Skin Dose Measurement for Patients Using Imaging Plates in Interventional Radiology Procedures

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IV. 1. Skin Dose Measurement for Patients Using Imaging Plates in Interventional Radiology Procedures

Ohuchi H., Satoh T.[*], Eguchi Y.[*], and Mori K.[**]

Graduate School of Pharmaceutical Sciences, Tohoku University
[*]Department of Radiology, Yamagata University Hospital
[**]Fuji Photo Film Co., Ltd.

Introduction

Interventional radiology (fluoroscopically-guided) techniques comprisguided therapeutic and diagnostic interventions, by percutaneous or other access, usually performed with fluoroscopic imaging used to localize the lesion/treatment site, monitor the procedure, and control and document the therapy. The use of interventional radiology (IR) has greatly increased in recent years, because it offers several significant benefits[1)]. However, prolonged fluoroscopy times and the cumulative X-ray doses delivered when making large numbers of radiographs of limited areas of the patient can cause deterministic effects ranging from transient erythema and dermatitis to skin necrosis[2,3)].

Since most installations avoid high dose rates in the vicinity of the patient and staff by using fluoroscopy equipment configured with an over-table image intensifier and an under-table X-ray tube, the patient's skin dose can be mapped by placing a large piece of films on the tabletop immediately under the patient. Mapping skin doses using two-dimensional radiation sensors such as films is critical way to detect overlap areas between irradiation fields and determine the most-exposed patient skin areas and the probability of injury in complex fluoroscopy interventions. Kodak EDR2 film and new radiochromic film, GAFCHROMIC-XR can be used this way. However, their dynamic ranges are not adequate to fulfill the range of interest during IR procedures, from 10 mGy to over 10 Gy. Furthermore, films like EDR2 and radiochromic films cannot be reused.

We therefore propose to use imaging plates (IPs) for mapping skin doses of patients in IR procedures. An IP made of europium-doped BaFBr, a photostimulated luminescence (PSL) material, is a highly sensitive two-dimensional radiation sensor. It has a wide dynamic range and high spatial resolution, and can be used repeatedly by irradiating them with visible light between uses. 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 Gy[4]. IPs show the same response in the range between 100 μGy/min and 3.73 Gy/min without a counting loss[5] and can thus be useful in IR procedures using high dose rates, such as digital subtraction angiography (DSA). Because the energy dependence of IPs is rather high, the IPs were characterized to have a sensitivity variation of about 13% was observed for effective energies of 32.7 to 44.7 keV[6], which are used in IR procedures. Simulation of actual interventional cardiology procedures showed that the variation of sensitivity was within 5%, meaning that IPs are practical for measuring skin doses during IR procedures[6].

In this work, the entrance skin dose (ESD) was measured in two clinical studies of transcatheter arterial embolization by fitting a large sheet of IPs around a patient's back using a corset, which was used to avoid a geometric discrepancy in dose estimate between IP and the patient body. The ESD obtained by IPs was compared with the results obtained by Dose Ace, which was commercially available a photoluminescent glass dosemeter.

Methods

Imaging plate and readout technique

The 20 cm x 40 cm BAS-TR type IP, manufactured by Fuji Photo Film Co., Ltd. was used. It has a 50 μm-thick photostimulable phosphor ($BaBrF:Eu^{2+}$) and has no protective surface layer. For measuring the ESD in patient, two IP sheets with closely matched sensitivities (within 5%) were coupled to make a 40 cm x 40 cm sheet for covering whole area of a patient's back. The IPs were wrapped in black polyethylene to shield them from sunlight 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 colored-cellophane technique[4,5] and a 200 μm x 200 μm BAS-1000 readout system (Fuji Photo Film Co., Ltd.), and were rescanned after annealing at 100°C for 70 hours.

Dose Ace

The GD-302M Dose Ace (Asahi Techno Glass Co., Japan) consists of a silver-activated photoluminescence glass dosemeter (PLD) chip. Each PLD chip was encapsulated within glass and was cylindrical, 1.5 mm in diameter and 12 mm in length. For each IR procedure, 10 points in the patient's back were selected for dose monitoring.

For each point, five PLD chips were used and placed inside the 13 mm x 14 mm holes that are present in the corset. The PL data from pulsed UV laser stimulation was read out from the chips with an FGD-1000 Dose Ace reader.

Corset

The corset consists of four 450 mm x 600 mm polyurethane sheets, three are 2-mm thick and one is 4-mm-thick. The 4-mm-thick sheet has 13 mm x 14 mm holes at 5-cm intervals in an 11 x 8 grid for placing the PLD chips inside. For measuring each patient's ESD, the IP was placed between two 2-mm-thick sheets and 50 PLD chips placed in the holes of the 4-mm-thick sheet on the reverse of the IP sheet. The structure of the corset and an arrangement of the IP sheet and PLD chips are shown in Fig. 1(a). The corset has three sets of Velcro bands on both sides to hold patient's body by fastening the ends of bands together. It can be easily worn and fit to the body as shown in Fig. 1(b).

