Total Entrance Skin Dose: An Effective Indicator of Maximum Radiation Dose to the Skin During Percutaneous Coronary Intervention

Koichi Chida[1]
Yutaka Kagaya[2]
Haruo Saito[1]
Yoshihiro Takai[1]
Shoki Takahashi[3]
Shogo Yamada[3]
Masahiro Kohzuki[4]
Masayuki Zuguchi[1]

OBJECTIVE. A number of cases of radiation-associated patient skin injury during percutaneous coronary intervention (PCI) have been reported. To protect against this complication, maximum skin dose to the patient should be monitored in real time. Unfortunately, in most cardiac intervention procedures, real-time monitoring of maximum skin dose is not possible. Angiographic X-ray units, however, display the patient's total entrance skin dose in real time. We therefore investigated the relation between maximum skin dose and total entrance skin dose to determine whether total entrance skin dose can be used to estimate maximum skin dose during PCI.

MATERIALS AND METHODS. The dose–area product was measured, and maximum skin dose and total entrance skin dose were calculated with a skin-dose-mapping software program. The target vessels of 194 PCI procedures were divided into four groups according to the American Heart Association (AHA) segment system.

RESULTS. The maximum skin dose constituted 48%, 52%, 50%, and 52% of the total entrance skin dose during PCI on AHA segments 1–3, 4, 5–10, and 11–15, respectively. There were significant correlations between maximum skin dose and total entrance skin dose during PCI ($r = 0.894$, 0.935, 0.859, and 0.898 for segments 1–3, 4, 5–10, and 11–15, respectively; $p < 0.001$).

CONCLUSION. Maximum skin dose during PCI is approximately 50% of the total entrance skin dose for each target vessel. Correlation between the two doses was very good. Total entrance skin dose is an effective predictor of maximum skin dose during PCI when the formula used is maximum skin dose = 0.5 × total entrance skin dose. Our results provide useful information for avoiding deterministic radiation skin injury to patients undergoing PCI.

Keywords: angiography, angioplasty, catheterization, coronary artery disease, radiation dose

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[1]Department of Radiological Technology, School of Health Sciences, Faculty of Medicine, Tohoku University, 2-1 Seiryo-machi, Aoba-ku, Sendai 980-8575, Japan. Address correspondence to K. Chida (chida@mail.tains.tohoku.ac.jp).

[2]Department of Cardiovascular Medicine, Tohoku University Graduate School of Medicine, Sendai, Japan.

[3]Department of Radiology, Tohoku University Graduate School of Medicine, Sendai, Japan.

[4]Department of Internal Medicine and Rehabilitation Science, Tohoku University Graduate School of Medicine, Sendai, Japan

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One of the most important problems in percutaneous coronary intervention (PCI) is the risk of radiation skin injury to the patient. Prolonged irradiation can result in absorbed radiation doses that exceed the safe threshold for skin [1]. To protect against this complication, the maximum skin dose to the patient should be monitored in real time [1]. When more than one effective working view is available, a combination of viewing angles and real-time monitoring of the maximum skin dose can be used to prevent any one skin area from receiving excess radiation and thereby reduce the risk of skin injury. Unfortunately, in most cardiac intervention procedures, real-time monitoring of maximum skin dose is not possible. In previous work, we investigated the relation between maximum skin dose and fluoroscopic time, dose–area product (DAP), and body weight [2, 3].

Angiographic X-ray units such as the PEMNET system (Clinical Microsystems) can display a patient's total entrance skin dose in real time and display the dose at the interventional reference point (IRP) [4, 5]. However, correlation between maximum skin dose and total entrance skin dose has not been examined in detail. We therefore investigated the relation between maximum skin dose and total entrance skin dose to determine whether total entrance skin dose can be used to estimate maximum skin dose during PCI.

