Relationship Between Fluoroscopic Time, Dose–Area Product, Body Weight, and Maximum Radiation Skin Dose in Cardiac Interventional Procedures

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OBJECTIVE. Real-time maximum dose monitoring of the skin is unavailable on many of the X-ray machines that are used for cardiac intervention procedures. Therefore, some reports have recommended that physicians record the fluoroscopic time for patients undergoing fluoroscopically guided intervention procedures. However, the relationship between the fluoroscopic time and the maximum radiation skin dose is not clear. This article describes the correlation between the maximum radiation skin dose and fluoroscopic time for patients undergoing cardiac intervention procedures. In addition, we examined whether the correlations between maximum radiation skin dose and body weight, fluoroscopic time, and dose–area product (DAP) were useful for estimating the maximum skin dose during cardiac intervention procedures.

MATERIALS AND METHODS. Two hundred consecutive cardiac intervention procedures were studied: 172 percutaneous coronary interventions and 28 cardiac radiofrequency catheter ablation (RFCA) procedures. The patient skin dose and DAP were measured using Caregraph with skin-dose-mapping software.

RESULTS. For the RFCA procedures, we found a good correlation between the maximum radiation skin dose and fluoroscopic time ($r = 0.801$, $p < 0.0001$), whereas we found a poor correlation between the maximum radiation skin dose and fluoroscopic time for the percutaneous coronary intervention procedures ($r = 0.628$, $p < 0.0001$). There was a strong correlation between the maximum radiation skin dose and DAP in RFCA procedures ($r = 0.942$, $p < 0.0001$). There was also a significant correlation between the maximum radiation skin dose and DAP ($r = 0.724$, $p < 0.0001$) and weight–fluoroscopic time product (WFP) ($r = 0.709$, $p < 0.0001$) in percutaneous coronary intervention procedures.

CONCLUSION. The correlation between the maximum radiation skin dose with DAP is more striking than that with fluoroscopic time in both RFCA and percutaneous coronary intervention procedures. We recommend that physicians record the DAP when it can be monitored and that physicians record the fluoroscopic time when DAP cannot be monitored for estimating the maximum patient skin dose in RFCA procedures. For estimating the maximum patient skin dose in percutaneous coronary intervention procedures, we also recommend that physicians record DAP when it can be monitored and that physicians record WFP when DAP cannot be monitored.

Keywords: angiography, cardiovascular imaging, interventional radiology, radiation dose, radiation injury

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Cardiac intervention procedures, such as percutaneous coronary intervention, can potentially result in high patient radiation doses [1]. Because high doses have the potential to cause harmful radiation skin injuries, such as erythema and skin burns, the maximum radiation skin doses should be recorded, given that a patient may undergo repeated cardiac intervention procedures [2, 3]. However, real-time maximum dose monitoring of the skin is unavailable for many of the X-ray machines that are used for cardiac intervention procedures. Therefore, some reports have recommended that physicians record the time that a patient spends undergoing fluoroscopically guided intervention procedures [2, 3], although the relationship between the fluoroscopic time and the maximum radiation skin dose is not clear. In addition, there have been few reports describing the relationship between fluoroscopic time and maximum radiation skin dose during cardiac intervention procedures [4]. Therefore, this article describes the correlation between the maximum radiation skin dose and the fluoroscopic time while undergoing cardiac intervention procedures.

