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Clinical Determinants of Radiation Dose in Percutaneous Coronary Interventional Procedures

Influence of Patient Size, Procedure Complexity, and Performing Physician

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Objectives The objectives of this work were to establish the primary clinical determinants of patient radiation dose associated with percutaneous coronary interventional (PCI) and to identify opportunities for dose reduction.

Background Use of X-ray imaging and associated radiation dose is a necessary part of PCI. Potential adverse consequences of radiation dose include skin radiation injury and predicted increase in lifetime cancer risk.

Methods Cumulative skin dose (CSD) (measured in gray [Gy] units) was selected as a measurement of patient radiation burden. Several patient-, disease-, and treatment-related variables, including 15 performing physicians, were analyzed in a multiple linear regression statistical model with cumulative skin dose CSD as the primary end point. The model results provide an estimate of the relative CSD increase (decrease) attributable to each variable.

Results Percutaneous coronary interventions performed on 1,287 male and 540 female patients were included. Median patient age was 68.6 years, median body mass index was 29.7 kg/m^2, and median weight was 88 kg. Median CSD was 1.64 Gy per procedure for male and 1.15 Gy for female patients. Increasing body mass index, patient sex, lesion complexity, lesion location, and performing physician were significantly associated with CSD. Physicians who performed more procedures were associated with lower CSD.

Conclusions Several primary determinants of patient radiation dose during PCI were identified. Along with physician development of radiation-sparing methods and skills, pre-procedure dose planning is proposed to help minimize radiation dose for PCI. (J Am Coll Cardiol Intv 2011;4:336–43)

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Understanding and reducing radiation dose in the coronary interventional practice are important to minimize both the potential for patient skin injury (a deterministic effect) and the predicted cancer risk (a stochastic effect) for patients and physician operators (1). In percutaneous interventional procedures, the tissue that receives the highest radiation dose is the skin (2–7). Other organs also absorb X-ray energy and contribute to patient effective dose. It is assumed that the probability of radiation-induced cancer increases in direct proportion to effective dose (8). Radiation dose reduction for percutaneous coronary intervention (PCI) is particularly important as procedures become more complex, potentially resulting in longer procedures with expanded X-ray imaging requirements.

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The radiation dose received by a patient during an interventional procedure is highly variable and depends on many technical and clinical factors. The technical factors affecting radiation dose are well known and are generally a function of the X-ray beam quality, X-ray geometry, X-ray beam limitation devices, and fluoroscopic and acquisition imaging dose rate settings (4). Clinical- and treatment-related factors that influence patient radiation dose have been described for diagnostic coronary angiography (CA) (9–12) and/or PCI procedures (13–25). Specific investigation of the influence of individual performing physicians and case volume on patient dose is underrepresented in current literature. The purpose of this report is to examine the primary determinants of radiation dose during PCI in a diverse interventional practice that includes several physicians and cardiology trainees.

Methods

PCI procedures. This work is based on retrospective analysis of PCI procedures performed over a 14-month period ending July 2009 and was approved by our Institutional Review Board. All PCI procedures performed over this time were considered. Patients who had not provided medical record research consent or whom also had concomitant peripheral vascular intervention were excluded. Ours is a teaching institution, and procedures were routinely performed by a staff interventional cardiologist and an interventional fellow-in-training. Fellow involvement ranged from assisting to performing the procedure under the direct supervision of a staff physician, though the level of fellow involvement was not recorded and cannot be estimated from this retrospective analysis. For all procedures, a staff physician was present at the procedure table and was responsible for all aspects of the case, including administration of radiation.

The Mayo PCI Registry contains prospectively collected data on all PCIs performed and includes detailed baseline clinical, angiographic, and procedural characteristics. Ten percent of the registry records are audited quarterly by the database supervisor for accuracy and quality control. For each procedure, radiation-monitoring data are recorded in a separate clinical information system. These data are reviewed monthly by our internal Cardiovascular Interventional Labs Radiation Safety Committee.