Materials and Methods

Radiation Dose Measurement and PCI

The methods used to evaluate skin radiation dose and the PCI procedures have been described previously [2, 3]. Briefly, PCI was performed with a digital cine X-ray system with 17-cm mode image intensifiers, an acquisition rate of 15 frames/s, and pulsed fluoroscopy (15 pulses/s). A single-plane imaging system was used, except in cases of chronic total occlusion. Variable angles and views were used during the procedures. DAP was measured, and maximum skin dose and total entrance skin dose

TABLE 1: Summary of Study

Variable	Overall Value	Value for Target Vessel of Percutaneous Coronary Intervention (American Heart Association Segment No.)			
		5–10	11–15	1–3	4
n	194	69	70	36	19
Total entrance skin dose (mGy)	2,885 ± 2,049	2,674 ± 1,750	3,075 ± 2,070	3,144 ± 2,499	2,460 ± 2,064
Maximum skin dose (mGy)	1,460 ± 992	1,338 ± 953	1,609 ± 1,011	1,499 ± 1,044	1,285 ± 948
Dose–area product (cGy × cm^2)	15,607 ± 10,676	15,843 ± 10,547	15,146 ± 9,540	15,737 ± 11,031	16,206 ± 14,657
r (total entrance skin dose vs maximum skin dose)[a]	0.885	0.859	0.898	0.894	0.935
r (total entrance skin dose vs dose–area product)[a]	0.867	0.833	0.881	0.922	0.989

[a]All correlations are $p < 0.0001$.

were calculated with a skin-dose-mapping software program (CareGraph, Siemens Medical Solutions) [2, 3, 6]. In the algorithm of the program, factors used to calculate skin dose include measured DAP and radiographic parameters such as collimation size, focus-to-skin distance, catheter table position, and angle view of the image intensifier [2, 6].

Subjects

This retrospective study was performed at a single institution. We studied 194 PCI procedures that involved a single target vessel (Table 1). The subjects were 153 men and 41 women. Of the PCI procedures, 139 involved the left coronary artery and 55 the right coronary artery. The mean patient age was 68.7 ± 9.4 (SD) years, and the mean body weight was 60.2 ± 10.0 kg. The subjects had participated in our previous study [3]. Three patients were excluded from analysis because the software did not display the total entrance skin dose. Three cardiologists performed PCI using the same protocol, indicating that the difference in operators had almost no influence on the results.

Statistics

The PCI target vessels were divided into four groups according to the American Heart Association (AHA) classification: segments 5–10, segments 11–15, segments 1–3, and segment 4. Total entrance skin dose, DAP, and maximum skin dose were recorded for each patient. Correlations between total entrance skin dose and maximum skin dose or DAP were analyzed with linear regression. The *p* value was obtained by analysis of variance, and statistical significance was defined as $p < 0.05$.

Results

The results are summarized in Table 1. The maximum skin dose constituted 48%, 52%, 50%, and 52% of the total entrance skin dose during PCI on AHA 1–3, 4, 5–10, and 11–15, respectively. Figures 1–4 plot the relation between maximum skin dose and total entrance skin dose during PCI for each target vessel group. There were significant correlations between maximum skin dose and total entrance skin dose during PCI for all segments ($r = 0.894$, 0.935, 0.859, and 0.898 for segments 1–3, 4, 5–10, and 11–15, respectively). The *r* value for correlation between maximum skin dose and total entrance skin dose in this study was higher than that for DAP or the product of patient weight and fluoroscopic time in our previous study [3].

Discussion

Many skin injuries caused by excessive radiation exposure during cardiac intervention procedures have been reported [1, 7–9]. To reduce the risk of skin injury, it is important to understand the details of the radiation dose experienced by patients undergoing PCI [10, 11]. Total entrance skin dose is a measure of a patient's risk of a stochastic effect, such as radiation-induced cancer. To our knowledge, no study has examined the relation between maximum skin dose and total entrance skin dose during PCI. We found a highly significant correlation, although the *r* value was somewhat lower for AHA segments 5–10 (left anterior descending coronary artery domain) than for the other segments. Furthermore, the *r* value for the correlation between maximum skin dose and total entrance skin dose in this study was higher than that between maximum skin dose and the product of patient weight and fluoroscopic time or DAP in our previous study [3].