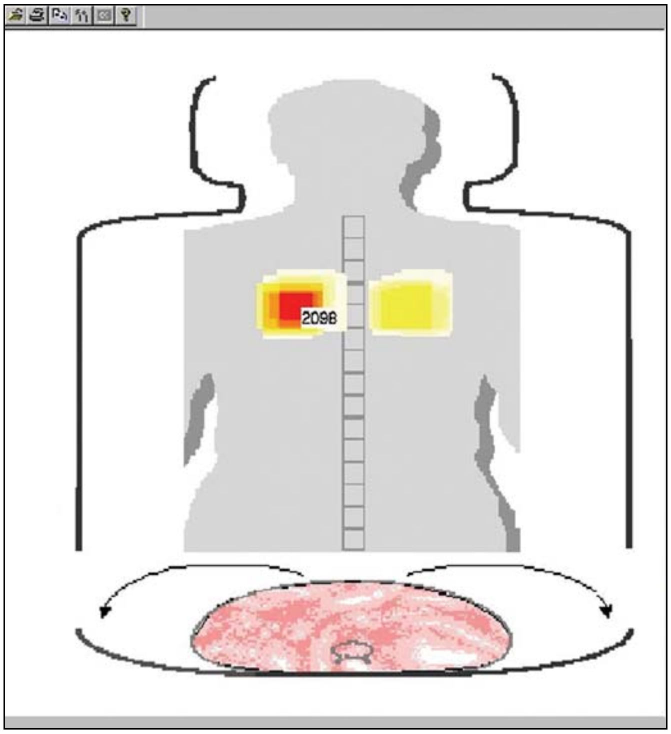

Fig. 1—Graphical display of Caregraph (Siemens Medical Solutions). Example shows dose distribution at skin after cardiac radiofrequency catheter ablation. In this study, dose–area product (DAP) was measured using Caregraph, which consists of the Diamentor M4 system (PTW Freiburg). Caregraph algorithm uses several factors to calculate patient skin dose, including measured DAP, X-ray parameters (such as collimation size and angle view of image intensifier), and patient size and position. Maximum radiation dose, which is shown in red, received by right back skin was 2,098 mGy (total fluoroscopic time = 214.5 min, DAP = 28,115 cGy × cm^2). Yellow shows areas of lesser radiation exposure.

In addition, the correlations between the maximum radiation skin dose and body weight, fluoroscopic time, and dose–area product (DAP) were investigated to examine whether these factors could prove useful in estimating the maximum skin dose during percutaneous coronary intervention or cardiac radiofrequency catheter ablation (RFCA) procedures.

Materials and Methods

The cardiac intervention procedures were performed using a digital cine biplane X-ray system (Bicor Plus, Siemens Medical Solutions). The control system for this equipment automatically sets the X-ray exposure kilovoltage and milliamperage. Digital cine acquisition was performed at 15 frames per second for the procedures. Although the duration of the cine runs was inconsistent, a typical cine run lasted 3–4 sec. RFCA and percutaneous coronary intervention procedures used pulsed fluoroscopy (7.5 and 15 pulses/sec, respectively) with 23- and 17-cm-mode image intensifiers, respectively, with a grid (11:1, 40 lines/cm). A single-plane imaging system was used in percutaneous coronary intervention procedures except in patients with chronic total occlusion; a biplane imaging system was used in RFCA and percutaneous coronary intervention procedures for the patients with chronic total occlusion. RFCA was performed using 30° right anterior oblique and 45° left anterior oblique views only. By contrast, the angles and views used while performing percutaneous coronary intervention procedures were not constant because accurate coronary diagnosis requires coronary injections in multiple views [5].

The patient skin dose and DAP were measured using a unit with skin-dose-mapping software (Caregraph, Siemens Medical Solutions) [6]. The DAP could then be obtained from either knowledge of the field settings and exposure factors or noninstrusive measurements with a transmission ionization chamber [7]. In this study, the DAP was determined using a transmission chamber fitted to an X-ray tube light beam diaphragm.

Caregraph is a useful tool for measuring the maximum skin radiation dose in real time; it consists of the Diamentor M4 system (PTW Freiburg), which includes a transmission ionization chamber attached to the collimator exit port of the X-ray tube and a PC on which the Caregraph software (version 1.0) is installed [6, 8, 9]. The Caregraph algorithm uses several factors to calculate the patient skin dose, including the measured DAP, X-ray parameters (collimation size, focus-to-skin distance, catheter table position, and angle view of image intensifier), and patient size (height and weight) and position (defined by the location of the tabletop) [6]. Figure 1 shows the graphical display of Caregraph. The Caregraph measurements (skin dose) were adjusted by comparing them with measurements obtained using a calibrated thimble-type 6-mL ion chamber (model 9015 dosimeter, Radcal). For this measurement, the 6-mL ion chamber was placed on the center of the entrance surface of a 20-cm-thick acrylic phantom using a 17-cm mode. Therefore, this measurement included backscatter.

