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Indicators of the Maximum Radiation Dose to the Skin During Percutaneous Coronary Intervention in Different Target Vessels

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Objectives: To evaluate whether the maximum radiation dose to the patient's skin (MSD) can be estimated during percutaneous coronary intervention (PCI) procedures, we investigated the relationship between the MSD and fluoroscopic time, dose-area product (DAP), and body weight, separately analyzing the relationships for different target vessels. Background: Many cases of skin injury caused by excessive radiation exposure during cardiac intervention procedures have been reported. However, real-time maximum-dose monitoring of the skin is unavailable for many cardiac intervention procedures. Methods: We studied 197 consecutive PCI procedures that involved a single target vessel and were conducted. The DAP was measured, and the MSD was calculated by a skin-dose mapping software program (Caregraph). The target vessels of the PCI procedures were divided into four groups based on the AHA classification system: AHA 5–10, left anterior descending artery domain (LAD), AHA 11–15, left circumflex artery domain (LCx), AHA 1–3 = R 1–3, and AHA 4 = R 4. Results: The correlation coefficient (*r*) between the MSD and fluoroscopic time was higher for the right coronary artery (RCA) vessels (R 1–3, 0.852; R 4, 0.715) than for the left coronary artery (LCA) vessels (LAD, 0.527; LCx, 0.646), and the *r* value between the MSD and DAP was higher for the RCA vessels (R 1–3, 0.871; R 4, 0.898) than for the LCA vessels (LAD, 0.628; LCx, 0.694). Similarly, the correlation coefficient between the MSD and weight × fluoroscopic time (WFP) was higher for the RCA vessels (R 1–3, 0.874; R 4, 0.807) than for the LCA vessels (LAD, 0.551; LCx, 0.735). Conclusions: The DAP and WFP can be used to estimate the MSD during PCI in the RCA but not in the LCA, especially the LAD.

Key words: catheterization; coronary intervention; angiography; patient radiation exposure; coronary diseases

INTRODUCTION

Cardiac intervention procedures have lower risks than surgical procedures, and their wide acceptance has led to an increasing number being performed [1,2]. Consequently, cardiac intervention procedures, such as percutaneous coronary intervention (PCI), have become common [3]. Although patients greatly benefit from these procedures, a primary disadvantage associated with cardiac intervention procedures is patient radiation exposure [4–9]. The area of skin that receives the maximum dose during intervention procedures is the site most vulnerable to injury because radiation-associated skin injuries, deterministic effects of radiation, are caused by prolonged irradiation resulting in absorbed radiation doses that exceed the threshold for affecting skin [10]. Many cases of skin injury caused by excessive radiation exposure during cardiac intervention procedures have been reported [11–16]. To reduce the risk of skin injury, it has been sug-

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TABLE I. The Characteristics of Our Study

		Target vessel			
	Total	LAD	LCx	R 1–3	R 4
N	197	69	72	36	20
No. of CTO	25	5	13	5	2
Age (years)	68.7 ± 9.4	66.9 ± 9.7	69.3 ± 8.9	69.4 ± 11.4	71.5 ± 4.7
Weight (kg)	60.1 ± 9.9	60.0 ± 10.2	60.4 ± 10.4	59.9 ± 8.5	59.7 ± 10.2
M/F	155/42	57/12	59/13	26/8	11/9
F. time (min)	38.4 ± 22.5	40.3 ± 23.5	39.6 ± 20.3	39.6 ± 26.3	25.9 ± 14.8
No. cine runs	35.7 ± 17.8	38.1 ± 17.9	33.4 ± 15.1	39.4 ± 23.5	28.5 ± 11.0
DAP (cGy cm^2)	15481.6 ± 10642.7	15843.1 ± 10546.7	14932.2 ± 9492.7	15737.1 ± 11031.3	15753.0 ± 14409.5
MSD (mGy)	1459.6 ± 985.0	1337.9 ± 953.2	1603.0 ± 999.6	1499.0 ± 1043.8	1292.1 ± 922.8

Values given are represented as average ± SD.
F. time, total fluoroscopic time; DAP, dose area product; MSD, maximum patient skin dose.