Cumulative skin dose. Percutaneous coronary interventions were performed using 1 of 7 X-ray systems. The "Type 1" systems (n = 3) have image intensifier detectors and charge-coupled device cameras (Type 1, Integris, Philips Medical Systems, Best, the Netherlands). All Type 1 systems have biplane X-ray and are outfitted with an accessory radiation monitoring system (PEMNET, Clinical Microsystems, Arlington, Virginia) that reports the X-ray exposure in air (in roentgen [R] units) at the location of the patient skin. The "Type 2" systems (n = 4) have flat panel digital detectors (Axiom Artis, Siemens Medical, Erlanger, Germany). Three Type 2 systems have biplane X-ray and all Type 2 systems report the air-kerma (in gray [Gy] units) at the interventional reference point (26). All systems of a given type were configured to result in nominally equal exposure or air-kerma rates.

The exposure in air values (R, Type 1) and the air-kerma values (Gy, Type 2) are both further referred to as total air-kerma ($K_{a,r}$). The procedure total air-kerma values do not include the contribution of X-ray backscatter from the patient on skin dose. Therefore, $K_{a,r}$ values were converted to cumulative skin dose (CSD) (Gy) through multiplication by a measured $K_{a,r}$ to skin dose conversion factor (f) specific to each X-ray plane. The dose conversion factors were measured using a stack of Solid Water phantoms of thickness 15 cm to 40 cm and a 6-cm^3 ionization chamber in conjunction with a calibrated MDH 1015 electrometer (Radcal Corporation, Monrovia, California). It is recognized that other works that address radiation dose for cardiac catheterization procedures have reported air-kerma area product (Gy cm^2) or a similar measurement (10,15–18,20,21,23,24,27–30). In this study, the CSD is used to characterize the radiation dose burden to the patient (25).

Abbreviations and Acronyms

BMI = body mass index
CA = coronary angiography
CABG = coronary artery bypass graft
CI = confidence interval
CSD = cumulative skin dose
CTO = chronic total occlusion
LCX = left circumflex artery
LM = left main artery
PCI = percutaneous coronary intervention
PVD = peripheral vascular disease
STEMI = ST-segment elevation myocardial infarction

The X-ray systems are configured to use frame rates of 15 s^{-1} for both fluoroscopy and cine acquisition imaging. By default, the "normal" (vs. "low" or "high") fluoroscopy dose rate mode was selected. The maximum air-kerma rate of normal fluoroscopy is controlled to be in the range 85 to 95 mGy/min. Although not specifically tracked, observation indicates that the fluoroscopic imaging mode was rarely changed from normal, 15 s^{-1}. The default cine acquisition mode was used for all procedures. Physician operators selected appropriate X-ray fields of view. For a 25-cm-thick Solid Water phantom, typical skin entrance dose rate values for X-ray fluoroscopy and cine acquisition mode imaging are 32 mGy/min and 6.4 mGy/s, respectively. The default stent for the majority of cases is frontal plane imaging, although biplane imaging capability is available for nearly all X-ray systems.

Statistical methods. Many patient, disease, and procedural descriptive variables were screened using a preliminary univariate analysis. The PCI procedures were assigned to 1 of 4 groups defined by CSD quartile. For each variable, the interquartile trend was examined using the Armitage test for categorical variables or with a contrast analysis in conjunction with analysis of variance for continuous variables. Variables that were considered primary descriptors of the patient, coronary disease, or procedure and that demonstrated a significant trend in the quartile analysis ($p < 0.05$) were included in a multiple linear regression model with ln[CSD] as the primary end point. The natural log of CSD was modeled due to the right skewed distribution of CSD. The multiple linear regression model provides a best-fit parameter estimate (beta) for each variable. The relative influence of each variable on cumulative skin dose is e^{beta}, which will be referred to as the "relative CSD increase" associated with each variable. Note that for beta <0, the relative CSD increase is <1.0.

The model was formulated such that the intercept reflects the expected ln[CSD] for a male patient with body mass index (BMI) of 30 kg/m^2 and no comorbidities undergoing PCI on 1 simple lesion (Type A or B1) (31) within either the left anterior descending or right coronary arteries. Independent model variables included the number of complex lesions (Type B2 or C, non–ST-segment elevation myocardial infarction [STEMI], nonchronic total occlusion [non-CTO]) treated per procedure, the number of CTO (non-STEMI) lesions treated, and primary PCI for patients presenting with STEMI. Both BMI and female sex were included to account for the influence of patient size on CSD. Patient history variables included diabetes, prior coronary artery bypass graft (CABG), peripheral vascular disease (PVD), and renal disease. Interventional locations of left circumflex artery (LCX) and the left main artery (LM) were included in the model. The type of X-ray system was included as a variable to minimize bias that might arise from differences in air-kerma rate. Use of the lateral X-ray plane was also included in the model. Finally, each of 15 staff physicians who had primary responsibility for the procedures were included as independent variables. Note that 1 "physician" was a group of 5 visiting physicians who performed 4.4% of the procedures. Secondary analysis was performed to investigate the relationship between the number of procedures performed per physician and physician-specific influence on patient dose.

