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Original Article

Evaluation of the Entrance Skin Dose in Animals Undergoing Diagnostic Radiology Using LiF, Mg, Ti Thermoluminescence Dosimetry (TLD-100)

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Abstract

Introduction
According to the International Commission on Radiological Protection publication numbers 60 and 21, the environmental control standards should ensure human and other species protection to a desirable degree. Since application of radiographic procedures in Veterinary Medicine has increased significantly, in this study, we aimed to evaluate the entrance skin dose to the animals (e.g., dogs, cats, horses, and birds) undergoing diagnostic radiology.

Materials and Methods
The entrance skin dose to the animals in different radiology procedures were estimated through a) indirect estimation using the output of X-ray tubes and b) direct measurement using LiF:Mg, Ti (TLD-100) thermoluminescence dosimeter. Regression analysis was performed for comparison of the two methods. The animals included in this study were cats, dogs, small birds, horses, parrots, and chough.

Results
The dose received by the animals varied from 20 μGy to 1189.2 μGy, depending on the animal thickness, focal spot to surface distance, imaging technique, and animal type.

Conclusion
Optimized procedures are suggested for obtaining high-quality images, with a reasonably low dose imposed to the animals.

Keywords: Radiology, Veterinary Medicine, Thermoluminescence Dosimeter, Dosimetry

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1. Introduction

According to the recommendations of the International Commission on Radiological Protection (ICRP) [1], the environmental control standards should provide human protection to a desirable degree, and ensure that other species are not endangered [1]. The current knowledge and investigations on the biological effects of ionizing radiation are based on human radiation protection. Therefore, establishing a comprehensive radiation protection system is mandatory for animals and plants [2].

The entrance skin dose (ESD) to patients in different radiography procedures, such as pediatric and adult diagnostic procedures and interventional radiology, has been widely estimated using different dosimeters or Monte Carlo simulations, and the diagnostic reference levels have been established in most countries [3-6]. However, few investigations were conducted on the ESD to animal species [7]; therefore, it seems necessary to perform further investigations for establishing the diagnostic reference levels in animals similar to those in humans.

ESD can be quantified using two distinct methods; the first method is direct ESD measurement using small-size radiation dosimeters, and the second one is dose estimation from the output curve of the X-ray tube. To the best of our knowledge, this is the first attempt focusing on indirect animal dose estimation. This study aims to evaluate the ESDs received by various animals in different X-ray examinations through indirect measurement using tube output and direct measurement using thermoluminescence dosimeter (TLD).

2. Materials and Methods

2.1.X-ray units

Two X-ray units were employed in the Radiology Department of School of Veterinary Medicine, Shiraz University, Shiraz, Iran, for performing radiographic examinations on the animals. The first one was a portable unit (Philips Practix 100/20Philips Medical System, Holland) and the other was a fixed unit (Philips Super M100, Philips Medical System, West Germany). The portable units are usually used for imaging of birds and small animals, while the fixed ones are regularly utilized for larger animals, e.g., big dogs, horses, and cattle.

2.2. ESD estimation

Two techniques were applied in this study for ESD estimation including: a) indirect method using the output of X-ray units and b) direct method using TLDs.

2.3. Indirect measurement of ESD

ESDs of each radiograph were estimated according to the following formula [4].

$$\text{ESDs} = \text{O}\left({}^{\mu\text{Gy}}/_{\text{mAs}}\right) \times \text{mAs} \times \text{BSF} \times \text{ISL} \qquad (1)$$

where O (μGy/mAs) is the X-ray unit output measured at 100 cm distance using a solid state detector for different voltages (kVp), mAs is the product of current (in mA) and exposure time (in sec) used in each procedure, the backscatter factor (BSF) takes into account the scattered radiation from the animals, and inverse square law (ISL) is for correction of the output from the measurement distance to the focal spot to surface distance (FSD).

To attain the X-ray units output, the dose at the distance of 100 cm from the source was measured using radiology probe of Solidose 400 with R100 dose detector (Elimpex-Medizintechnik, Austria), the response of which is calibrated for different kVps. Then, the output curves of each X-ray unit, O(μGy/mAs) vs. kVp, were obtained, and a second-order polynomial was fitted to each output curve for a good estimation of the ESD.