Two hundred consecutive cardiac intervention procedures were studied: 172 percutaneous coronary intervention and 28 RFCA procedures. For the 172 percutaneous coronary intervention patients (135 men, 37 women), the patient age was 68.7 ± 9.7 years (mean ± SD) and the body weight was 60.1 ± 9.9 kg. For the 28 RFCA patients (13 men, 15 women), the respective values were 50.8 ± 15.7 years and 58.0 ± 8.6 kg. Of the percutaneous coronary intervention procedures, 96 were performed to place a stent and 23 were performed in patients with chronic total occlusion. Of the RFCA procedures, 11 patients had paroxysmal supraventricular tachycardia, seven had atrial fibrillation, and five each had Wolff-Parkinson-White syndrome and ventricular tachycardia. One of three cardiologists performed the percutaneous coronary intervention or RFCA procedure following the protocol for the respective intervention procedure. At our institution, the cardiologists attend a radiation safety course twice a year.

This was a retrospective single-institutional study and was approved by the local committee on human research. We have recorded the following data for each patient since April 2002: body weight (kg), fluoroscopic time, DAP, and maximum radiation skin dose. The fluoroscopic time and DAP for the biplane system were the total fluoroscopic time and total DAP for both planes (i.e., total DAP = DAP obtained in plane A + DAP obtained in plane B). The correlations between body weight, fluoroscopic time, and DAP and maximum radiation skin dose were analyzed using linear regressions. We also use the so-called "double product" combined with body weight, which is the weight–fluoroscopic time product (WFP), because the radiation skin dose will be greater in larger patients [2]. The p value was obtained from an analysis of variance. Statistical significance was defined as a p value of less than 0.05.

Results

Table 1 shows the body weight, fluoroscopic time, number of cine runs, DAP, and maximum radiation skin dose in this study. The values are given as means ± SD. There was no radiation-induced skin injury in our study.

Correlations Between Maximum Skin Dose and Factors During RFCA

Figures 2 and 3 show the correlations between the maximum radiation skin dose and fluoroscopic time ($r = 0.801$, $p < 0.0001$) and DAP ($r = 0.942$, $p < 0.0001$), respectively, in the RFCA procedures. We found a poor correlation between the maximum radiation skin dose and body weight ($r = 0.434$, $p < 0.05$).

Correlations Between Maximum Skin Dose and Factors During Percutaneous Coronary Intervention

Figures 4 and 5 show the correlations between the maximum radiation skin dose and fluoroscopic time ($r = 0.628$, $p < 0.0001$) and DAP ($r = 0.724$, $p < 0.0001$), respectively, in the percutaneous coronary intervention procedures. We found a poor correlation between the maximum radiation skin dose and body weight ($r = 0.348$, $p < 0.0001$). Figure 6 shows the correlation between the maximum radiation skin dose and WFP ($r = 0.709$, $p < 0.0001$) in the percutaneous coronary intervention procedures. Figure 7 shows the correlation between DAP and WFP in the percutaneous coronary intervention procedures ($r = 0.736$, $p < 0.0001$).

TABLE 1: Characteristics of Our Study

Characteristic	Percutaneous Coronary Intervention ($n = 172$ patients)	Cardiac Radiofrequency Catheter Ablation ($n = 28$ patients)
Body weight (kg)	60.1 ± 9.9	58.0 ± 8.6
Total fluoroscopic time (min)	37.4 ± 22.5	120.8 ± 62.6
No. of cine runs	34.8 ± 17.3	18.0 ± 12.4
Dose–area product (Gy × cm^2)	148.6 ± 102.9	109.7 ± 74.7
Maximum skin dose (mGy)	1,454.5 ± 991.5	635.0 ± 551.6

Note—All data are mean ± SD.

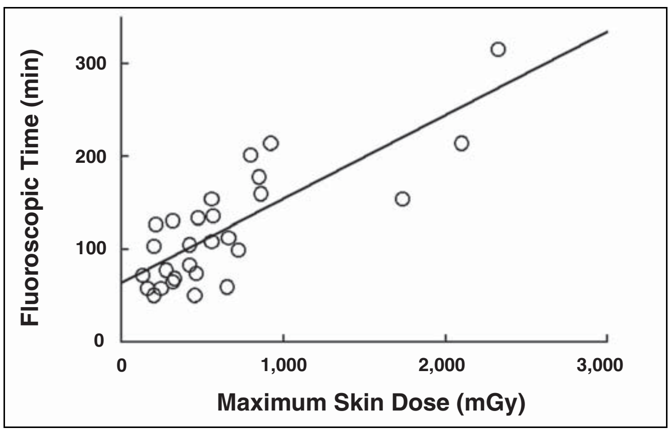

Fig. 2—Graph shows correlation between maximum patient skin dose and fluoroscopic time in cardiac radiofrequency catheter ablation ($r = 0.801$, $p < 0.0001$).