TABLE II. The Correlations (*r*) Between the Maximum Radiation Dose to the Patient's Skin (MSD) and the Analyzed Factors

			Target vessel							
	Total	*P*	LAD	*P*	LCx	*P*	R 1–3	*P*	R 4	*P*
Weight	0.290	<0.0001	0.083	0.496	0.465	<0.0001	0.286	0.091	0.348	0.132
F. time	0.641	<0.0001	0.527	<0.0001	0.646	<0.0001	0.852	<0.0001	0.715	<0.001
DAP	0.712	<0.0001	0.628	<0.0001	0.694	<0.0001	0.871	<0.0001	0.898	<0.0001
WFP	0.700	<0.0001	0.551	<0.0001	0.735	<0.0001	0.874	<0.0001	0.807	<0.0001

F. time, total fluoroscopic time; DAP, dose area product; MSD, maximum patient skin dose.

gested that physicians track the radiation dose of patients undergoing these procedures [10,17]. However, real-time maximum-dose monitoring of the skin is unavailable for many cardiac intervention procedures.

We previously reported a relationship between the maximum radiation dose to the patient's skin (MSD) and fluoroscopic time, dose-area product (DAP), and body weight in cardiac intervention procedures [18]. To evaluate whether the MSD can be estimated during PCI procedures, we investigated the relationship between the MSD and several factors in approximately 200 patients, analyzing the relationships for different target vessels separately.

MATERIALS AND METHODS

Patients

We studied 197 consecutive PCI procedures that involved a single target vessel: 141 of the cases involved the left coronary artery (LCA) and 56 involved the right coronary artery (RCA). Table I summarizes the characteristics of the 197 patients (155 men, 42 women; average age: 68.7 ± 9.4 years, range: 37–86 years). Ninety-eight of the PCI procedures were performed to insert stents, and 25 patients had chronic total occlusion (CTO).

Measurement of Radiation Dose

The methods used for measuring the skin radiation dose have been described previously [18]. Briefly, the PCI procedures were performed using a digital cine X-ray system (Bicor Plus: Siemens, Erlangen, Germany) with 17 cm mode image intensifiers (I.I.), an acquisition rate of 15 frames/s, and pulsed fluoroscopy (15 pulses/s). A single-plane imaging system was used, except in the CTO cases. Variable angles and views were used while performing the procedures. Three cardiologists performed the PCI, following the protocol for the intervention procedures. Therefore, the variation among operators in this study is likely to have been small. In addition, the physicians take a radiation safety course once a year.

The DAP was measured, and the MSD was calculated by a skin-dose mapping software program (Caregraph; Siemens) [19,20]. The Caregraph measurement (skin dose) was adjusted by comparison with a calibrated, thimble-type, 6 cc ion chamber(model-9015 dosimeter: Radcal, CA) placed at the center of the entrance surface of a 20 cm-thick acrylic phantom, using a 17 cm mode I.I. Therefore, this measurement included backscatter from the acrylic plate. Consequently, when a smaller radiation field (collimation) is used in PCI, the Caregraph measurement will have a small percentage error based on the different amount of backscatter.

Statistics

The target vessels of the PCI procedures were divided into four groups based on the American Heart Association (AHA) classification system: AHA 5–10, left anterior descending artery domain (LAD), AHA 11–15, left circumflex artery domain (LCx), AHA 1–3 = R 1–3, and AHA 4 = R 4. The following data were recorded for each patient: body weight, fluoroscopic time, DAP, double product combined with body weight, weight × fluoroscopic time (WFP), and MSD. Correlations between the MSD and body weight, fluoroscopic time, DAP, or WFP were analyzed using linear regression. The *P*-value was obtained from an analysis of variance, and statistical significance was defined as $P < 0.05$.

RESULTS

Table I shows the body weight, fluoroscopic time, DAP, and MSD values (average ± SD) for the patients in this study. The correlations between the MSD and the factors analyzed are summarized in Table II.

