https://doi.org/10.17221/15/2018-VETMED

# Radiation exposure during C-arm-guided (fluoroscopy) small animal orthopaedic surgery

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**ABSTRACT**: The purpose of the current study was to investigate the radiation exposure level of surgeons performing C-arm guided small animal orthopaedic surgery using thermoluminescent dosimeters located inside and outside personnel shielding devices at major body parts. A prospective study was conducted to measure the radiation exposure dose of individuals in three positions (first assistant, operating surgeon and anaesthesiologist) using thermoluminescent dosimeters placed inside and outside protective devices. The lead equivalent protective devices included panorama mask, thyroid shield, apron and arm shield placed at five anatomic sites (eye, thyroid, breast, gonad and hand). Radiation exposure was measured during 12 surgical procedures with mean kVp of 51 and mean mAs of 1.6. The equivalent doses for thyroid, breast and gonad (outside/inside in mSv) were 1.75/0.58, 2.01/0.13 and 3.03/0.11, respectively, for the first assistant and 1.69/1.46, 4.82/0.35 and 5.25/0.22 for the operating surgeon. The dose of eye, thyroid, breast, gonad and arm for the anaesthesiologist were 0.61/0.51, 0.35/0.3, 0.67/0.34, 0.72/0.29 and 0.62/0.35, respectively. The exposure dose to gonads outside the lead protection showed the highest values in all participants. With lead protection, there was a significant reduction in the exposure dose to the gonads (first assistant, 96%; operating surgeon, 96%; anaesthesiologist, 60%). These results suggest that a radiation shield is essential in veterinary surgery with C-arms, particularly for gonad protection. In addition, these results demonstrate that exposure dose decreases with increasing distance from the C-arm machine.

**Keywords**: veterinary orthopaedic surgery; fluoroscopic guidance; scatter radiation; protective device; surgical team; surgeon

Over the past several decades, the use of C-arms (fluoroscopy) has become universal in human orthopaedic surgery (Tuohy et al. 2011). The use of fluoroscopy facilitates direct visualization of the surgical site, allowing the orthopaedic surgeon to monitor the progress and make immediate corrections during the operation. Therefore, it increases the accuracy of procedures and allows minimally invasive techniques to be conducted with a reduced operation time. Because of these advantages, orthopaedic surgeries with fluoroscopic guidance have become routine in recent years in small animal medicine (Wheeler et al. 2007; Tonks et al. 2008; Jones et al. 2015; Boekhout-Ta et al. 2017; Rohwedder et al. 2017).

However, a major disadvantage of such approaches is the unavoidable radiation exposure of the surgical team from fluoroscopic projections in the operating room. Many studies have reported on the radiation exposure of medical personnel during procedures with C-arm fluoroscopy in human medicine (Mehlman and DiPasquale 1997; Tremains et al. 2001; Athwal et al. 2005; Abas et al. 2014).

In veterinary medicine, one study evaluated the exposure dose of scatter radiation by site and position of the patient and body part of the restrainer

Supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Republic of Korea (Project No. 2015R1D1A1A01056738).

https://doi.org/10.17221/15/2018-VETMED

(Barber and McNulty 2012). Another study that used a portable X-ray machine reported that the radiation exposure dose of the assistant was greater than that of the veterinarian. This measured dose was close to the annual recommended dose limit of the International Commission on Radiological Protection (ICRP) (Canato et al. 2014). However, to the authors' knowledge, there has been no report comparing the exposure dose according to position or body part of team members when using fluoroscopy or C-arm machines in veterinary medicine.

The purpose of the current study was to investigate the radiation exposure level of surgeons performing C-arm-guided small animal orthopaedic surgery using thermoluminescent dosimeters (TLDs) located on personnel shielding devices for major body parts.