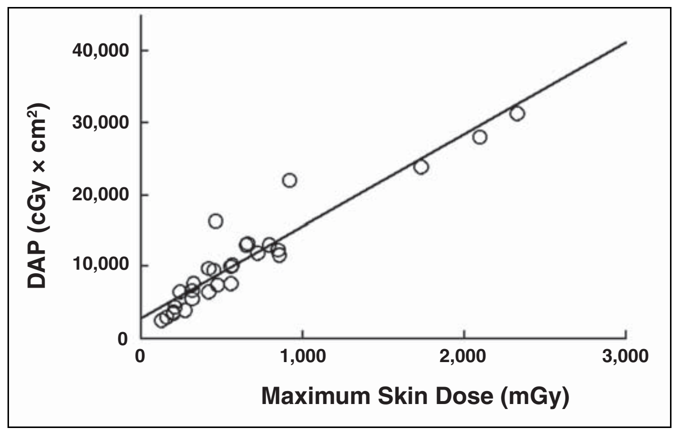

Fig. 3—Graph shows correlation between maximum patient skin dose and dose–area product (DAP) in cardiac radiofrequency catheter ablation ($r = 0.942$, $p < 0.0001$).

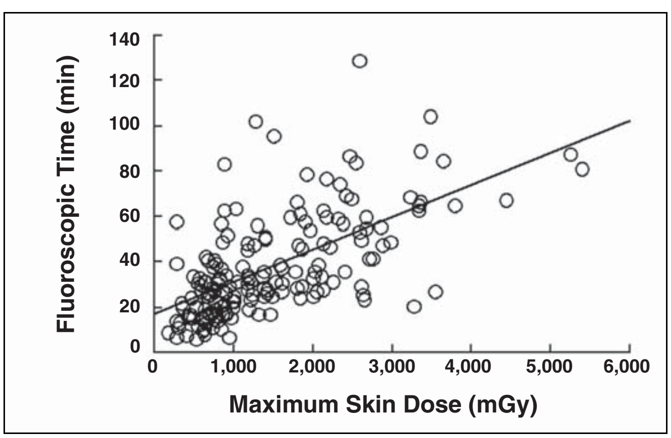

Fig. 4—Graph shows correlation between maximum patient skin dose and fluoroscopic time in percutaneous coronary intervention ($r = 0.628$, $p < 0.0001$).

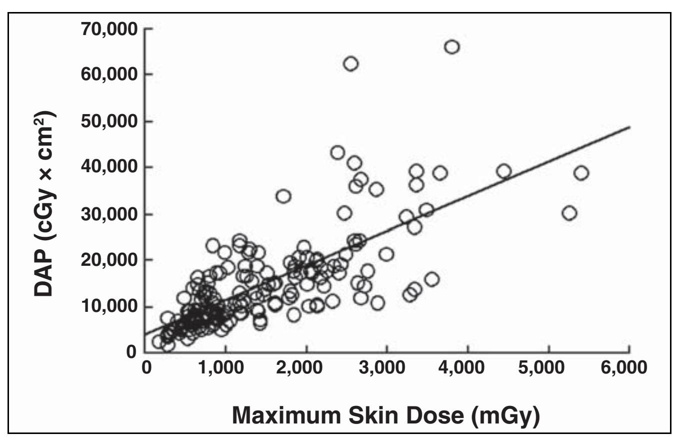

Fig. 5—Graph shows correlation between maximum patient skin dose and dose–area product (DAP) in percutaneous coronary intervention ($r = 0.724$, $p < 0.0001$).