The MSD and body weight were either not correlated or were poorly correlated for all the target vessels (correlation coefficient (r): LAD, 0.083; LCx, 0.465; R 1–3, 0.286; and R 4, 0.348). The r between the MSD and fluoroscopic time was higher for the RCA vessels (R 1–3, 0.852; R 4, 0.715; Figs. 3A and 4A) than for the LCA vessels (LAD, 0.527; LCx, 0.646; Figs. 1A and 2A), and that between the MSD and DAP was higher for the RCA vessels (R 1–3, 0.871; R 4, 0.898; Figs. 3B and 4B) than for the LCA vessels (LAD, 0.628; LCx, 0.694; Figs. 1B and 2B). Similarly, the r between the MSD and WFP was higher for the RCA vessels (R 1–3, 0.874; RCA 4, 0.807; Figs. 3C and 4C) than for the LCA vessels (LAD, 0.551; LCx, 0.735; Figs. 1C and 2C). The MSD had a greater r value for its correlation with the WFP than with the fluoroscopic time alone for each of the target vessels, which agrees with our previous study [18]. For the PCI procedures performed in the LCA, the correlation values between the MSD and the other factors investigated were all lower for the LAD than for the LCx.

DISCUSSION

The biological effects of radiation are of two types: stochastic (such as radiation-induced cancer) and deterministic (such as erythema) [10]. In PCI procedures that are likely to be repeated, both deterministic effects and stochastic effects are possible, especially in younger patients. Currently, however, one of the most important problems in PCI procedures is the occurrence of a deterministic effect of radiation because the number of case reports documenting patient skin injuries from PCI is increasing [12,13,15,16]. Therefore, the MSD should be kept as low as reasonably possible to avoid skin injuries during PCI.

Miller et al. [21] reported similar data to ours but for noncardiac procedures. Previous studies have indicated that fluoroscopic time and DAP values provide rough indications of skin dose in PCI procedures [4,10]. However, few reports have examined the correlations between MSD and the other factors examined

