IV. 5. Skin Dose Measurement for Patients Using Imaging Plates in Interventional Radiology Procedures II

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Introduction

Fluoroscopically-guided interventional radiology (IR) procedures have been under increased scrutiny in recent years. However, reports of radiation-induced severe injuries to patients' skin have steadily increased since the early 1990's.¹² To prevent patients from suffering radiation skin injuries, estimating the radiation dose delivered to the skin of patients during IR procedures should be important.

According to ICRP Publication 85³, the patient dose of priority concern is the absorbed dose in the area of skin that receives the maximum dose during an interventional procedure. The easiest way to determine the entrance skin dose (ESD) is a direct measurement by using small dosimeters such as thermoluminescence (TL) dosimeters and photoluminescence glass dosimeter (PLD) chips. However, these methods using a limited number of dosimeters possibly miss spots of the maximum cumulative dose, resulting in underestimation of the maximum ESD. This is so because the points that receive the maximal ESD might vary widely and unexpectedly with individual procedures, and they could be widely scattered; additionally, radiation fields may overlap during IR procedures. We therefore proposed to use imaging plates (IPs) for mapping skin doses of patients in IR procedures. The ESD was measured by fitting a 40 × 40 cm IP sheet around a patient's back using a corset in clinical studies of a patient who underwent IR procedures at Sendai Kousei Hospital. The corset can minimize a geometric discrepancy in the dose estimate by putting an IP sheet between sheets during the procedure. At the same time, the ESD was measured using a commercially available PLD. PLDs were held in the holes of the polyurethane sheet in the corset. The results of ESDs thus obtained by IPs and PLDs were compared.
Materials and methods

Imaging plate and readout technique

A 20 cm × 40 cm BAS-TR type IP (Fuji Film Co., Ltd.) was used. It has a 50-μm-thick photostimulable phosphor (BaFBr:Eu²⁺) affixed to a 250-μm-thick polyethyleneterephthalate layer as support and has no protective surface layer. The phosphor, whose density is 2.61 g/cm³, contains Ba (37.82%), F (5.23%), Br (22.01%), and I (34.94%) by weight. BAS-TR type IP can accurately measure X-ray doses ranging from 1 μGy to 100 Gy and the dose-response is linear up to about 10 Gy⁴). IPs show the same response in the range between 100 μGy/min and 3.73 Gy/min without a counting loss. For measuring the ESD in a patient, to cover the whole area of a patient's back, a 40 × 40 cm IP was formed by coupling together two BAS-TR sheets. The IPs were wrapped in black polyethylene to shield them from light during irradiation and put inside a corset to make IPs fit to the patient's back. The IPs were scanned within a few hours after irradiation using a coloredcellophane technique⁴,⁵) and a 200 × 200 μm BAS-1000 readout system (Fuji Film Co., Ltd.). The IPs were then rescanned after annealing at 100°C for 70 h to minimize the effect of fading and estimate a quantitative dose precisely.

Photoluminescent Glass Dosemeter and Corset

The GD-302M (Asahi Technoglass Corp.) consists of a silver-activated photoluminescence glass dosemeter (PLD) chip. Each PLD chip is encapsulated within glass and is cylindrical, 1.5 mm in diameter and 12 mm in length and then fixed in a plastic holder, 2.8 mm in diameter and 13 mm in length. The corset consists of four 450 mm × 600 mm polyurethane sheets, three are 2-mm thick and one is 4-mm-thick. The 4-mm-thick sheet has 13 mm × 14 mm holes at 5-cm intervals in an 11 × 8 grid for placing the PLD chips inside. The corset has three sets of Velcro bands on both sides to hold it close to patient's body by fastening the ends of bands together. It can be easily worn and fit to the body. For measuring a patient's ESD, the IP was placed between two 2-mm-thick sheets and 48 PLD chips were distributed inside 48 discrete holes at 5-cm intervals in an 8 × 6 grid one by one, as shown in Fig. 1. By fastening Velcro bands, IPs and PLD chips were held steady inside the corset. This made it possible to match each corresponding measuring region in IP images with that of PLD chips.

