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Evaluation of scattered radiation from fluoroscopy using small OSL dosimeters

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Abstract

Recently, there has been a significant amount of interest in studying the importance of radiation doses to the eye lens during endoscopic retrograde cholangiopancreatography (ERCP). A study that focused on measuring the scattered radiation using an ionization chamber survey meter reported that a lead curtain was useful in reducing the scattered radiation. The over-couch X-ray tube system tends to deliver higher doses to the head and neck of the staff involved in the procedure than the under-couch X-ray tube position. In this study, a small optically stimulated luminescence (OSL) dosimeter called the nanoDot was used to evaluate and measure the amount of radiation; this dosimeter was developed by Landauer Ltd. and was specifically designed for point measurements. There are numerous studies that have reported the usefulness of personal OSL dosimeters other than the nanoDot to measure scattered radiation. Here, we evaluated the amount of scattered radiation, along with the degree of reduction achieved with the use of a protective curtain, while employing a personal OSL dosimeter and nanoDot. When the scattered radiation dose was measured using the nanoDot, the maximum recorded value without a protective curtain was 0.363 mGy and that with a protective curtain was 0.026 mGy, both at the height of 100 cm. The maximum reduction rate of scattered radiation while using a protective curtain was approximately 93% and 97% at 100 cm and 150 cm, respectively. The measured values recorded using both personal OSL dosimeters and nanoDot machine were strongly correlated.

Keywords Fluoroscopy · Endoscopic retrograde cholangiopancreatography · Scattered radiation · Dosimetry · Radiation protection · Small OSL dosimeter

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1 Introduction

In 2011, the International Commission on Radiation Protection (ICRP) set the threshold dose for cataract occurrence in the crystalline lens of the eye at 0.5 Gy. The equivalent dose limit for the lens of the eye was 20 mSv per year averaged over 5 years and was published under Publication 118 [1]. As a result, there was a widespread increase in awareness regarding radiation exposure to the eye lens, in the medical field. Numerous studies have assessed the dose of exposure to the eye lens in interventional radiology (IVR)-related and endoscopic retrograde cholangiopancreatography (ERCP)-related procedures [2–4]. An X-ray tube can be in the over-couch or under-couch position in X-ray fluoroscopic procedures, including ERCP-related procedures. In the former position, the X-ray tube is positioned above the bed and the scattered radiation from the patient may be directed at the head and neck of the staff, which may result in exposure to higher doses in these parts of the body. Studying this parameter of research is important, since the examination time may need to be prolonged based on the difficulty level of each procedure or in a situation when the patient inside the examination room requires some form of assistance during the procedure.

Yoshida et al. reported that the radiation doses in air during ERCP-related procedures were estimated using an ionization chamber. Their study reported that the using a protective curtain with the over-couch X-ray tube during ERCP-related procedures reduced the radiation exposure to the operators and other staff inside the X-ray room [5]. Here, a small OSL dosimeter called nanoDot was used to evaluate the radiation while performing these procedures; this dosimeter was developed by Landauer Ltd. and was specifically designed to perform point measurements. The nanoDot is significantly compact and does not interfere with diagnostic procedures. It has been used in various studies, e.g., for a dosimetric evaluation during radiation therapy using external beam radiation therapy (EBRT) [6, 7] to assess the accuracy of repetitive measurements obtained with the nanoDot by irradiating it with diagnostic X-rays [8]. However, only a handful of studies using the nanoDot have focused on scattered radiation-dose measurements.

This study aimed to evaluate the scattered radiation dose using nanoDots and to verify the reduction rate in scattered radiation when using a protective curtain.

2 Materials and methods

2.1 nanoDots and microStar

The nanoDot (Nagase Landauer Ltd.) dosimeter had no additional filter and contained a single aluminum-oxide element with a diameter of 5 mm and detector thickness of 0.3 mm. It was covered with plastic for light shielding with a label that was affixed to identify the dosimeter. The outer casing dimensions are 10 mm × 10 mm × 2 mm, and the measurement effective area was a circle with a diameter of 4 mm. The nanoDot can be used to record single-point measurements and was relatively easy to use. In addition, considering the fact that the detection element is often very thin, the angular dependence characteristics were small with respect to any type of radiation. Due to an absence of an additional filter, it was necessary to correct for the energy dependence. The energy response of the aluminum-oxide material was 4 times to 40 keV photons higher than that of Cs-137 γ-rays. Since the type and energy of the radiation is known while irradiating the nanoDot dosimeters, we can compensate and correct the energy dependence by calibrating the OSL reader, i.e., the reader is calibrated to use nanoDots in the diagnostic energy range only.