X-ray irradiation

The IPs were irradiated by beams from the X-ray generator (KXO-2050, Toshiba Medical Co.,) at Yamagata University Hospital. The reference dosemeter was an ionization chamber (6 ml effective volume, model 1015, RADCAL Co.,), which is traceable to the Japanese national standard maintained by the JQA. The filters for the X-ray generator were 1.1-mm-thick Al plus 0.03-mm-thick Ta. The effective energies varied between 32.7 and 44.7 keV when the tube voltage was varied between 60 and 120 kV. The dose-response of PLD chips in the range from 1 mGy to 2 Gy was evaluated by placing four PLD chips at every irradiation on the tabletop immediately under an acrylic phantom (i.e., entrance skin location) and providing the X-ray beam from under the table with using tube voltages of 60, 80, 100, and 120 kV. The acrylic phantom was 20-cm-thick and had a 33 cm x 33 cm front face. Each exposure was determined with the RADCAL ionization chamber model 1015 by placing chamber in the center of IPs and PLD chips.

Results and discussion

The variation of the measured values among four PLD chips at each irradiated dose or tube voltage was within about 5%. The PLD chip dose–response relations are shown in Fig. 2 for each tube voltage. The linearity was observed for all the doses at all tube voltages, and the response of the PLD was equal from 80 kV to 120 kV although sensitivity at 60 kV was about 10% less than that at other voltages.

Case 1 and 2 were 68 and 77-year-old female patients each with Hepatocellular Carcinoma (HCC), which were treated by Transcatheter arterial embolization (TAE). Fluorocsopy times were about 1 hr and 2 hr, individually and tube voltages were recorded at 3 min intervals during fluoroscopy. A contour dose map of patient 2 obtained by scanning of IPs with the annealing technique is shown in Fig. 3(a). Ten measuring points where PLD chips were placed were shown in Fig.3(b). An example of ESD monitoring of patient 2 obtained by the PLD chips and IPs at the same point is given in Table 1. Although the variation among PLD chips was within about 5%, the estimated dose by PLD chips at points 4, 8, and 9 showed 2.5, 1.6, and 1.9 times variation among 5 chips. IP's dose distributions in Fig.3(b) clearly showed that these points were located just on the places where the dose changed sharply. Overall, both doses in Table 1 show agreement, however, the doses obtained with the PLD chips were consistently lower than those obtained with the IPs. The highest dose among ten points was observed at point 7 and the difference between the dose obtained with the PLD chips and that with IPs was more than 40%. This discrepancy partly comes from the absorption of the X-rays by the IPs, which was estimated to be 7.7% at a tube voltage of 80 kV, since the PLD chips were placed on the reverse side of the IP sheet against the X-ray generator. It also comes from a variation of sensitivity of the PLD chip, whose sensitivity depends on the direction from which the X-rays are incident on a PLD chip. The X-rays come from the direction along a long axis of a PLD chip have about 60% of the sensitivity of those come from the direction along a short axis[7,8] when tube voltages are 50, 80, 100, and 140 kV. An area including peak skin dose (PSD) can be easily recognized visually by variations of PSL density in Fig. 3(a), however, the PSD area cannot be recognized from the results obtained by discrete numbers of PLD chips.

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Table 1. Comparison of entrance skin dose, ESD (mGy) of patient 2 at the same point obtained by the PLD chips and the IPs.

Measuring Points	ESD obtained by 5 PLD chips (mGy)	ESD obtained by IPs (mGy)
1	16.66 ~ 21.23	19.99 ~ 22.51
2	14.87 ~ 17.85	18.49 ~ 19.79
3	5.37 ~ 6.41	10.29 ~ 10.86
4	389.91 ~ 992.88	398.12 ~ 1,124.83
5	113.50 ~ 134.96	94.43 ~ 192.01
6	12.99 ~ 13.68	19.01 ~ 21.23
7	990.29 ~ 1,029.60	1,099.08 ~ 1,602.81
8	265.54 ~ 429.47	444.75 ~ 679.27
9	113.89 ~ 216.8	115.46 ~ 260.57
10	12.46 ~ 13.22	17.56 ~ 19.27