2.4. Direct measurement of ESD

Thermoluminescence dosimetry method has been widely applied for determining patient dose in diagnostic radiology [3, 4, 8-11], radiation therapy [12, 13], and other fields of dosimetry [14]. ESD was assessed for animals undergoing different types of radio-diagnostic imaging using thermoluminescence dosimetry. This investigation was conducted in Veterinary Department of Shiraz University of Medical Sciences, Shiraz, Iran.

A TLD batch containing 50 TLD chips with predetermined element calibration coefficient (ECC) values was selected for this study. All

TLD chips were annealed using a standard procedure before use, i.e., 1 hour at 400°C and 20 hours at 80°C. Three TLD chips packed in a dark plastic cover were assigned for ESD measurement of each animal, and five TLD chips were used for background measurement.

The technician responsible for the imaging was asked to put the TLD pocket of each animal at the center of the radiation field. After imaging, the TLD chips were read out by a TLD reader (model Harshaw 4500, Harshaw, USA) in the Radiation Research Center of Shiraz University, Shiraz, Iran. The TLD chips were calibrated using an X-ray unit at Shiraz University with the same filtration as the X-ray units in the School of Veterinary -.

The TLDs employed for calibration were divided into several groups and were exposed to different doses ranging from 50 μGy to 1.2 mGy. Afterwards, the TLDs were read out by the TLD reader, and the calibration curve, which is dose versus the TLD response (in nc), was drawn. As the TLD response is energy-dependent, especially in low-energy X-rays, three calibration curves were obtained for three different tube voltages of 45, 60, and 80 kVp. Each calibration curve was used for dose estimation of radiological procedures with similar voltages.

2.5. Comparison of Direct and Indirect Methods

To compare the results of the two methods, regression analysis was performed. The y=x line was fitted to the data, and the goodness of fit was achieved as follows.

First, the sum of squares due to error (SSE) was obtained as the total deviation of the predicted results from the fit, (y=x) to the observed results (Equation 2).

$$SSE = \sum_{i=1}^{n}(y_i - f_i)^2 \qquad (2)$$

where y_i is the observed data value and f_i is the value predicted from the y=x fit.

Then, the total sum of squares (SST) was obtained according to Equation 3.

$$SST = \sum_{i=1}^{n}(y_i - y_{av})^2 \qquad (3)$$

where y_{av} is the mean value of the observed data.

Finally, R-squared is defined as the goodness of the fit according to Equation 4.

$$R^2 = 1 - [\frac{SSE}{SST}] \qquad (4)$$

The R-squared values closer to 1 indicate that a greater proportion of variance is accounted for by the model. All the calculations were performed in MATLAB 8.5.

3. Results

3.1. Indirect Measurement of ESD

The output curves of the two X-ray tubes are shown in Figures 1 and 2. The second-order polynomials shown on the curves are used to estimate the output of the tubes at different kVps. As can be noted in figures, the R^2 values of the fitted curves are approximately equal to 1. Tables 1 and 2 demonstrate the dose ranges imposed to the animals undergoing diagnostic radiology by the above-mentioned X-ray machines estimated by the indirect method.

