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 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-
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

<table>
<thead>
<tr>
<th>Body parts</th>
<th>Restrainer A (–)</th>
<th>Restrainer B (+)</th>
<th>Observer C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>outside lead protection</td>
<td>inside lead protection</td>
<td>outside lead protection</td>
</tr>
<tr>
<td>Eye</td>
<td>3.04</td>
<td>0.42</td>
<td>2.29</td>
</tr>
<tr>
<td>Thyroid</td>
<td>2.93</td>
<td>0.01*</td>
<td>1.97</td>
</tr>
<tr>
<td>Breast</td>
<td>1.01</td>
<td>0.04</td>
<td>0.73</td>
</tr>
<tr>
<td>Gonad</td>
<td>0.07</td>
<td>0.01*</td>
<td>0.01*</td>
</tr>
<tr>
<td>Hand</td>
<td>2.81</td>
<td>1.43</td>
<td>1.17</td>
</tr>
</tbody>
</table>

*The minimal value of the cumulative equivalent dose with TLD
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 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

<table>
<thead>
<tr>
<th>Body parts</th>
<th>Restrainer A</th>
<th>Restrainer B</th>
<th>Observer C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye</td>
<td>86.18</td>
<td>92.58</td>
<td>98.18</td>
</tr>
<tr>
<td>Thyroid</td>
<td>99.66</td>
<td>99.49</td>
<td>94.78</td>
</tr>
<tr>
<td>Breast</td>
<td>96.04</td>
<td>98.63</td>
<td>96.88</td>
</tr>
<tr>
<td>Gonad</td>
<td>85.71</td>
<td>–*</td>
<td>93.75</td>
</tr>
<tr>
<td>Hand</td>
<td>49.11</td>
<td>99.15</td>
<td>87.5</td>
</tr>
</tbody>
</table>

*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

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
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REFERENCES


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