Results

Summary of patients, procedures, and lesions treated. Of the 1,933 PCI procedures performed during the study period, 1,827 were included in the study. Forty-one combined PCI and vascular procedures were excluded as were 65 PCIs performed on 58 patients who did not consent to have their records used for research. Procedures were performed on 1,287 (70%) male patients and 540 (30%) female patients. Considering all patients, the median age was 68.6 years, BMI was 29.7 kg/m^2, and weight was 88 kg. The median age of female patients (71.7 years) was 4.2 years greater than that of male patients (67.5 years) (Table 1). Although BMI was independent of sex, male patients were larger than female patients, with median weights being 91 kg and 75 kg, respectively. Diagnostic coronary angiography was performed in conjunction with 86% of the procedures. Stents were deployed in 93% of the patients and 85% of the segments treated. Cardiovascular trainee physicians were involved in 97% of the procedures. Additional patient, procedure, and treated lesions summary statistics are provided in Tables 2 and 3.

CSD summary. Air-kerma to skin dose conversion factors (f) were in the range 6.9×10^{-3} to 1.02×10^{-2} Gy/R for the Type 1 systems and 8.1×10^{-4} to 9.8×10^{-4} (Gy/mGy) for the Type 2 systems. For a given X-ray imaging plane, f varied by <6% in the phantom thickness range 15 to 40 cm.

A histogram of CSD values is provided in Figure 1 and CSD is plotted against BMI in Figure 2. The median CSD for male, female, and all patients was 1.64 Gy, 1.15 Gy, and 1.48 Gy, respectively (Table 4). There is a large variation in CSD with the 95th percentile CSD 7.8× greater than the 5th percentile CSD.

Table 1. Statistical Summary of Patient Population

	Median	Mean	25th Percentile	75th Percentile
Age, men, yrs	67.5	66.6	58.1	75.4
Age, women, yrs	71.7	69.9	61.0	79.9
BMI,* men, kg/m^2	29.7	30.6	26.9	33.2
BMI,* women, kg/m^2	29.3	30.4	25.4	34.8
Weight, men, kg	91.0	94.3	82.0	104.0
Weight, women, kg	75.0	78.3	65.0	90.0

*Included as a variable in the multiple linear regression model.
BMI = body mass index.

Table 2. Summary of Patients and Procedures

Men	1,287 (70)
Women	540 (30)
Diabetes	530 (29)
Hypertension	1,438 (83)
Hypercholesterolemia	1,502 (88)
Prior PCI	716 (39)
Prior CABG	388 (21)
Cancer	270 (15)
PVD	179 (10)
Renal disease	70 (4)
Multivessel disease	1,104 (63)
Congestive heart failure	246 (14)
Symptoms at presentation	
STEMI	200 (11)
Stable angina	195 (11)
Unstable angina	915 (50)
Other	517 (28)
Procedural details	
Radial access	156 (9)
Femoral access	1,668 (91)
Concomitant diagnostic CA	1,578 (86)
Segments treated per procedure, n	1.5 ± 0.8
Stents per procedure	1.4 ± 1.0
Fluoroscopy time, min	20.9 ± 13.8

Values are n (%) or mean ± SD. Included as a variable in the multiple linear regression model.
CA = coronary angiography; CABG = coronary artery bypass graft; PCI = percutaneous coronary intervention; STEMI = ST-segment elevation myocardial infarction.

All procedures included use of the frontal X-ray plane and 13.7% also used the lateral plane. The lateral X-ray plane accounted for a median of 40% (mean = 38%, 25th percentile = 12%, 75th percentile = 58%) of the CSD for procedures in which it was used and 7% of the CSD overall. The lateral plane was used in 20% of procedures performed on patients with renal insufficiency compared with 13% of the remaining patients ($p = 0.10$). Fluoroscopic (vs. acquisition) mode imaging accounted for 55% (55%, 43%, 66%) of the CSD.