The nanoDot dosimeters were read using the microStar (Nagase Landauer Ltd.) reader. The typical lower dose measurement limit of this reading apparatus was 10 μGy, which was achieved, by configuring one optical filter just before the photomultiplier tube (PMT), the signal-to-noise ratio was improved and the lower dose measurement limit can be lowered to 1 μGy, as demonstrated in Fig. 1. Here, nanoDot dosimeters were read three times to reduce statistical error [8, 9].

2.2 Protective curtain for scattered radiation (lead curtain)

A lead curtain (Hoshina Corporation) was attached to the X-ray tube when it was placed in the over-couch position during fluoroscopic procedures; the curtain had shielding material that was equivalent to 0.25 mm of Pb. As shown in Fig. 2, the lead curtain covers the entire irradiation field of X-rays during fluoroscopy and shields the staff from scattered radiation. It is also possible to expect a reduction in the scattered dose to the staff, such as the surgeons in an examination room.

2.3 Measurement of the dose in air

The jungle gym method (Nagase Landauer Ltd.) was used during the measurements. The jungle gym method, which was developed by Dr. Ikuo Kobayashi of Nagase-Landauer, was used to provide a safe way for researchers to detect radiation doses inside a room with radiation emitting medical equipment, i.e., researchers or radiation protection

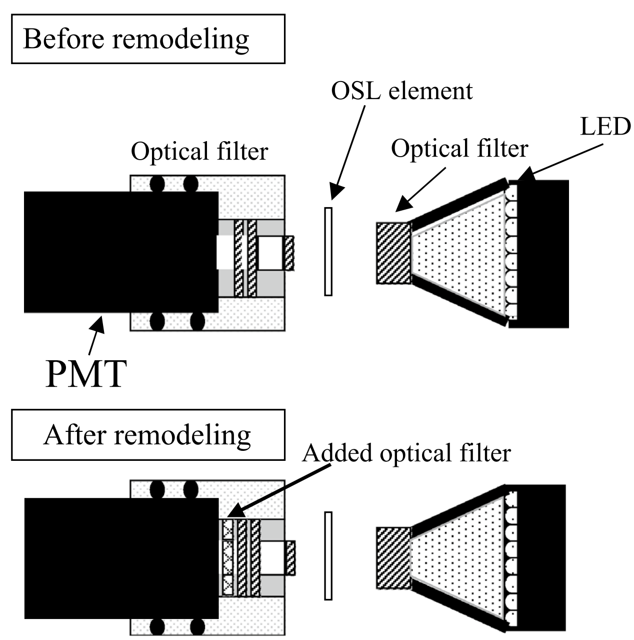

Fig. 1 Structure of the optical filter. This figure shows the structure of microStar reader. In the second (after remodeling) figure, an optical filter is added in front of the photomultiplier

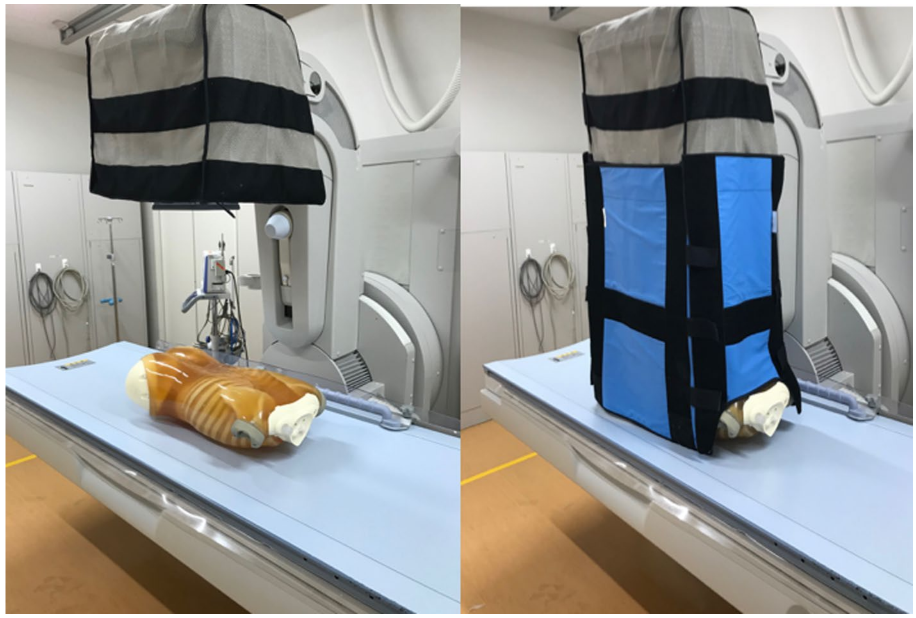

Fig. 2 Protective curtain for scattered radiation (lead curtain). This figure shows the appearance of the lead curtain, which is made of four lead-containing walls and is attached to cover the subject