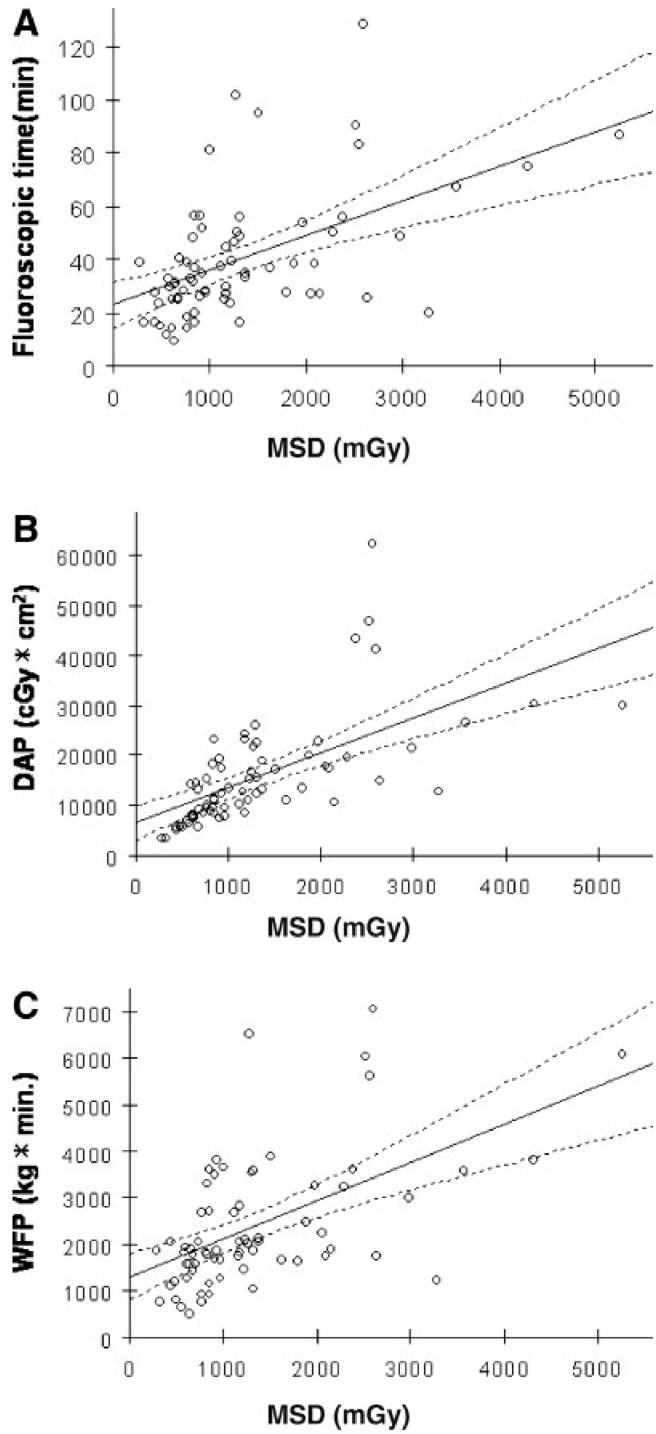

Fig. 1. **(A) Correlation between the maximum patient skin dose (MSD) and fluoroscopic time in PCI (LAD domain, $n = 69$). $r = 0.527$, $p < 0.0001$, $y = 22.86 + 0.013x$. Dashed line (---): 95% confidence interval. (B) Correlation between the maximum patient skin dose (MSD) and the dose-area product (DAP) in PCI (LAD domain, $n = 69$). $r = 0.628$, $p < 0.0001$, $y = 6540.8 + 6.953x$. Dashed line (---): 95% confidence interval. (C) Correlation between the maximum patient skin dose (MSD) and the double product (patient weight × fluoroscopic time: WFP) in PCI (LAD domain, $n = 69$). $r = 0.551$, $p < 0.0001$, $y = 1302.4 + 0.871x$. Dashed line (---): 95% confidence interval.**