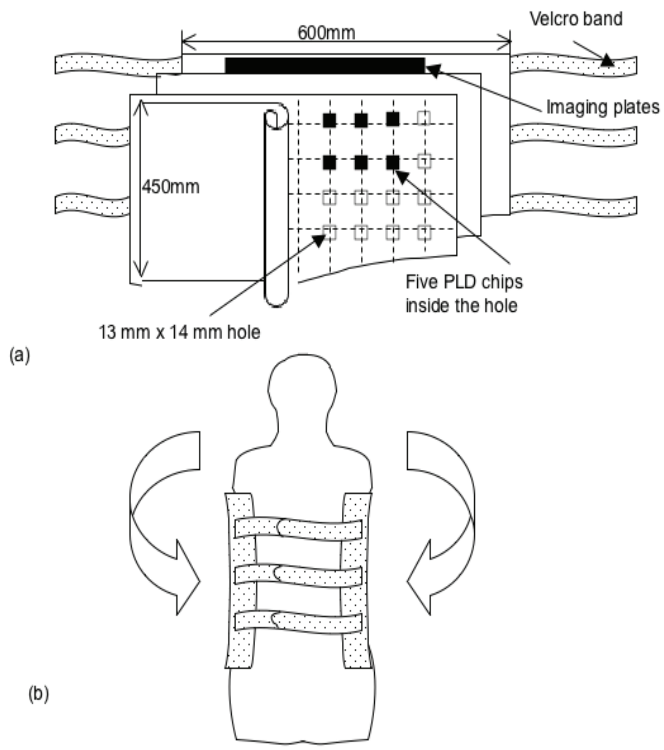

Figure 1. (a) Structure of the corset and an arrangement of IP sheet and Photoluminescence glass dosemeter (PLD) chips. (b) Patient's body are held by fastening the ends of Velcro bands together. It can be easily worn and fit to the body.

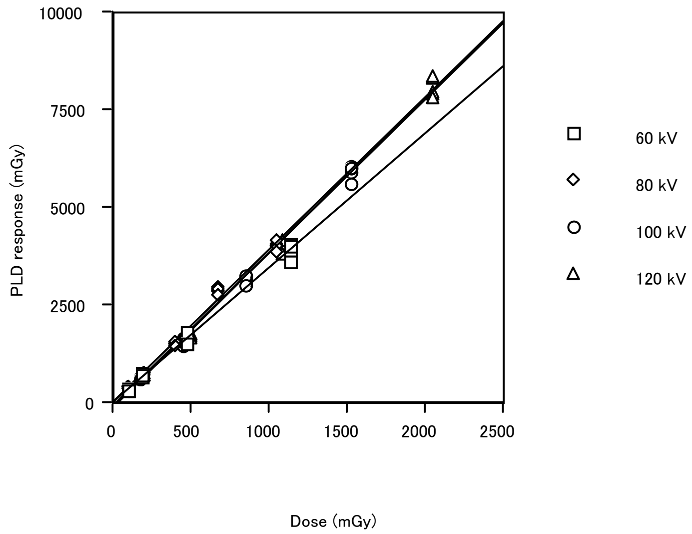

Figure 2. PLD chip dose-response relations on the acrylic phantom for the tube of 60, 80, 100, and 120 kV.

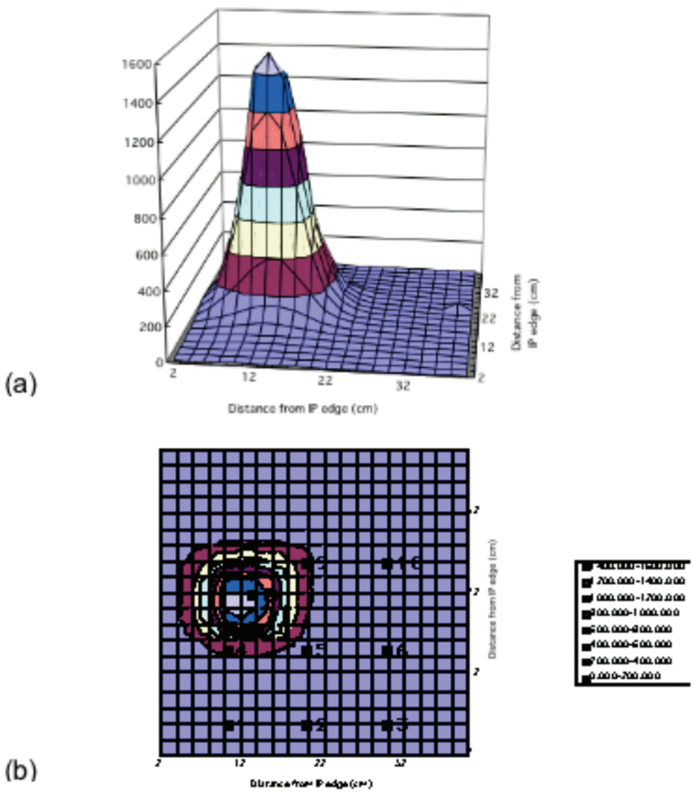

Figure 3. Contour dose map of patient 2 obtained by scanning of IPs. (a) 3-D map. (b) 2-D map. Ten measuring points were selected for dose monitoring with PLD chips. For each point, five PLD chips were placed.