officers would be able to estimate the scattered radiation doses inside a room without them being exposed to unnecessary irradiation. The jungle gym method also provides an easier way to gather radiation-dose measurements at multiple positions inside a room per irradiation. Multiple nanoDot dosimeters can be used in multiple positions to measure the radiation dose per irradiation. As shown in Fig. 3, the jungle gym apparatus consists of paper pipes joined together using plastic joints; the apparatus is then installed inside the fluoroscopic examination room. The structure contained a total of 48 points, 8 measurement points at each horizontal row, and 6 measurement points at each vertical column. The measurement points had an interval of 50 cm. The nanoDots and the Luminess badge (Nagase Landauer Ltd.) were affixed to each measurement point that was used to measure the dose. The measurement points with heights of 100 cm and 150 cm may be assumed to represent the height of the abdomen and the lens of the eye. ZEXIRA DREX-ZX80 (Canon Medical Systems) was used in this study as the X-ray fluoroscope with the following normal ERCP conditions: tube voltage, 80 kV; tube current, 20 mA; pulse width, 10.0 ms; and fluoroscopic frame rate, 7.5 fps. The height of the bed from the floor was 80 cm and the irradiation field was 34 cm × 34 cm. The whole-body Phantom PBU-60 (Kyoto Science) was set in the center as the scattering medium, and the fluoroscopy time was set at 10 min. Total 96 dose measurements were performed. In addition, nanoDot was positioned on the whole-body phantom at center of irradiation field and entrance surface to measure the radiation dose. Dose measurements were performed with and without the presence of the lead curtains, under the same fluoroscopic conditions.

Fig. 3 Appearance of the jungle gym method. The figure on the left shows the arrangement and structure of the jungle gym that was set up at the time of measurement. The figure on the right is an enlarged view of one of the joints of the gym. The nanoDots and the Luminess badge are affixed to each measurement point

2.4 Comparison of doses to the staff at each position

Figure 4 shows the approximate position of the staff while performing ERCP-related procedures in the examination room of this study's facility. Point A is the doctor who performs the main procedure such as an endoscopic operation. Point B is the doctor who performs the catheter operation and administers the contrast medium injection, etc. Points C and D are nurses that handle patient monitoring, maintenance of medical records in the examination room, and equipment delivery, among other tasks. The doses at each position were compared with or without the lead curtain.

3 Results

The entrance surface dose both with and without lead curtain was measured to be 60 mGy. Figure 5 shows the nanoDots dose measurements at heights of 100 cm and 150 cm from the floor. At both 100 cm and 150 cm, the scattered dose decreased as the distance of the scattering medium increased. When the protective curtain was not used, the doses were around 0.1–0.4 mGy per 10 min of irradiation, and the doses at the 150-cm height seemed to be higher than those at the 100-cm height. At 200 cm away, the doses were close to the lower dose-measurement limit of the dosimeter.

Table 1 demonstrates the results of measuring the radiation dose using a nanoDot at the approximate position of the staff as well as the reduction rate. The presence of the lead curtain ensured that the dose significantly decreased at all of the approximate positions of the staff. The reduction rate at point A, which is closest to the X-ray tube, was the highest (93% at the height of 100 cm and 97% at the height of 150 cm).

Table 2 demonstrates the measurement results for the nanoDots and Luminess badges near the X-ray tube. There was a strong correlation between the two, having a correlation coefficient of $r=0.970$ (Fig. 6).