Table 3. Summary of Lesions Treated

Site of PCI	
LAD	1,053 (38)
RCA	876 (32)
LCX*	598 (22)
LM*	82 (3)
Saphenous vein graft	158 (6)
Lesion type	
A	41 (1.5)
B1	339 (12)
B2*	794 (29)
C*	1,236 (45)
Not specified	95 (33)
STEMI–type not applicable	264 (10)

Values are n (% of lesions). *Included as a variable in the multiple linear regression model. Combined, Type B2 and C lesions represent the complex lesion variable.
LCX = left circumflex artery; LM = left main artery; RCA = right coronary artery; other abbreviations as in Table 2.

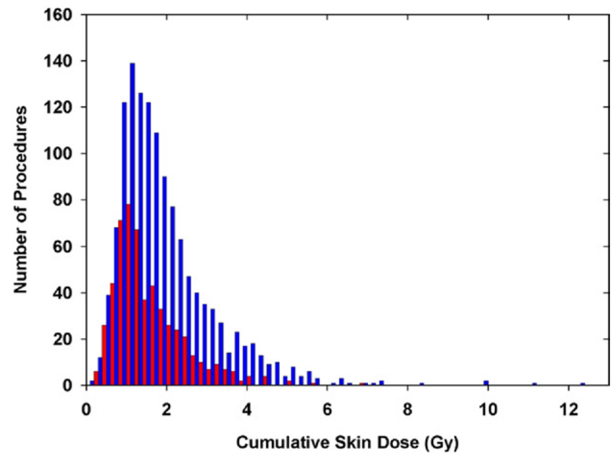

Figure 1. Distribution of the Number of Procedures as a Function of CSD

The distribution of the number of procedures for 1,287 men **(blue)** and 540 women **(red)** studied. The overall distribution is log-normal. CSD = cumulative skin dose.

Model results. For the multiple linear regression model for ln[CSD], inspection of plot residuals (normal quantile plot, and vs. predicted values) did not reveal any violations of the assumptions of model residuals being normally distributed with a common variance. The model intercept, corresponding to the expected dose for the reference male patient with a BMI of 30 kg/m^2, was 1.12 Gy (95% confidence intervals [CI]: 1.05 Gy to 1.19 Gy). The relative CSD increase presented in Figure 3 is the expected relative change in CSD

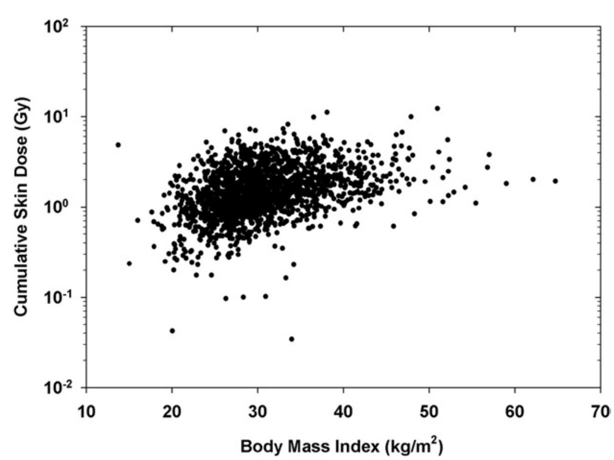

Figure 2. Semi-Log Plot Showing Relationship of CSD to BMI

Semi-log plot demonstrating increased cumulative skin dose (CSD) with increasing body mass index (BMI).

Table 4. Statistical Summary of CSD*

	Median	Mean	25th Percentile	75th Percentile
Men	1.64	1.96	1.12	2.41
Women	1.15	1.39	0.77	1.83
All	1.48	1.79	0.99	2.24

*Cumulative skin dose (CSD) is measured in gray (Gy) units.

when a variable is present during PCI (or when BMI is increased by 5 kg/m^2). The net influence of multiple variables is multiplicative. The statistical model accounted for 42% of the variability in the original ln[CSD] dataset ($r^2 = 0.42$).