## MATERIAL AND METHODS

This prospective study was conducted in the Chonbuk Animal Medical Center, College of Veterinary Medicine, Chonbuk National University. The radiation exposure dose of three personnel was measured at designated positions (Figure 1) – first assistant (120 cm from the X-ray tube of the C-arm), operating surgeon (80 cm) and anaesthesiologist (150 cm) – using TLDs. The study was carried out in an orthopaedic surgical theatre equipped with a digital C-arm machine (ZEN 2090 Pro, Genoray, Republic of Korea). The lead-equivalent protective devices used included a panorama mask (0.10 mm),

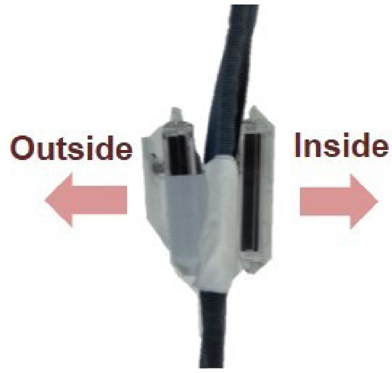


Figure 2. TLDs were placed on the inside and outside of the protective gear

thyroid shield (0.35 mm), lead apron (0.35 mm) and hand protector (0.35 mm). TLDs were placed on the inside and outside of the protective gear at five different anatomic sites (eye, thyroid, breast, gonad and arm) (Figures 2 and 3). TLDs (UD-802AS, Panasonic Co., Japan) are one of the most common personnel monitoring devices used to measure cumulative exposure dose (Figure 4). All of the TLDs were calibrated by element correction factor calculation to normalize the element's response with a known dose from a specific radiation source (Cs-137 2ci). When orthopaedic surgery required use of a C-arm, the surgical team (first assistant, operating surgeon, anaesthesiologist) wore protective gear with attached TLDs while performing the operation.

The first assistant and operating surgeon did not wear the panorama mask and hand protector for convenience during surgery. The other personnel measured the operation time of the C-arm and recorded the time, kVp and mAs.

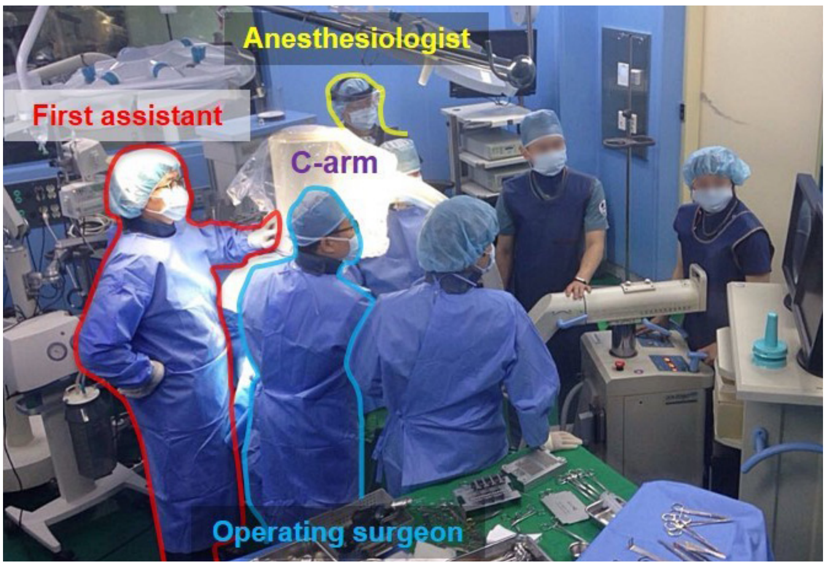


Figure 1. Three personnel at designated positions in the operating room: first assistant (120 cm from the X-ray tube of the C-arm), operating surgeon (80 cm) and anaesthesiologist (150 cm)

https://doi.org/10.17221/15/2018-VETMED

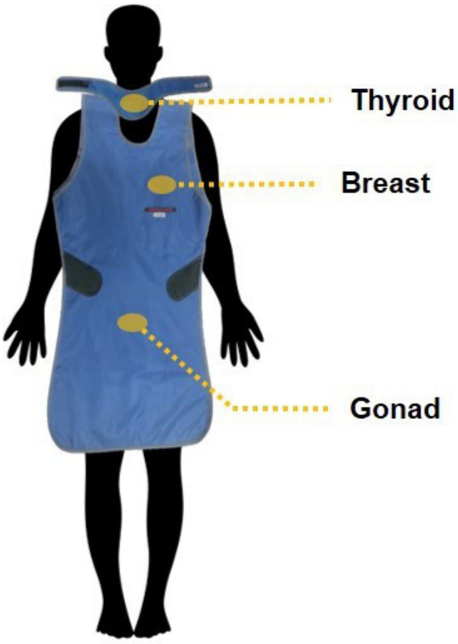


Figure 3. TLDs were placed at different anatomic sites on the thyroid shield and lead apron

The protective devices were isolated from the operating room after surgery or when no operation was being performed.

