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Technical note

Real-time patient radiation dosimeter for use in interventional radiology

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ABSTRACT

There is currently no effective real-time patient dosimeter available for use in interventional radiology (IR). We conducted a feasibility study in a clinical setting to investigate the use of the new dosimeter using photoluminescence sensors during procedures. Reference dosimeters were set at almost the same position of the prototype dosimeter sensors.

We found excellent correlations between the reference measurements and those of the prototype dosimeter ($r^2 = 0.950$). The sensor of the new dosimeter does not interfere with the IR procedure. The new dosimeter will be an effective tool for the real-time measurement of patient skin doses during IR.

1. Introduction

Although numerous patients have benefited greatly from interventional radiology (IR), radiation-induced skin injuries (deterministic effects) have been reported following IR procedures [1–12]. Therefore, the real-time monitoring of patient radiation doses is essential for avoiding radiation-induced skin injuries [13–20]. To protect against radiation-induced skin injury, the maximum radiation skin dose (MSD) should be monitored in real-time. When more than one effective working view is available, a combination of different viewing angles and real-time MSD monitoring can be used to prevent the delivery of excessive radiation to any particular skin area, thereby reducing the risk of radiation-induced skin injury. On the other hand, passive dosimeters (including films and thermoluminescent dosimeters [TLDs]) do not monitor radiation doses in real-time. However, there is currently no effective real-time patient dosimeter available for use in IR [21].

Although skin dose monitors (SDMs; McMahon Medical, San Diego, CA, USA) were previously used for the real-time measurement of patient radiation doses, they are no longer produced because they contained zinc-cadmium phosphor (red-emission phosphor), which is a toxic substance [21]. Patient skin dosimeters (PSD; Unfors Co., Ltd., Billdal, Sweden) can also measure patient doses in real-time. However, the PSD sensor and cable are markedly visible on fluoroscopic images, thus seriously impeding IR. Therefore, PSD cannot be used in IR [21]. In light of this, new technologies that enable real-time monitoring of the radiation dose received by IR patients are required. The development of a novel real-time patient radiation dosimeter for use during IR is the logical next step.

In a previous study, we found that Y_2O_2S:Eu,Sm phosphor is a suitable red-emission phosphor that is nontoxic and exhibits relatively high sensitivity [22]. Furthermore, we manufactured a novel (prototype) real-time patient dosimeter that utilizes this nontoxic phosphor for IR and reported on its basic performance [23]. Our results indicated that the prototype dosimeter provided good fundamental performance, although no clinical trial data exists. We therefore conducted a feasibility study in a clinical setting (coronary angiography; CAG, catheter ablation; ABL, percutaneous coronary intervention; PCI) to investigate the use of the prototype dosimeter during procedures.

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2. Patients and methods

2.1. Patients

This study included 63 patients (26 CAG, 30 ABL, 7 PCI) and was conducted at the Research Institute for Brain & Blood Vessels-Akita (Akita, Japan). The patients were selected at random and consisted of 48 males and 15 females (Table 1). This was a single-institution study and was approved by the local Committee on Human Research.

2.2. X-ray equipment

The main angiography X-ray unit used in this study was a digital cine single-plane system (Infinix-Celeve-I; Toshiba, Japan) with a 7-inch mode flat-panel detector. Digital cine acquisition was performed at 15 frames/s. Pulsed fluoroscopy was performed at 7.5 or 15 pulses/s.

We used six standard tube angulations in our clinical setting for CAG: left anterior oblique (LAO) 50° view, LAO 20° + craniocaudal (caudal) 30° view, LAO 30° + caudocranial (cranial) 20° view, right anterior oblique (RAO) 30° view, RAO 10° view + caudal 30° view, and RAO 10° view + cranial 30° view. ABL was mainly performed using RAO 30° and LAO 50° views. By contrast, the angles and views used while performing PCI were inconstant.

2.3. Dosimetry

The prototype real-time dosimeter consists of photoluminescence sensors (nontoxic phosphor, maximum of four sensors), an optical fiber cable, a photodiode, and a digital display that includes the power supply [23]. The Y_2O_2S:Eu,Sm phosphor is used in prototype dosimeter sensors [23]. Y_2O_2S:Eu,Sm is nontoxic and exhibits relatively high sensitivity [23].