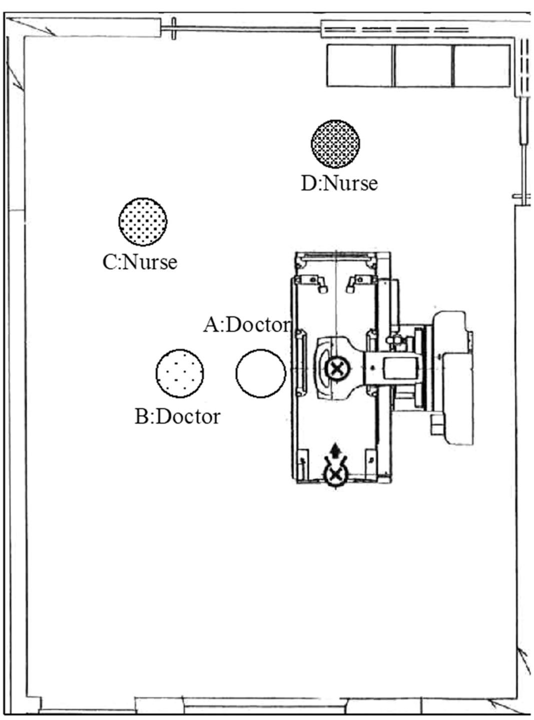

Fig. 4 Positions of medical staff during the fluoroscopic procedure. This figure shows the position of medical staff during ERCP. **a** Represents the doctor performing the main procedure (endoscopy). **b** Represents the doctor who operates the catheter, contrast medium injection, etc. **c**, **d** Represent nurses who constantly check the vitals of a patient, which includes his/her heart rate, respiratory rate, blood pressure, etc.

4 Discussion

4.1 Dose in the air inside the examination room during ERCP-related procedures

The results demonstrated that in the absence of the protective curtain, the doses measured by the nanoDot seemed to be higher at the 150-cm point than those at the 100-cm point. This might be because the X-ray equipment was used in an over-couch position and the dose measured was the scattered radiation from the phantom and the scattered X-rays from the X-ray tube, which was closer to the measurement point at the 150-cm height [10].

At the point 200 cm away from the scattering medium, the doses were noted and the lower dose-measurement limit of the dosimeter. Kusama [11] reported that it is safe to leave a 200-cm distance between the staff and the X-ray tube. In this study, at the 200-cm distance, the doses were approximately identical to the lower dose-measurement limit. However, in the presence of a protective curtain, there was a significant reduction in the dose at every measurement point.

At 100 cm from the floor, the dose tends to increase in the longitudinal direction of the bed from either the head or the leg. This is the result of a gap in the lead curtain shown in Fig. 2, to allow the patient's head and legs to extend beyond, similar to that reported by Yoshida et al. [5]. Although the scattered radiation drastically decreased after using a lead curtain, there were still a number of gaps that leaked the scattered radiation from the phantom and bed. It was possible to reduce occupational exposure by conducting educational/awareness activities for the medical staff to ensure that they do not inadvertently approach the leakage site and also choose the best position where they can stand during fluoroscopic procedures.