Three months after the start of the study the TLDs were sent to a specialized company (Orbitech Co., Republic of Korea) and the equivalent doses were measured by an automatic TLD reader machine (UD-716AGL, Panasonic Co., Japan).

## RESULTS

In total, 12 surgical procedures (10 dogs, one cat and one neonatal calf) were included in this study with a total exposure time of 11 732 seconds. Some cases that did not adhere to the controlled conditions for this study were excluded because the surgeons could not maintain their designated positions. The mean kVp was 51, mean mAs was 1.6 and mean exposure time was 978 seconds. Values of equivalent doses and reduction ratios in respective participants are presented below (Tables 1–3).


Figure 4. This thermoluminescent dosimeter (TLD) which measures ionizing radiation exposure by determining the intensity of visible light emitted by a crystal inside the detector was used in this study

Table 1. Radiation exposure doses of first assistant

| Body part | Outside | Inside | Reduction |
|---|---|---|---|
| Thyroid | 1.75 | 0.58 | 67 |
| Breast | 2.01 | 0.13 | 94 |
| Gonad | 3.03 | 0.11 | 96 |

Outside = equivalent dose outside lead protection (mSv), Inside = equivalent dose inside lead protection (mSv), Reduction = reduction ratio conferred by radiation protection equipment (%)

Exposure doses measured at each position were greatest in the operating surgeon, followed by the first assistant and anaesthesiologist. The gonads received the highest exposure dose in all participants. In all participants, exposure dose was highest in the gonads, followed by breast and thyroid. The reduction ratio in exposure dose conferred by the radiation protection equipment ranged from 14 to 96%.

## DISCUSSION

In the present study, the operating surgeon recorded the highest equivalent doses compared with other participants for all body parts. The anaesthesiologist, who was the participant farthest from the C-arm, recorded the lowest exposure dose. These results are similar to a previous study in human medicine. Mehlman and DiPasquale (Mehlman and DiPasquale 1997) evaluated exposure of the surgeon, first assistant, scrub nurse and anaesthesiologist during pelvic surgery. Superficial (skin

Table 2. Radiation exposure doses of operating surgeon

| Body part | Outside | Inside | Reduction |
|---|---|---|---|
| Thyroid | 1.69 | 1.46 | 14 |
| Breast | 4.82 | 0.35 | 93 |
| Gonad | 5.25 | 0.22 | 96 |

Outside = equivalent dose outside lead protection (mSv), Inside = equivalent dose inside lead protection (mSv), Reduction = reduction ratio conferred by radiation protection equipment (%)

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Table 3. Radiation exposure doses of anaesthesiologist

| Body part | Outside | Inside | Reduction |
|---|---|---|---|
| Thyroid | 0.35 | 0.3 | 14 |
| Breast | 0.67 | 0.34 | 49 |
| Gonad | 0.72 | 0.29 | 60 |
| Eye | 0.61 | 0.51 | 16 |
| Hand | 0.62 | 0.35 | 44 |

Outside = equivalent dose outside lead protection (mSv), Inside = equivalent dose inside lead protection (mSv), Reduction = reduction ratio conferred by radiation protection equipment (%)

and hand) exposure was 0.29 mSv/min for the surgeon, 0.1 mSv/min for the first assistant and 0.02 mSv/min for the scrub nurse. Deep (whole body) exposure for the surgeon and first assistant were 0.2 mSv/min and 0.06 mSv/min, respectively. No deep exposure was detected at the scrub nurse position, and superficial and deep exposure was not recorded for the anaesthesiologist. These results demonstrate that increasing the distance from the beam (C-arm) reduces the exposure dose.