We found the maximum skin dose was approximately 50% of the total entrance skin dose during PCI and that the percentage was similar for all four groups of target vessels. In other words, total entrance skin dose is twice the maximum skin dose. Therefore, if the total entrance skin dose is 4 Gy, it is likely that the threshold of transient erythema (2 Gy) has been crossed. That is, when total entrance skin dose is greater than 4 Gy, the physician should alter the radiographic projection so that the dose to the patients is distributed over more than one skin entrance port. This step should reduce the risk of a deterministic effect.

Total entrance skin dose appears to be a very good indicator of maximum skin dose and can be used to predict the risk of skin injury during PCI. To reduce the risk of both stochastic and deterministic effects, we recommend that physicians record the total entrance skin dose, when it can be monitored, to estimate maximum skin dose. If the total entrance skin dose cannot be monitored, however, physicians cannot avoid using rough predictors of maximum skin dose, such as fluoroscopic time.

The PEMNET system can display total entrance skin dose, although only on Philips Medical Systems X-ray machines [4]. Modern angiographic X-ray systems can display the dose at the IRP, which can be used to estimate total entrance skin dose, although the correlation between dose at the IRP and total entrance skin dose during PCI is not clear [9]. Miller et al. [12] reported good correlation between maximum skin dose and dose at the IRP ($r = 0.862$), although that study did not include cardiac interventional procedures. Further study of the relation between dose at the IRP and total entrance skin dose or maximum skin dose during PCI is necessary. Nevertheless, it is thought that doses at the IRP and total entrance skin dose are roughly identical, so 50% of the dose at the IRP may be the maximum skin dose.

The DAP for a procedure has been called a surrogate measurement of the total amount of X-ray energy delivered to a patient [1, 9]. We found good correlation ($p < 0.001$) between total entrance skin dose and DAP during PCI (Table 1). DAP, however, is expressed in Gy × cm^2, a unit difficult to use in the evaluation of maximum skin dose. Although total entrance skin dose can be estimated from the measured DAP, this measurement requires

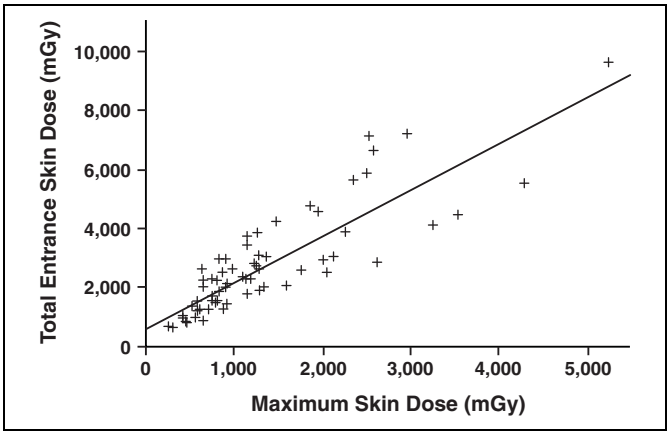

Fig. 1—Graph shows relation between maximum patient skin dose and total entrance patient skin dose in percutaneous coronary intervention on American Heart Association segments 5–10 ($r = 0.859$).