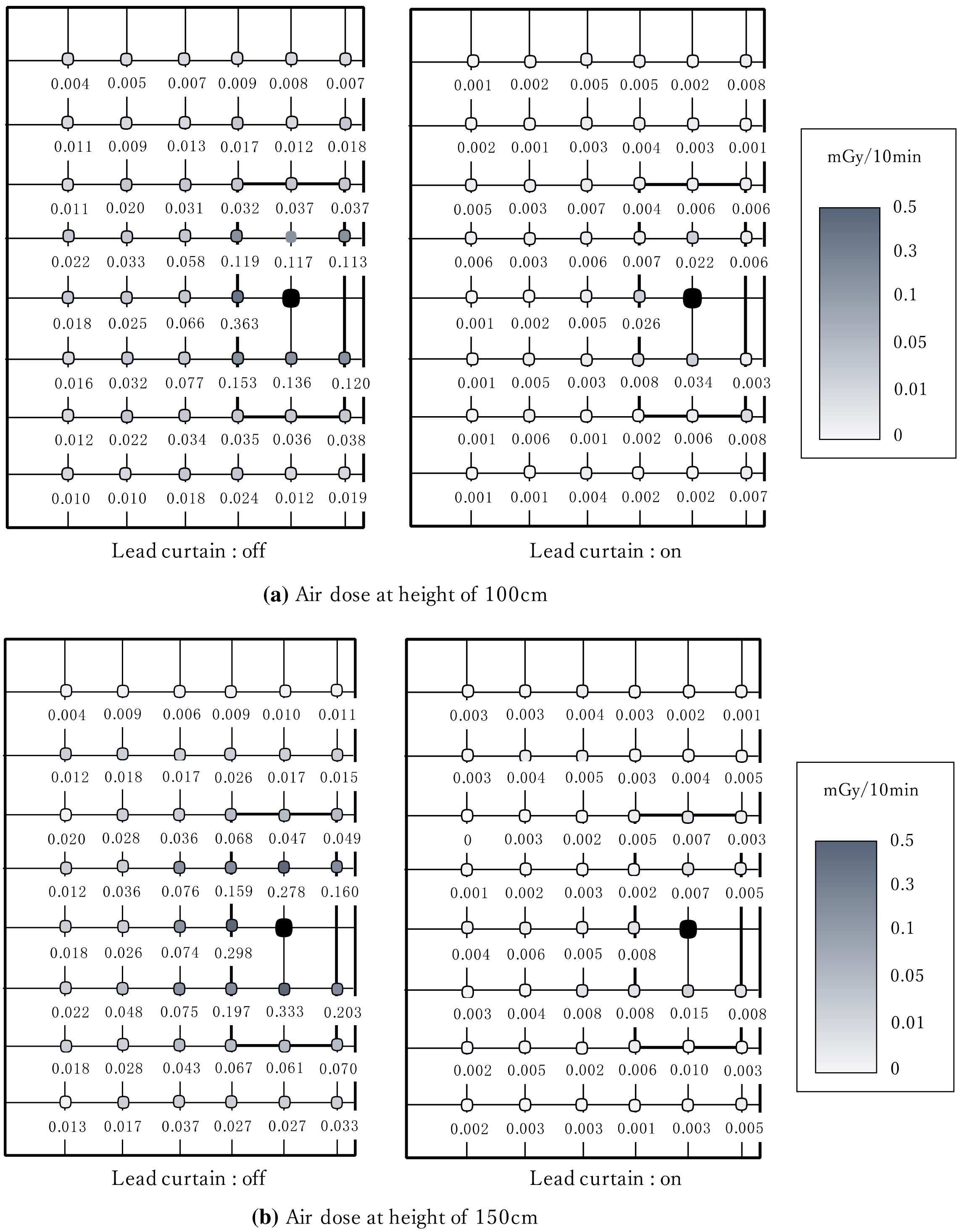

Fig. 5 Air-dose-measurement results. This figure presents the distribution of the air dose. **a** Represents the air dose at a height of 100 cm, and **b** represents the same at a height of 150 cm. Darker color indicates higher air dose. At both 100 cm and 150 cm, the scattered dose demonstrated a notable decrease in its value with the increase in the distance of the scattering medium

4.2 Comparison of doses at each of the approximate positions of the staff

The highest radiation dose measured was at Point A, which was close to the scattering medium and the X-ray tube. The doses reduced as the distance from the X-ray source with an increase in the scattering medium. The lowest dose measured was at the position of the nurse at Point D, since it

Table 1 Dose comparison at each position of the staff

Position	Dose [mGy/10 min]		Reduction rate (%)
	Lead curtain: off	Lead curtain: on	
(a) Dose at a height of 100 cm			
A	0.363	0.026	93
B	0.025	0.002	92
C	0.031	0.007	79
D	0.008	0.002	71
Position	Dose [mGy/10 min]		Reduction rate (%)
	Lead curtain: off	Lead curtain: on	
(b) Dose at a height of 150 cm			
A	0.298	0.008	97
B	0.025	0.006	76
C	0.036	0.005	85
D	0.010	0.002	82

Table 2 Measured and relative values obtained with the luminescence badge (Hp 0.07) and nanoDot near an X-ray tube

Measurement point	Luminess Hp0.07 (mGy)	NanoDot (mGy)	Relative value
1	0.080	0.113	0.706
2	0.090	0.117	0.767
3	0.120	0.119	1.007
4	0.340	0.363	0.936
5	0.120	0.120	0.997
6	0.110	0.136	0.808
7	0.140	0.153	0.913
8	0.170	0.160	1.059
9	0.290	0.278	1.045
10	0.170	0.159	1.067
11	0.370	0.298	1.243
12	0.200	0.203	0.984
13	0.390	0.333	1.171
14	0.190	0.197	0.963