In our study, the highest exposure equivalent dose was recorded in the gonads in all participants. Breast showed the second highest equivalent dose, and thyroid was the lowest. Similar to the correlation between radiation dose and position relative to the fluoroscopy machine, we hypothesize that lower parts of the body such as the gonads might be more exposed since scatter radiation from interactions between the radiation generator located under the operating table and patients could be directed primarily towards lower body parts. An additional potential source of radiation is leakage from radiation passing through the X-ray tube housing. Proper monitoring and maintenance of the machine should minimize leakage (Singer 2005). However, different results were obtained under similar conditions in human medicine. Three studies showed that the radiation exposure dose of the gonads was lower than that of the chest or neck (Athwal et al. 2005; Park et al. 2012; Mahajan et al. 2015). The exact reason for this discrepancy is unknown, but might reflect various differences between small animal surgery and human surgery such as the size of the patient or body parts, position of patient and surgeons and height of the operating table.

One possible reason for reduction ratio of the thyroid gland region being lowest in all participants is as follows: the thyroid gland is located higher than the breast and gonads, so the exposure dose itself is low. When the surgeons bend over the patient on the surgical table or turn their head and neck while looking around the room, the movement involved results in a loosening of the thyroid shields. Consequently, the possibility that radiation reached the inside of the thyroid shield during the operations evaluated in this study might have been high.

A total of 12 operations were evaluated in this study with an average of 978 seconds per operation, but the duration of C-arm usage varied widely among operations. Moreover, the operation time, the number of operations and the position of each surgeon on the C-arm machine can differ greatly depending on the animal hospital. The results of this study were measured in one quarter, i.e., over three months. However, in order to account for a hospital setting where orthopaedic surgeries are frequently performed the number of operations was increased ten-fold and the resulting number was multiplied by four to calculate the annual dose limit (Table 4). The annual equivalent dose in skin, hands and feet recommended by the ICRP is less than 500 mSv per year (ICRP 2007), while the annual equivalent dose in the lens of the eyes is less than 20 mSv per year (ICRP 2013). Based on our data, the exposure doses of the eye in the first assistant and operating surgeon are likely to be higher than in the anaesthesiologist, and exceed the annual limit in all participants. Therefore, radiation protection for the eye must be taken into consideration by veterinary surgeons. The remaining data for the three personnel in this study were within the annual recommended doses, but in veterinary hospitals where many orthopaedic surgeries are performed, care must be taken to minimise radiation exposure

Table 4. Annual doses, calculated by multiplying equivalent doses of each body part by 40

| Body part | First assistant | | Operating surgeon | | Anaesthesiologist | |
|---|---|---|---|---|---|---|
| | outside | inside | outside | inside | outside | inside |
| Thyroid | 70 | 23.2 | 67.6 | 58.4 | 14 | 12 |
| Breast | 80.4 | 5.2 | 192.8 | 14 | 26.8 | 13.6 |
| Gonad | 121.2 | 4.4 | 210 | 8.8 | 28.8 | 11.6 |
| Eye | – | – | – | – | 24.4 | 20.4 |
| Hand | – | – | – | – | 24.8 | 14 |

outside = outside lead protection (mSv), inside = inside lead protection (mSv)

https://doi.org/10.17221/15/2018-VETMED

from the C-arm, and radiation protection of the surgeons is essential.

The limitations of this study are as follows. First, the sample size (number of operations) is small. The study was conducted using data for 12 surgeries, but the results in practice may vary greatly depending on the operations performed in each hospital. In addition, the surgeons may not be able to stay at a constant distance from the C-arm depending on the surgical situation. Finally, it is necessary to compare the conditions of the operating room to determine why the results from this study are different from those in human medicine.

In conclusion, radiation exposure doses correlated with degree of proximity to the C-arm and were highest in the operating surgeon followed by first assistant and anaesthesiologist. The most exposed organs were the gonads, followed by breast and thyroid. The exposure dose of the eye exceeded the annual limit, so radiation protection for the eye is essential. Most of the radiation doses were lower than the annual doses specified by the ICRP, but it is still advisable to wear protective equipment for radiation protection during surgery with a C-arm.

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Received: February 1, 2018
Accepted after corrections: August 21, 2018