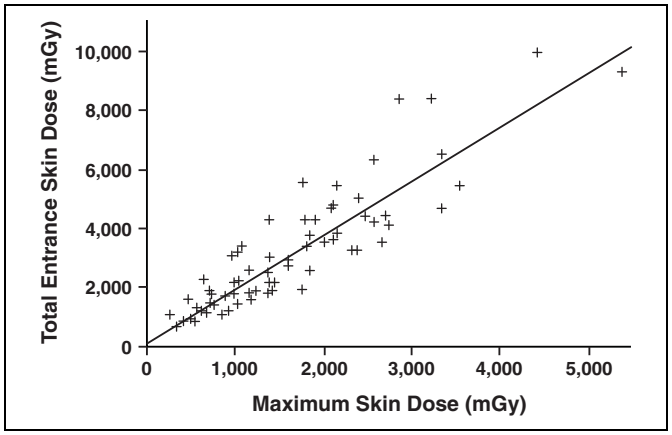

Fig. 2—Graph shows relation between maximum patient skin dose and total entrance patient skin dose in percutaneous coronary intervention on American Heart Association segments 11–15 ($r = 0.898$).

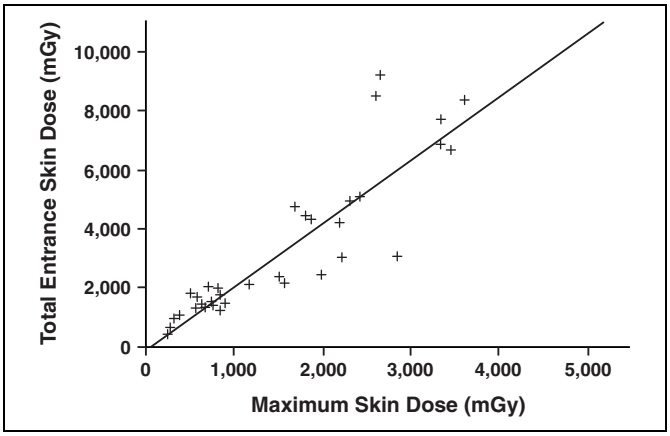

Fig. 3—Graph shows relation between maximum patient skin dose and total entrance patient skin dose in percutaneous coronary intervention on American Heart Association segments 1–3 ($r = 0.894$).

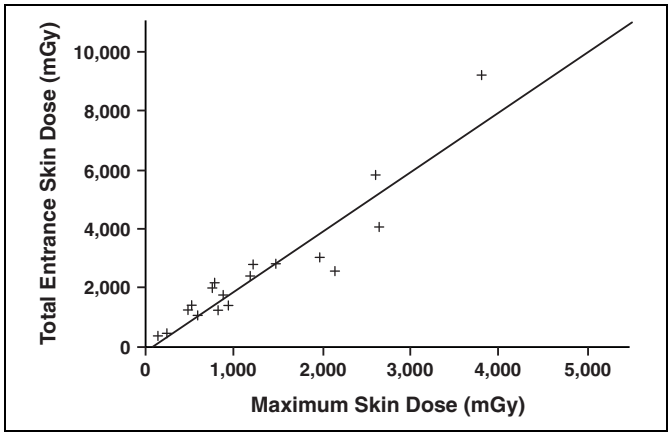

Fig. 4—Graph shows relation between maximum patient skin dose and total entrance patient skin dose in percutaneous coronary intervention on American Heart Association segment 4 ($r = 0.935$).

the use of many factors, such as field size, focus to image intensifier distance, and focus-to-skin distance. These requirements make it difficult to calculate maximum skin dose in real time during PCI.

We investigated the relation between maximum skin dose and total entrance skin dose to determine whether total entrance skin dose can be used for estimation of maximum skin dose during PCI. There was significant correlation between maximum skin dose and total entrance skin dose during PCI, especially when the target vessels were AHA segments 1–3, segment 4, and segments 11–15. Maximum skin dose was approximately 50% of total entrance skin dose for each target vessel. In other words, total entrance skin dose is twice the maximum skin dose. Total entrance skin dose is an effective predictor of maximum skin dose during PCI with use of the formula maximum skin dose = 0.5 × total entrance skin dose, when it can be monitored. Real-time monitoring of maximum skin dose is unavailable for most PCI procedures. Therefore, our results provide useful information for avoiding deterministic radiation skin injuries to patients undergoing PCI. Because our study was conducted at a single institution, further validation is needed.

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