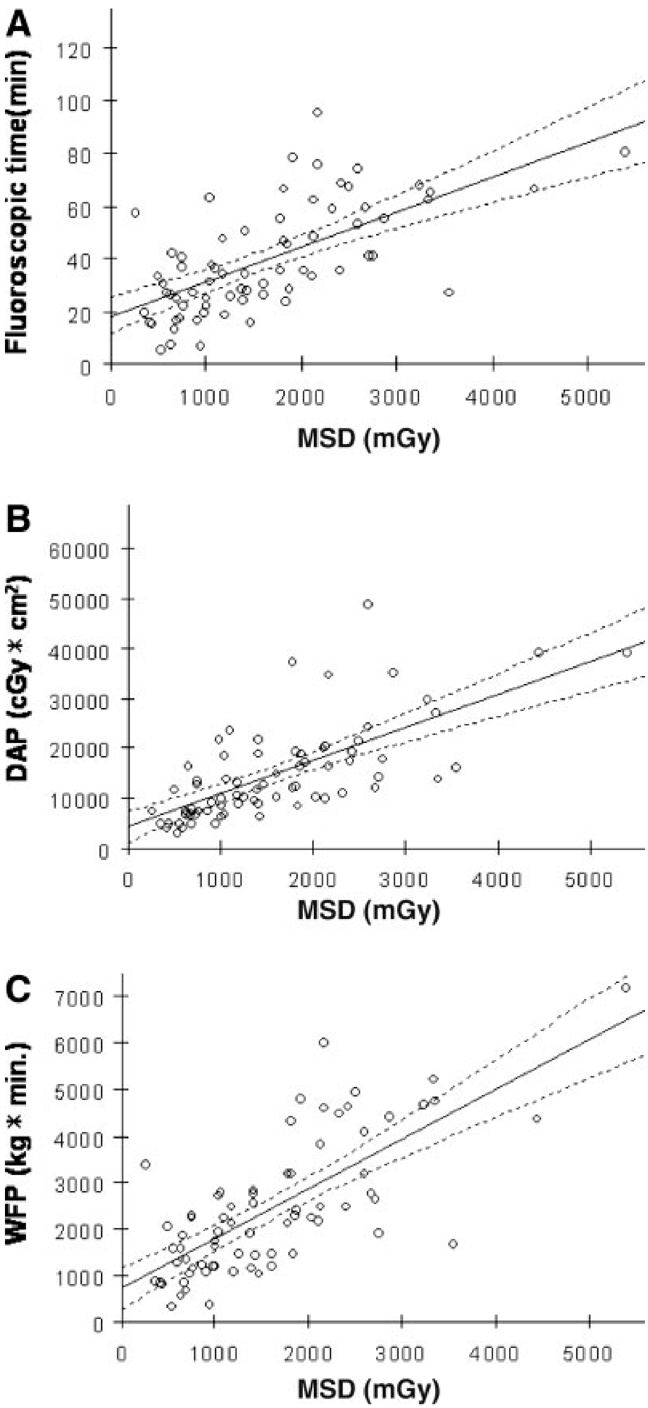

Fig. 2. (A) Correlation between the maximum patient skin dose (MSD) and fluoroscopic time in PCI (LCx domain, $n = 72$). $r = 0.646$, $p < 0.0001$, $y = 18.56 + 0.013x$. Dashed line (---): 95% confidence interval. (B) Correlation between the maximum patient skin dose (MSD) and the dose-area product (DAP) in PCI (LCx domain, $n = 72$). $r = 0.694$, $p < 0.0001$, $y = 4360.5 + 6.595x$. Dashed line (---): 95% confidence interval. (C) Correlation between the maximum patient skin dose (MSD) and the double product (patient weight $\times$ fluoroscopic time: WFP) in PCI (LCx domain, $n = 72$). $r = 0.735$, $p < 0.0001$, $y = 723.6 + 1.073x$. Dashed line (---): 95% confidence interval.

