuring instrument was calibrated to limit the variation value up to 3% by the National Calibration Agency and the three-month cumulative background radiation value of TLD was estimated to be approximately 0.3 mSv. Additionally, newer protective devices for personnel have been generally introduced into clinics. Previously 0.5-mm lead aprons were widely used, but more light and efficient protective devices are now employed. Therefore, these relatively newer protective devices were tested in this study.

In human studies, it is recommended that a finger dosimeter should be worn on the little finger of the hand nearest to the X-ray tube in order to

Table 3. Reduction (%) of the exposure dose when using lead protection

Body parts	Restrainer A	Restrainer B	Observer C
Eye	86.18	92.58	98.18
Thyroid	99.66	99.49	94.78
Breast	96.04	98.63	96.88
Gonad	85.71	–*	93.75
Hand	49.11	99.15	87.5

*The value was not estimated because the exposure dose for restrainer B for the gonad recorded the minimal value both inside and outside the lead protection

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monitor the hand in interventional or conventional radiology (Hausler et al. 2009; Martin 2009). Generally, it is recommended that a monitoring device be worn at the thyroid or upper chest level on the inside of the apron. Sometimes, however, a personnel monitoring device is placed outside the lead apron and not under it. The wearing of the TLD badge outside the lead apron is mainly done to measure or estimate the radiation dose for the organs not covered by the simple apron, such as the eyes and thyroid, etc. On the other hand, it is believed that most aprons are able to shield from X-ray beams and, moreover, that there should be no measurable exposure underneath it. As no previous reports have measured the radiation dose inside of the shields and because the radiation dose outside and inside of the personnel monitoring devices has not been measured in practice, this study first presented how the inside organs are exposed during radiography. Nevertheless, the degree of radiation exposure inside of the organs once covered by protective shield is very low or negligible in terms of occupational dose equivalent limits. A limitation of this study were the fluctuating conditions, because the body positions of the restrainers and exposure dose varied according to the patient and the region of interest for X-ray examination. However, the procedure of X-ray examination in this study was identical to the practical situation of manual restraint in contrast to previous studies; therefore, the results are significant and applicable to clinical small-animal radiography. In conclusion, scatter radiation results in significantly high exposure, especially to the eye, during manual restraint without lead protective devices. Therefore, special consideration must be given to the radiation protection of eyes, and, although it is well known that radiation protection must be secured, we need to stay alert to the fact that protective equipment and apparel can dramatically reduce radiation exposure when restraining patients in small animal radiography. In addition, manual restraint should be avoided as much as possible and should only be employed when sedation or anaesthesia are not feasible.

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