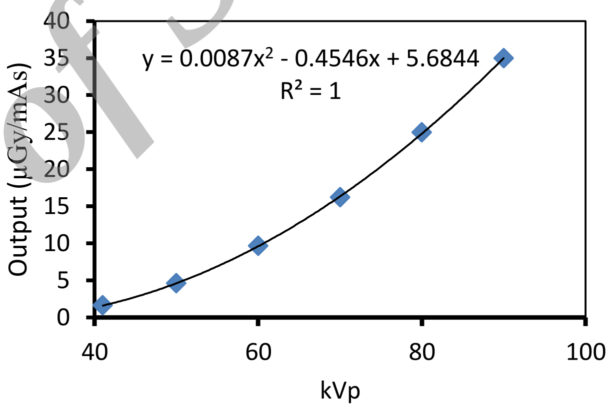

Figure 1. The output curve of Philips Super M100 X-ray tube

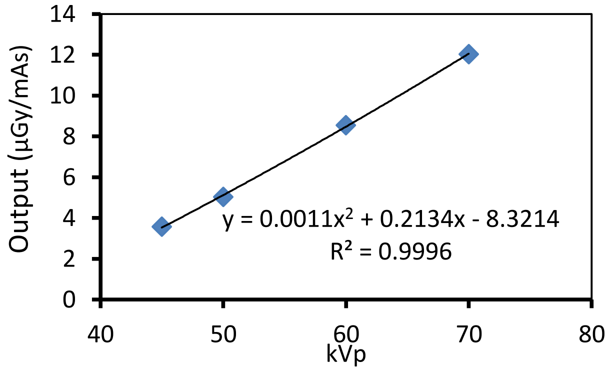

Figure 2. The output curve of Philips Practix 100/20 X-ray tube

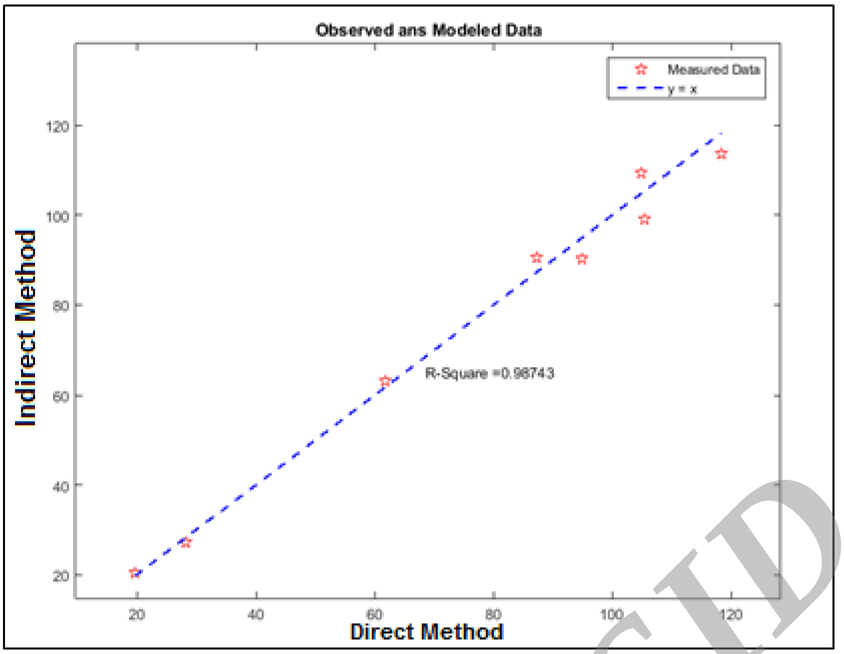

Figure 3. The results of regression test; the results of this analysis showed that the results of the two methods are consistent with each other, as the linear model y=x is fitted to the data with R^2=0.99.

Table 1. The range of the entrance skin dose values estimated with indirect method for different animals undergoing diagnostic imaging using Philips Super M100 unit for mAs=2.5

	Animal	image site	Dose (min-max) average (µGy)
1	Dog	Leg	(53.5-132.14) 82.64
2	Horse	Leg	(103.93-1189.15) 471.5
3	Dog	Lung	(207.3-343.77) 275.54
4	Dog	Abdomen	(127.73-306.64) 197.40

Table 2. The range of the entrance skin dose values estimated with indirect method for different animals undergoing diagnostic imaging using Philips Practix unit, for different values of mAs used for imaging

	Animal	Image site	Dose(µGy)
1	Dog	Abdomen	(38.5-133.69) 86.10
2	Dog	Neck	(47.16-165.04) 106.1
3	Parrot	Abdomen	(44.65-56.7) 50.68
4	Dog	Leg	(113.54-116.85) 115.20
5	Small birds	Leg	(29.09-61.87) 42.22

According to Table 1, the ESDs to the animals in the imaging procedures performed by Philips Super M100 unit vary between 53.5 µGy and 1189.2 µGy. While the ESD values for Philips Practix unit ranged between 29.09 µGy and 165.04 µGy. Such differences in ESD values are due to tube outputs and different imaging techniques, e.g., kV, mAs, field size, source to surface distance, and animal thickness.