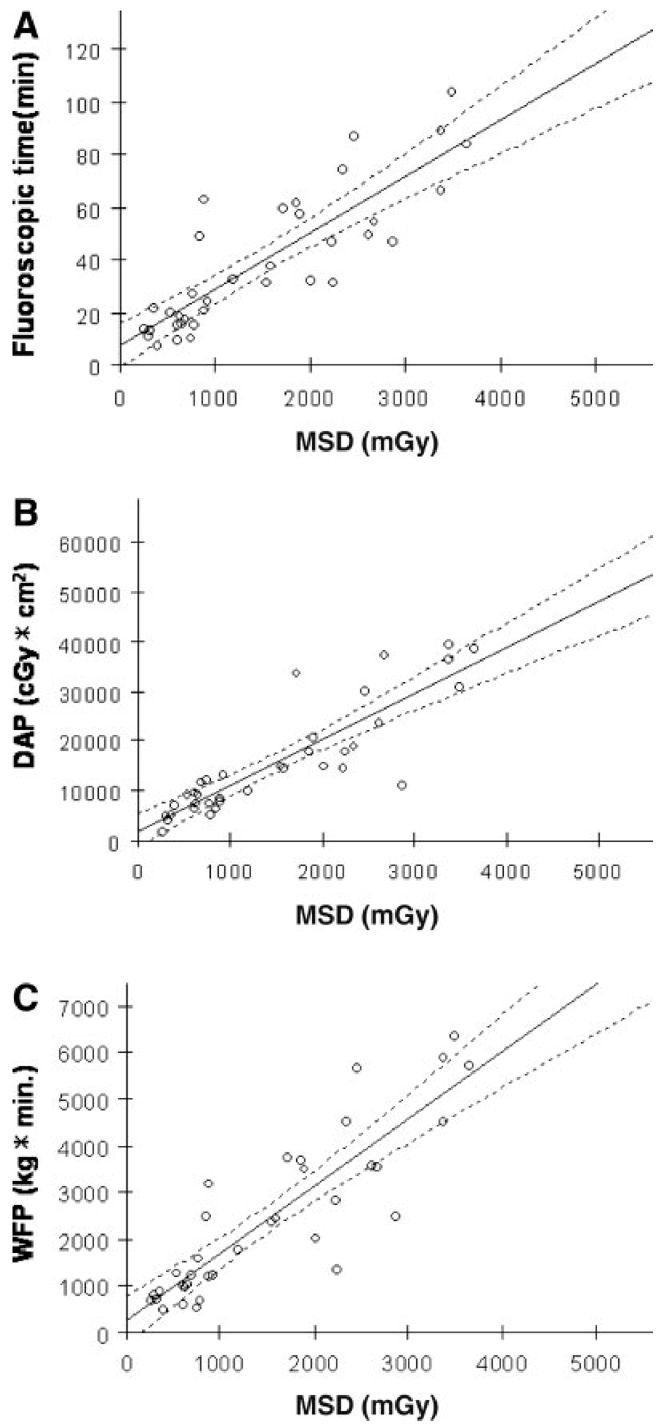

Fig. 3. (A) Correlation between the maximum patient skin dose (MSD) and fluoroscopic time in PCI (RCA 1–3, $n = 36$). $r = 0.852$, $p < 0.0001$, $y = 7.45 + 0.021x$. Dashed line (---): 95% confidence interval. (B) Correlation between the maximum patient skin dose (MSD) and the dose-area product (DAP) in PCI (RCA 1–3, $n = 36$). $r = 0.871$, $p < 0.0001$, $y = 1942.1 + 9.203x$. Dashed line (---): 95% confidence interval. (C) Correlation between the maximum patient skin dose (MSD) and the double product (patient weight $\times$ fluoroscopic time: WFP) in PCI (RCA 1–3, $n = 36$). $r = 0.874$, $p < 0.0001$, $y = 257.5 + 1.441x$. Dashed line (---): 95% confidence interval.