X-ray irradiation

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The ESDs of patients during IR procedures in clinical studies were measured. An X-ray unit, KX0-100G (Toshiba Medical Systems Co.) with 2.6-mm-thick Al filter was used. The tube voltage, tube current, and exposure time were recorded at 3 min intervals during fluoroscopy. The effective conditions of X-ray irradiation were estimated from these records. The dose response of IPs and PLD chips in the range from 1 mGy to 2 Gy was evaluated with the X-ray unit by placing IPs and PLD chips on the tabletop immediately under an acrylic phantom (i.e., entrance skin location) and providing the X-ray beam from under the table with tube voltages of 60, 80, 100, and 120 kV. The acrylic phantom was 20 cm thick and had a $33 \times 33$ cm front face. Two $1 \times 1$ cm IPs, which were cut from a 20 x 40 cm IP sheet, and four PLD chips were irradiated at each tube voltage and each exposure was determined by placing an ionization chamber in the center of IPs and PLD chips. Ionization chambers, the VICTOREEN model 500 of 3.26 ml effective volume (Elimpex-Medizintechnik) was used. It is traceable to the Japanese national standard maintained by the Japan Quality Assurance Organization (JQA) in Tokyo, Japan.

**Results and discussion**

The PSL density (PSL/mm$^2$) and PLD response (mGy) for tube voltages of 60, 80, 100, and 120 kV on the acrylic phantom are obtained as a function of the dose (mGy) and plotted in Fig. 2a and 2b. Both variations of the measured values between two IPs or among four PLD chips at each irradiated dose or tube voltage were within about $\pm 2.5\%$. Each relationship has linearity in the measured range.

A case of a 66-year-old male patient who underwent Percutaneous Coronary Intervention (PCI) is exhibited as an example of entrance skin dose monitoring with IPs and PLD chips. Neither the joint formed by coupling together two IP sheets nor the corset interfered with diagnosis. The average tube voltage was calculated to be 81.0 kV and the ESDs were calculated using an equation obtained from the regression line in Fig. 2a and 2b. Distributions of the ESD were thus obtained from the PSL density in IP images and PLD chips and both mapped dose distributions showed quite similar shape. The 3-D and 2-D contour dose maps obtained with IPs are shown in Fig. 3a and 3b, respectively, giving 1,400 mGy as the peak skin dose. Each value of ESD estimated by IPs and PLD chips in a region where the ESDs were rather high (including hot spot) is given in Table 1. The number and alphabet of measuring regions in Table 1 correspond to those exhibited in Fig. 1 and 3b. The spatial relative dose profiles from both dose estimates showed generally
good agreement. However, the doses obtained with PLD chips are consistently lower than those obtained with IPs except a few cases. The highest dose was observed at region B1 and the difference of the doses measured with the two dosemeters was 34%.

One reason for this discrepancy is the radiation shielding effect for X-rays by the IP. As PLD chips were distributed on the reverse of the IP sheet in this study, a portion of the X-rays might have been absorbed by the IPs during IR procedures. The absorption was estimated to be 7.7% at a tube voltage of 80 kV\(^6\). Another reason may be associated with differences in angular response between them for low-energy X-rays. Fig. 4 shows an angular response of PSL signals of IPs for X-rays with tube voltages of 60, 80, 100, and 120 kV. The angular dependence was determined by rotating the IP along the source-to-detector axis in the directions of -90° to 90° in 15° step. Two 2 x 3 cm IPs were irradiated in air at each irradiation and each point on the graph corresponds to the average value of them. The maximum variations among individual readings of two IPs are 1.6%, 2.6%, and 2.1% at tube voltages of 60, 80, and 100 kV, respectively, except -90° to 90°. The results revealed that the IP has an almost isotropic efficiency within ±75° at all tube voltages. Relatively low responses of the IP are observed at ±90°, because large numbers of incidences might not hit the surface of the thin IP and/or X-rays might be attenuated by the IP itself as they traverse the IP. The corset can offer advantages of minimizing not only a geometric discrepancy between the IP and the patient body reducing effects of large angle incidence when the X-ray tube rotates during the IR procedure.