Compared with the reference treatment of a single simple lesion (Type A or B1), a treatment of each complex (1.22; 95% CI: 1.18 to 1.25) or CTO (1.42; 95% CI: 1.35 to 1.49) lesion treated is associated with increased dose (Fig. 3). Similarly, primary PCI in STEMI patients (1.09; 95% CI: 1.01 to 1.19) is associated with a modest dose increase. We found that CSD increases with BMI and is presented in Figure 3 as a relative increase in dose (1.23; 95% CI: 1.20, 1.25) for each BMI increment of 5 >30 kg/m^2. Regardless of whether actual patient BMI is > or <30 kg/m^2, the absolute influence of BMI is $1.23^{(BMI - 30)/5}$. In this manner, the expected relative dose increase (or decrease) attributable to BMI can be estimated. Compared with the reference male patient, significantly lower CSD was observed in female patients (0.72; 95% CI: 0.68 to 0.75). The influence of diabetes (1.04; 95% CI: 0.99 to 1.10) and renal disease (0.94; 95% CI: 0.83 to 1.07) on CSD was insignificant, whereas prior CABG (1.07; 95% CI: 1.01 to 1.14) and PVD (1.1; 95% CI: 1.02 to 1.19) are both predictive of increased dose. Compared with other interventional sites, PCI of the LCX (1.14; 95% CI: 1.08 to 1.20) was associated with increased dose, whereas dose was unaffected by PCI of the LM (1.02; 95% CI: 0.91 to 1.14). Use of the lateral X-ray plane (1.37; 95% CI: 1.28 to 1.47) was associated with a large dose increase and use of Type 1 X-ray systems (1.09; 95% CI: 1.03 to 1.15) was also associated with increased dose.

The physician-specific influence on CSD was in the range 0.81 (95% CI: 0.76 to 0.87) to 1.25 (95% CI: 1.11 to 1.41) as shown in Figure 4, except that the influence of the group of 5 visiting physicians (1.11; 95% CI: 0.00 to 1.23) was excluded. There is a significant inverse correlation between the number of procedures performed and the physician-specific relative CSD increase. The slope of the linear regression fit to the data of Figure 4 is −0.14 per 100 procedures ($r^2 = 0.46$, $p = 0.008$).

Discussion

The findings of this work are specific to adult PCI procedures and the major findings included: 1) lesion complexity, PCI of LCX, and number of lesions treated was correlated with CSD; 2) patient body habitus was correlated with CSD; 3) previous CABG and PVD were correlated with CSD, but radial access, diabetes, and renal insufficiency were not; and 4) performing physician was significantly

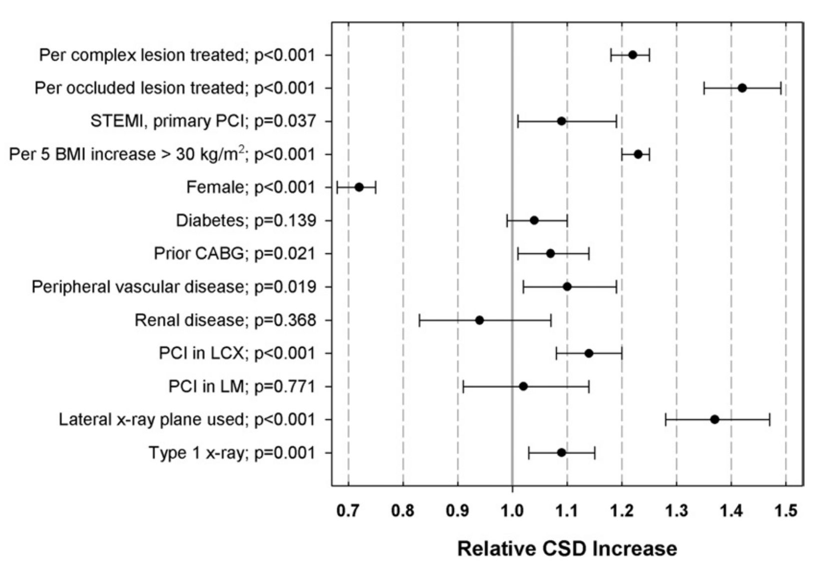

Figure 3. Relative Effect of Nonphysician Variables on CSD

Error bars represent 95% confidence interval. CABG = coronary artery bypass graft; CSD = cumulative skin dose; LCX = left circumflex artery; LM = left main artery; PCI = percutaneous coronary intervention; STEMI = ST-segment elevation myocardial infarction.