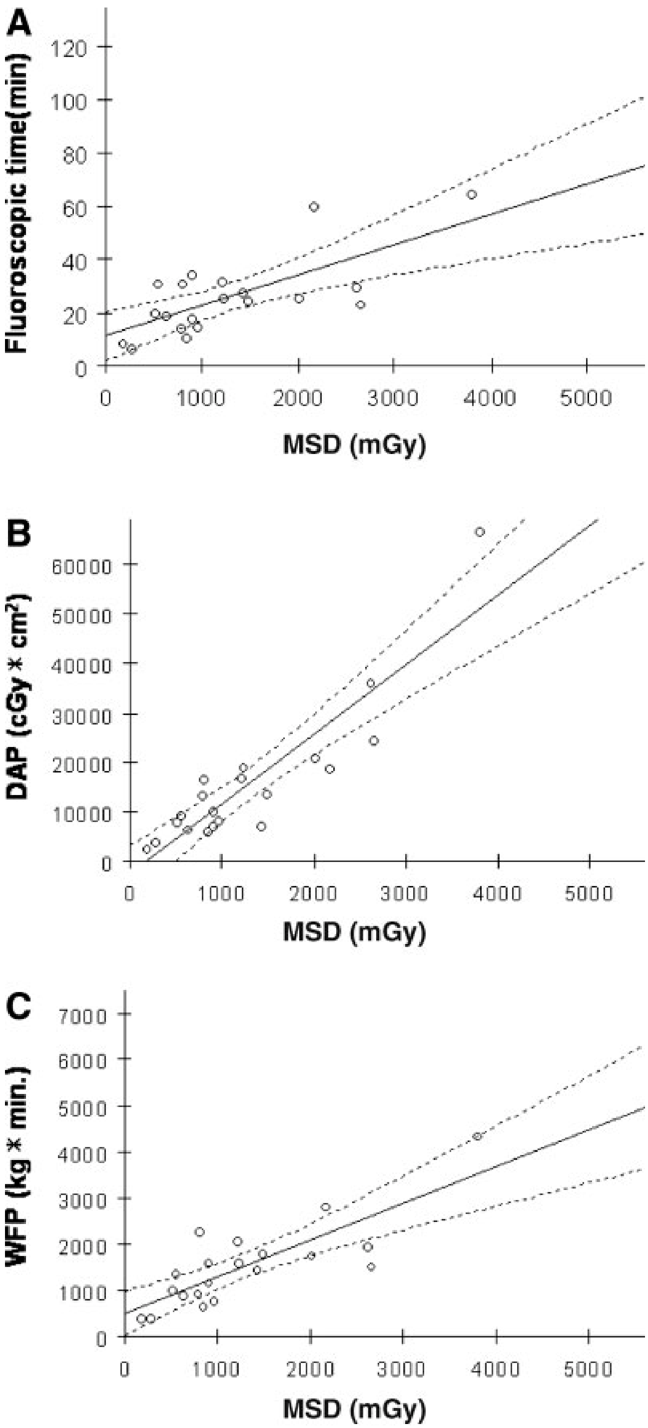

Fig. 4. (A) Correlation between the maximum patient skin dose (MSD) and fluoroscopic time in PCI (RCA 4, n = 20). r = 0.715, p < 0.0001, y = 11.04 + 0.021x. Dashed line (---): 95% confidence interval. (B) Correlation between the maximum patient skin dose (MSD) and the dose-area product (DAP) in PCI (RCA 4, n = 20). r = 0.898, p < 0.0001, y = −2358.9 + 14.017x. Dashed line (---): 95% confidence interval. (C) Correlation between the maximum patient skin dose (MSD) and the double product (patient weight × fluoroscopic time: WFP) in PCI (RCA 4, n = 20). r = 0.807, p < 0.0001, y = 512.8 + 0.795x. Dashed line (---): 95% confidence interval.

here [18,20,22], and, to our knowledge, no study has examined these correlations for different target vessels in PCI. In this study, we investigated the correlation between MSD and patient weight, fluoroscopic time, and DAP during 197 PCI procedures in different target vessels to determine whether any of these factors could be useful for estimating MSD. Our results suggest that DAP and WFP measurements can be good indicators of MSD and could be used as predictors of skin injury risk during PCI in the RCA but not in the LCA.

We found good correlations between the MSD and the fluoroscopic time, DAP, and WFP for the PCI procedures performed in the RCA. In contrast, the correlations between the MSD and the fluoroscopic time, DAP, and WFP were poor for the procedures performed in the LCA, especially in the LAD. The lower correlation coefficients for the LCA when compared with the RCA are likely attributable to the use of a greater number of different angles and views while performing PCI in the LCA when compared with the RCA. This is necessary to accommodate the somewhat complex coronary anatomy (coronary artery branching) of the LCA, especially the LAD, and the associated difficulty of distinguishing the target vessel from other branches while advancing the catheter and guide wire.

The use of a thermoluminescence dosimeter and radiographic film are well-established methods for measuring MSD [22,23], but real-time measurements are not available with these methods. To avoid radiation injury to the skin of patients undergoing interventional procedures, it is important to provide the interventionist with a real-time display of the MSD [10,24]. The Caregraph skin-dose mapping software [18–20] used in this study and the skin dose monitor (SDM) [25] are useful for measuring the MSD in real-time; however, Caregraph and SDM are no longer available because the production and sale of these products ended.

The dose at the interventional reference point (IRP) has been reported to be useful for characterizing patient exposure in real-time [4,26]. However, only very modern X-ray machines display the dose at the IRP, although according to new FDA regulations, all new fluoroscopes sold in the US from May 2006 onward will have a dose at IRP capability. Therefore, the dose at the IRP is not widely used to estimate the MSD yet. In addition, it has been reported that IRP values are overestimates and have a margin of error that may be as much as a factor of two or greater [4].

In summary, we did not find good correlational trends between the MSD and DAP or WFP for the PCI procedures overall (r: 0.712 and 0.700, respectively), but when we separately analyzed the relationships for different target vessels, we did find good correlational trends between the MSD and the DAP or WFP for PCI procedures performed in the RCA (R 1–3: 0.871, 0.874; R 4: 0.898, 0.807, respectively) but not for those in the

LCA (LAD: 0.628, 0.551; LCx: 0.694, 0.735, respectively). Therefore, for estimating the MSD during PCI performed in the RCA, physicians can record the DAP when it can be monitored or the WFP when the DAP cannot be monitored. By contrast, the DAP and WFP provide very rough indications of the MSD during PCI performed in the LCA, especially in the LAD.

Because real-time monitoring of the MSD is unavailable on many X-ray machines, this study provides very useful information regarding reducing the risk of a patient receiving a skin injury during PCI.

CONCLUSIONS

We found good correlations between the MSD and the DAP or WFP for PCI procedures performed in the RCA but not for those in the LCA, especially not the LAD. Therefore, the DAP and WFP may be suitable for estimating the MSD during PCI in the RCA but not in the LCA. This article is important because it will help interventional cardiologists to estimate patients' radiation exposure more accurately.

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