The angular dependence of PLD chips was determined in the same way and exhibited in Fig. 5a. The maximum variations among individual readings of two PLD chips are 6.4%, 6.2%, and 2.0% at tube voltages of 60, 80, and 100 kV, respectively, except -90° to 90°. The results revealed that the angular dependence of the radio-photo luminescence (RPL) signal of PLD chips becomes large as the incidence angle increases especially more than ±45°, and the largest decrease is observed at 60 kV. A decrease of the RPL signal at ±70° is estimated to be 24-28% at 80 kV and 40% at 60 kV, respectively, by expressing the RPL signal as a fraction of an intensity measured at angle 0°. The cylindrical shape of the PLD chip and the readout way using the FDG-1000 reader can explain this result. Schematic diagram of the readout of a PLD chip is given in Fig.5b. The FDG-1000 reader uses pulsed UV laser excitation (narrow beam; \(\phi 1.0\) mm) and the UV beam comes into a chip horizontally, then, the RPL from the 6-mm aperture is collected into a photomultiplier tube. As the energy of incident X-rays decreases, thus, the angular
dependence increases because of the attenuation by the dosemeter itself whose effective atomic number is 12.04. Besides, the thickness of PLD chips might cause the self-shielding of both the excitation and the emitted light during the reading process. This large angular dependence of the PLD chip might result in underestimation of the ESD including scattered X-rays with various angles during IR procedure.

Comprehensive results of this study demonstrated that IPs were able to measure ESD in even small high dose regions with steep dose gradients in all ranges used during IR procedures without an angular dependence by using the corset and then determine the peak skin dose without missing hot spots.

References


Table 1. Comparison of ESD (mGy) obtained by IPs and a PLD chip at the same measuring region.

<table>
<thead>
<tr>
<th>Measuring regions</th>
<th>ESD obtained by IPs (mGy)</th>
<th>ESD obtained by a PLD chip (mGy)</th>
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<tbody>
<tr>
<td>A1</td>
<td>130</td>
<td>78</td>
</tr>
<tr>
<td>A2</td>
<td>86</td>
<td>60</td>
</tr>
<tr>
<td>A3</td>
<td>31</td>
<td>37</td>
</tr>
<tr>
<td>B1</td>
<td>1,400</td>
<td>930</td>
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<td>56</td>
</tr>
<tr>
<td>C1</td>
<td>140</td>
<td>200</td>
</tr>
<tr>
<td>C2</td>
<td>300</td>
<td>320</td>
</tr>
<tr>
<td>C3</td>
<td>43</td>
<td>52</td>
</tr>
</tbody>
</table>

Figure 1. Individual PLD chips were distributed inside 48 discrete holes at 5-cm intervals in an 8 × 6 grid.
Figure 2. Dose response of (a) IPs and (b) PLD chips using KX0-100G at Sendai Kousei Hospital, respectively, evaluated by placing IPs and PLD chips on the acrylic phantom and providing the X-ray beam with tube voltages of 60, 80, 100, and 120 kV.

Figure 3. Contour dose map obtained by scanning of IPs. (a) 3-D and (b) 2-D mapped images of ESDs. In Fig. 3b, measuring points where PLD chips were placed are exhibited by superposing on the IPs' image.

Figure 4. Angular response of PSL signals of IPs for X-rays with tube voltages of 60, 80, 100, and 120 kV.
Figure 5. (a) Angular distribution of PLD chips for X-rays with tube voltages of 60, 80, 100, and 120 kV. (b) Schematic diagram of the readout of a PLD chip.