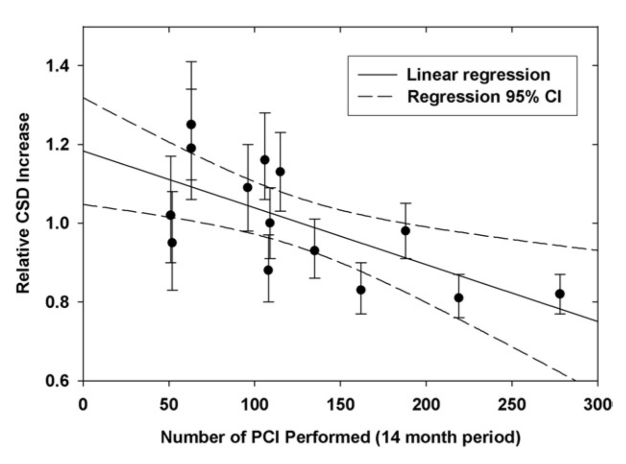

Figure 4. Influence of the Number of Procedures Performed on Physician-Specific Relative CSD Increase

Error bars represent 95% CI; linear fit slope = −0.14 per 100 procedures. Visiting physicians were excluded. CI = confidence interval; other abbreviations as in Figure 3.

correlated with CSD, with radiation dose reduction associated with higher volume operators CSD.

Lesion complexity and STEMI. Each non-STEMI procedure had an average of 1.5 lesions treated. Most of these procedures (73%) involved at least 1 complex lesion, each of which has an associated relative CSD increase of 1.22. Correlation between CSD and lesion type is consistent with the intent of the modified AHA/ACC Task Force lesion type score (31) and other works that reported on the influences of lesion complexity on dose (18,20,21,25). Similarly, that treatment of CTO is also associated with a relative CSD increase of 1.42 is related to the increased difficulty crossing, dilating, and then placing stents within these lesions (13,32). Compared with the defined reference patient for whom a single simple lesion was treated, primary PCI for STEMI patients is associated with increased CSD (1.09). This result should be interpreted in the context of other patient procedures that typically involve treatment of 1 or more complex (1.22 per lesion) and/or CTO (1.42) lesions. In this context, radiation dose associated with primary PCI for STEMI is lower than that for complex PCI (27).

Patient size. Using a BMI of 30 kg/m^2 as the reference value, there is a substantial CSD increase (decrease) for patients with BMI >30 kg/m^2 (<30 kg/m^2), which can be expressed as $1.23^{(BMI - 30)/5}$. Compared with the reference male patient, there is a substantial dose reduction for females patients (0.72; 95% CI: 0.68 to 0.75) of equal BMI (but who weigh an average of 16 kg less than male patients) (21,23). Both of these influences are consistent with increased (decreased) radiation dose rate implications of the automatic brightness control feature of the X-ray systems for larger (smaller) patients (4). Our experience is that the relationship between patient dose and image quality can be better managed if specific X-ray programs are used for patients of varying size.

Patient history. In addition to accounting for lesion complexity and patient size, the model demonstrates a radiation dose increase of 1.07 for procedures performed on patients who had prior CABG surgery (18) and 1.10 for patients with PVD. These influences are modest, but are likely a result of increased coronary disease severity, which tends to increase the difficulty of the procedure. Although both diabetes and renal disease were suggestive of association with dose in the quartile analysis, neither of these variables demonstrated independent statistical significance in the model analysis. In this case, the apparent dose relationship to these variables observed in the quartile analysis was more closely associated with other independent variables in the model.

Lesion location. Compared with PCI performed in other arteries, PCI performed in the LCX was associated with a CSD increase of 1.14. In this report, lesion location of LM artery was not independently associated with variation in dose, whereas others have reported reduced dose for PCI in the LM (21).

X-ray equipment-related influences. Use of the lateral X-ray plane (1.37) in 14% of the procedures was associated with a substantial increase in CSD. This result suggests that lateral plane imaging, used either instead of or simultaneously with the frontal plane, is overall less dose efficient than frontal plane imaging. One reason for this is that lateral patient thickness is greater than posterior-anterior patient thickness, thereby resulting in increased skin dose rate for lateral plane imaging. Also, when imaging simultaneously with the frontal and lateral X-ray planes, it is unlikely that the clinical information provided by the additional plane is proportional to the additional radiation dose delivered by that plane. Model results included that the Type 1 X-ray equipment, compared with the Type 2 equipment, was associated with a CSD increase of 1.09. This result is otherwise unremarkable.