Patient dose measurements obtained with the prototype real-time dosimeter were compared with measurements obtained using a calibrated reference dosimeter. We used radiophotoluminescence glass dosimeters (RPLDs) as the reference dosimeter [24–26]. The measurement/readout system used for the RPLDs (sensor, GD-302M; Asahi Techno Glass, Tokyo, Japan) was the DoseAce FGD-1000 (Chiyoda Technol Corp., Tokyo, Japan). The calibration factor of the RPLD used in this study was 0.311, based on a calibration experiment conducted in air using a thimble-type 6-ml ion-chamber (model-9015; Radcal Corp., Monrovia, CA, USA; traceable from the national standard exposure dose).

We examined the measured radiation skin dose using three or four sensors of the prototype real-time dosimeter, arbitrarily positioned at the left and/or right, upper and/or lower back skin of each patient. Reference dosimeters were set at almost the same position (within 1 cm) of the prototype real-time dosimeter sensors. Both sensors (the RPLD and the prototype dosimeter) are sensitive to backscattered radiation. Thus, the doses measured in clinical settings by both sensors are equivalent to the skin doses.

We also interviewed physicians regarding the visibility (i.e., whether the view was impeded) of the radiographic images, which contained the prototype dosimeter sensors.

The relationship between the reference measurements and the prototype dosimeter measurements was analyzed using linear regression.

3. Results

Fig. 1 shows the correlations between the RPLDs measurements and the prototype dosimeter measurements ($r^2 = 0.950$). It shows that there is a clear correlation between both sets of measure-

Table 1
Summary of the patient characteristics (mean ± standard deviations where applicable).

	Total	CAG	ABL	PCI
Number of patients	63	26	30	7
Age (years)	62.1 ± 13.0	67.1 ± 12.6	55.4 ± 10.8	72.6 ± 7.0
Male/Female	48/15	22/4	22/8	4/3
Height (cm)	164.9 ± 9.9	163.9 ± 9.3	168.0 ± 8.8	154.8 ± 10.1
Weight (kg)	67.2 ± 12.8	65.6 ± 13.0	70.5 ± 12.2	58.3 ± 10.9
Fluoroscopic time (min)	22.0 ± 14.2	10.3 ± 6.2	30.0 ± 11.7	31.2 ± 15.8
Dose area product (Gy*cm^2)	70.9 ± 57.6	33.5 ± 23.8	97.6 ± 62.7	95.1 ± 50.8

CAG, coronary angiography; ABL, catheter ablation; PCI, percutaneous coronary intervention.

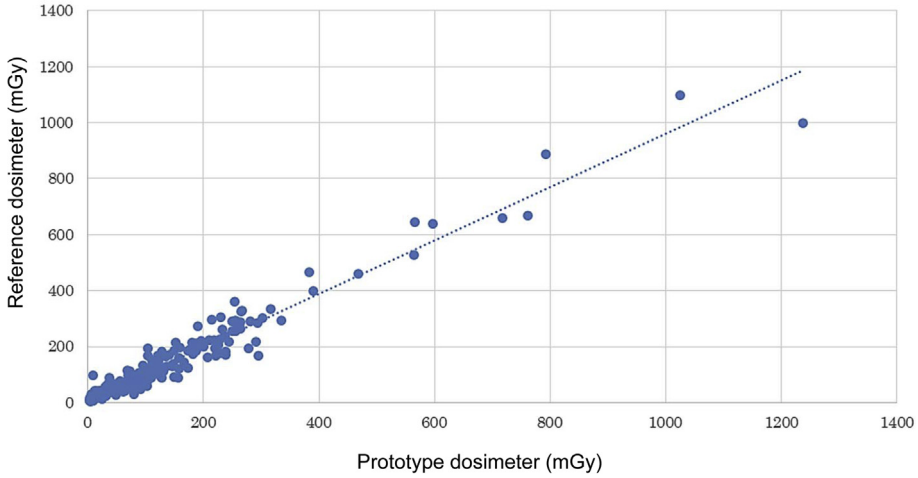

Figure 1. Relationship between the reference dosimeter (radiophotoluminescence glass dosimeter; RPLD) measurements of the patient radiation dose and those of the prototype dosimeter in a clinical setting. ($R^2 = 0.950$, $y = 0.9529x + 6.862$).