3.2. Direct measurement using TLD

The results of TLD for the two units and different animals are compared with the indirect dose estimation shown in Table 3. According to Table 3, the difference between TLD and indirect method was less than 5%. The uncertainty analysis for TLDs is exhibited in Table 4. As can be observed in the table, the quadrature combination of total statistical uncertainties (types A and B) were found to be 7.84%.

Table 3. The comparison between the entrance skin dose estimated by thermoluminescence dosimetry and the indirect method

A) Philips Super M100

Animal	Image site	View	kVp	mAs	Dose (µGy) TLD*	Dose (µGy) Indirect method
Dog	Chest	Lat	70	2.5	61.7±4.84	63.2±3.41
Dog	Chest	AP	72	2.5	118.3±9.27	113.7±7.40
Dog	Pelvis	Lat	72	2.5	105.3±8.26	99.2±5.89
Dog	Pelvis	AP	74	2.5	104.8±8.22	109.5±7.88

B) Philips Practix 100/20

Animal	Image site	View	kVp	mAs	Dose (µGy) TLD	Dose (µGy) Indirect method
Cat	Hand	lat	55	5	87.3±6.84	90.5±6.48
Chough	Wing	AP	55	5	19.7±1.54	20.4±1.12
	Abdomen	Lat	50	5	28.2±2.21	27.1±1.51
Horse	Femur	Lat	80	2.5	94.9±7.44	90.4±6.33

* Thermoluminescence dosimeter

Table 4. Uncertainty analysis of results

Component of uncertainty	Type A (%)	Type B (%)
Repetitive TLD* measurements	5.5	—
TLD dose calibration	—	5.5
Correction for energy dependence of TLD	—	0
TLD positioning	—	1.0
Quadrature combination	5.5	5.59
Total uncertainty	7.84	

* Thermoluminescence dosimeter

3.3. Regression analysis

To establish the relationships between the results of the two methods, linear regression analysis was performed for the results demonstrated in Table 3. Our results indicate that the linear model y=x is fitted to the data with R^2 approximately equal to 0.99. The fitted line and the R^2 are exhibited in Figure 3.

4. Discussion

The obtained results revealed that the values of ESD to the animals depend on the radiographic technique, animal thickness, FSD, and the X-ray tube output. According to Table 3, the doses imposed to eight animals, as measured by the TLDs, ranged between 19.7 µGy and 105.3 µGy, which were in close agreement with indirect evaluation of the dose to these animals.

Tables 1 and 2 show a great variation in the dose values obtained through indirect evaluation. By evaluation of the imaging techniques for the animals receiving doses greater than 1000 µGy, it was found that for one of the animals receiving 1189.2 µGy the FSD was 30 cm; therefore, the doses were increased significantly according to the ISL.

Comparison of the results obtained in this study with those of previous investigations demonstrated that the doses to dogs undergoing chest radiography in this study (average=275.54 µGy) were less than those of a study performed by Veneziani et al. (average: 0.53 mGy for small dogs, 0.59 mGy for medium dogs, and 1.45 mGy for big dogs) [15]. This discrepancy was due to different radiography techniques used in the two investigations. Analysis of the quality of the images showed that the techniques used by the technician of Shiraz University were more efficient for obtaining high-quality images with imposing lower doses to the animals. Thus, application of low-dose imaging techniques, i.e., low mAs and increasing the SSD for reduction of the dose to animals, are recommended.

5. Conclusion

The ESD to animals undergoing diagnostic radiology was evaluated through direct and indirect methods. The direct measurements were performed using TLDs and TLD-100. The tube output in each kVp was multiplied by the mAs to evaluate the ESD indirectly. It should be mentioned that the corrections for BSF and ISL were also applied in indirect method.

The results revealed that the obtained dose was less than the dose reported in previous investigations, which might be due to the fact that the protocols used in this study were according to the recommendations of ICRP. Since establishing a radiological protection system for animals and plants is necessary, optimized procedures are suggested for obtaining high-quality images, with a reasonably low dose imposed to the animals. Further comprehensive studies should be performed on optimization of the imaging technique for attaining acceptable images.

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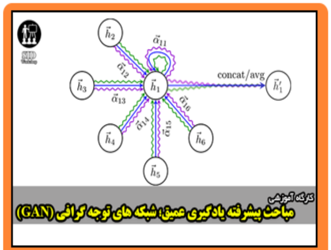
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