Physician influence. A major finding of this work is that patient dose is significantly influenced by the staff physician with primary responsibility for the procedure (95% CI: 0.81 to 1.25) (Fig. 4). This result is independent of patient size, lesion complexity, or other model variables. This finding is consistent with differences in individual clinical practices, experience, and attention to dose reduction methods (18,23) (Table 5). Also, this current work demonstrates an inverse correlation between the number of procedures performed by individual physicians, over the 14-month study period, and radiation dose (Fig. 4). This suggests that performing many rather than few interventional procedures may help physicians develop and maintain skills that ultimately lead to reduced patient dose. However, physician-specific dose variation may also be influenced by the degree to which fellows either performed or assisted in the procedures. It has

Table 5. Strategies for Reducing Patient Radiation Dose

Use best X-ray geometry (distance and angle) practices
Minimize use of steep caudal and cranial angles
Routinely monitor real-time air-kerma measurements during the procedure
Establish a clear treatment plan for complex and occluded lesions
Consider influences of new treatment technologies on radiation dose
Use lateral X-ray plane only when clinically necessary
Use lowest possible fluoroscopy dose rate mode, including frame rate
Minimize the duration of X-ray beam use (fluoroscopy and cine)
Develop and maintain interventional skills

been shown by others that increased operator experience results in a reduction of radiation dose (33); therefore, physicians who preferentially allow trainees to perform rather than assist with procedures may be associated with increased radiation dose. Though it is known that fellows were involved in 97% of the procedures, the extent to which fellows performed versus assisted procedures varied considerably between cases and the degree to which the staff physician actively supervised the administration of radiation by the fellows is unknown. Therefore, this work offers no specific insight into the influence that trainee fellows have on patient radiation dose.

Summary of nonfactors. Other authors have reported radiation dose association for radial versus femoral access (18) whereas some others have reported no association (19). For the current work, vascular access site did not demonstrate a significant trend in the preliminary quartile analysis and, therefore, was not included in the multiple linear regression model. Although it is intuitive that PCI immediately preceded by CA should use a greater radiation dose than PCI alone (21), this trend was not indicated by the quartile analysis. This finding is consistent with a previous report from our laboratory (14). In this case, the anticipated effect of CA (or absence of CA) is likely masked by the large variability in CSD for PCI procedures (Fig. 2).

Dose trend over time. Considering all procedures, the median CSD (1.48 Gy) was 55% lower than that reported for interventional procedures performed at our site in 1997 (3.2 Gy) (14). Compared with that study, the patients in this study were larger with a mean weight of 89.6 kg versus 82.2 kg for the previous study. That patient skin dose has decreased as patient size increased during the 12 years between these studies indicates that substantial improvements have been made to radiation dose management over this time. This dose reduction over time can be attributed to a combination of improved X-ray imaging technology resulting in lower dose rate and improved interventional methods and devices and radiation safety practices. Notable among technical factors is that the standard frame rate for both fluoroscopy and acquisition imaging has decreased from 30 s^{-1} in 1997 to 15 s^{-1}.

Methods for dose reduction. Based on the results of this work, there are several opportunities to reduce patient radiation dose during PCI. Nearly one-half of the procedures were performed on patients who are obese. Although patient size cannot be modified at the time of the procedure, it is known that steep X-ray tube angles result in increased effective patient thickness and radiation dose rate (14,21). To minimize radiation dose (Table 5), it is particularly important to minimize X-ray beam path length through the patient by using the least possible X-ray projection angles. When treating complex or CTO lesions, radiation management should be incorporated into pre-procedure planning. Also for complex and CTO lesions, the potential for use of advanced technology such as improved interventional devices (34), 3-dimensional vessel modeling (35–38), or magnetic catheter guidance (39) to reduce dose should be further investigated. This work demonstrates that use of the lateral X-ray plane results in increased patient radiation burden. To minimize radiation, the lateral X-ray plane should be used sparingly and only during those procedures for which it is a clinical necessity. Finally, this work demonstrates that individual physician operators can have a substantial influence on patient dose. All staff and trainee physicians should be well trained and skilled at their craft and must uniformly adopt established technical and behavioral methods to minimize radiation dose (4).

Conclusions

Several primary determinants of radiation burden to patients undergoing PCI were identified. Complexity, number, and location of lesions were associated with radiation skin dose. Skin dose correlated with patient size, increasing significantly with increasing BMI and decreasing for female versus male patients. Notably, this work demonstrates that patient radiation dose varies substantially among physicians and that there is an inverse correlation of patient dose with operator volume.

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Key Words: percutaneous coronary intervention ■ physician influence on dose ■ radiation skin dose.