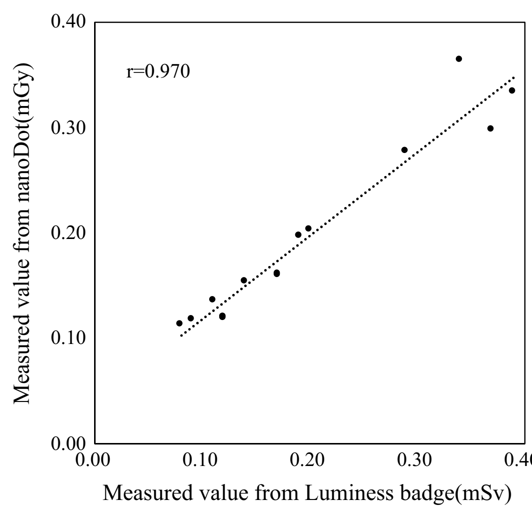

Fig. 6 Graph of the measured values from the Luminess badge (Hp 0.07) and the nanoDots. This figure shows the measurement results for the nanoDots and Luminess badges near the X-ray tube, as shown in Table 2. There was a strong correlation, with the correlation coefficient being $r = 0.970$

was the farthest from the X-ray source and the scattering medium. The reduction rate of scattered radiation by the protective curtain was 90% or more, particularly at Point A. At points B, C, and D, the reduction rate was lower at 71–85% than point A. The nanoDot has 5% variation due to individual differences of each element and background which was residual count that was noted after annealing. At points B, C, and D, which have relatively low dose rates, the contribution of these effects was considered to increase and to appear as a decrease in the reduction rate. In addition, point D seemed to include the influence of scattered radiation leaked from the gap of the lead curtain.

In comparison with other fluoroscopic examinations, ERCP-related procedures tend to require a longer irradiation time. Therefore, if the doctor at Point A performing the main procedure in the vicinity of the X-ray tube performed 55 fluoroscopic procedures with an irradiation time of 10 min, without the lead curtain installed, he would exceed the 20-mGy per year dose limit for the lens of the eye averaged over 5 years will be exceeded.

In this study, the dose in air was measured, but in the actual procedure, the doctor was often closely watching the endoscope monitor and the perspective monitor, and the dose difference between the right and left crystalline lenses is also a concern. Further studies should be conducted to examine the differences in the dose between the left and right eyes.

4.3 Comparison of the dose readings from the nanoDot and the Luminess badge

Tomita et al. [12] reported that the scattered doses were measured inside a CT room using OSL dosimeters and a semiconductor detector. In this experiment, readings from the OSL dosimeters were significantly similar to those noted using a semiconductor detector, without any observable errors.

Table 2 demonstrates that the dose measurement obtained by the nanoDot was within ± 20% with considering the Luminess badge. The correlation coefficient was $r = 0.970$. Therefore, the nanoDot was deemed to be useful to measure scattered radiation doses.

4.4 The jungle gym method

Yoshida et al. [5] reported that the measurements were carried out using an ionization chamber-type survey meter. To successfully measure doses at different points of interest, the person holding the survey meter will have to measure each point individually. Therefore, he/she will be irradiated and exposed to high doses particularly in the following regions: head, neck, and extremities. In addition, using a survey meter would require a longer irradiation time. This study used the nanoDot and Luminess badges; furthermore, the jungle gym method could be easily assembled to allow the researchers to measure the scattered dose by sticking the nanoDots and Luminess badges at each point of interest. Therefore, it was possible to measure the radiation dose at various points of interest without the risk of being exposed to high-radiation doses. The main disadvantage was that it takes a significant amount of time to assemble and place the dosimeters in each measurement position, although the total irradiation time would be considerably shorter and ease the burden on the X-ray tube. Therefore, it is easier and safer to measure the scattered radiation doses using the nanoDots unlike the conventional ionization chamber survey meter.

5 Conclusion

Using a small OSL dosimeter, it is possible to easily measure the radiation dose in air. In this study, the dose distribution inside an X-ray room was measured and evaluated. Exposure to radiation for the medical staff during fluoroscopic examinations, including ERCP-related procedures, was too significant to ignore. Surveillance is particularly needed for those positioned near the X-ray tube. During an examination, it is important to use radiation protective equipment such as lead curtains, which can greatly reduce radiation exposure.

Compliance with ethical standards

Conflict of interest Ikuo Kobayashi is an employee of Nagase Landauer Ltd., Japan. All authors, except Ikuo Kobayashi, declare no conflict of interest. The device (nanodot, microStar) used in this study was provided by Nagase Landauer Ltd., Japan.

Human rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Review Board (IRB) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent This article does not contain any studies with human participants performed.

Animal rights This article does not contain any studies with animals performed.

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