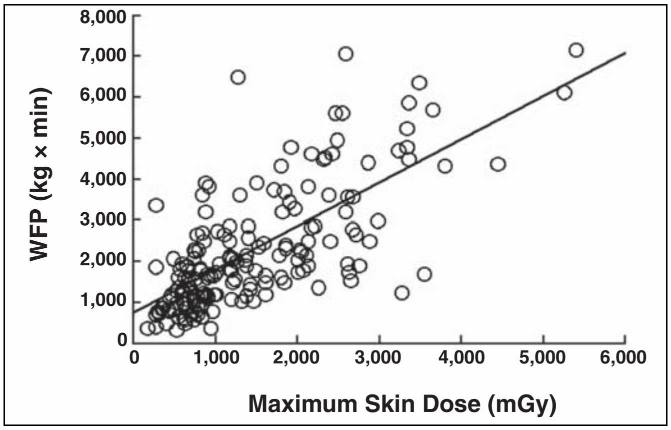

Fig. 6—Graph shows correlation between maximum patient skin dose and double product (body weight × fluoroscopic time, or WFP [weight–fluoroscopic time product]) in percutaneous coronary intervention ($r = 0.709$, $p < 0.0001$).

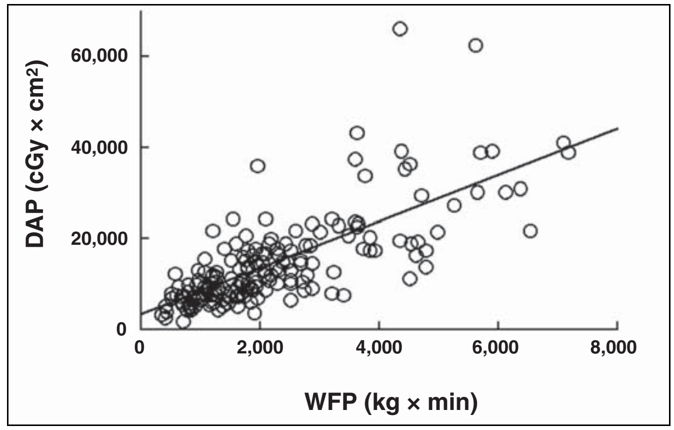

Fig. 7—Graph shows correlation between dose–area product (DAP) and double product (body weight × fluoroscopic time, or WFP [weight–fluoroscopic time product]) in percutaneous coronary intervention ($r = 0.736$, $p < 0.0001$).

Discussion

For RFCA, we recommend that physicians record the DAP for estimating the maximum patient skin dose when it can be monitored and that physicians record the fluoroscopic time when DAP cannot be monitored. There was a strong correlation between DAP and the maximum radiation skin dose ($r = 0.942$) and a good correlation between the fluoroscopic time and the maximum radiation skin dose ($r = 0.801$).

Fluoroscopic time is the factor that the U.S. Food and Drug Administration (FDA) and the International Commission on Radiological Protection (ICRP) recommend be monitored during fluoroscopically guided intervention procedures [2, 3]. Miller et al. [10] reported the maximum radiation skin dose and DAP were correlated in fluoroscopically guided intervention procedures except cardiac intervention procedures. To our knowledge, few studies have examined the correlation between maximum radiation skin dose and body weight, fluoroscopic time, or DAP in RFCA procedures [4]. McFadden et al. [4] examined the correlation between the maximum radiation skin dose measured using two thermoluminescence dosimeters (TLDs), positioned at thoracic vertebrae 9 and 11, and DAP ($r = 0.71$) and fluoroscopic time ($r = 0.64$) in RFCA; their correlations were poorer than ours. One reason for their lower correlations is that the TLDs positioned at the thoracic vertebrae were not in the primary X-ray beam for some of the projections during the procedure. However, we found good correlations between the maximum radiation skin dose and fluoroscopic time and DAP in RFCA. Our results suggest that fluoroscopic time and DAP measurements are good predictors of skin injury risk in RFCA, although this applies only for a fixed field of view. Because the correlation of the maximum radiation skin dose with DAP is more striking than that with fluoroscopic time, physicians should record not only the fluoroscopic time but also the DAP when it can be monitored for estimating the maximum patient skin dose.

For percutaneous coronary intervention procedures, we also recommend that physicians record DAP for estimating the maximum patient skin dose, although the correlation coefficient between DAP and the maximum patient skin dose was lower for percutaneous coronary intervention procedures than for RFCA procedures. When DAP cannot be monitored, we recommend that physicians record the WFP (i.e., patient weight × fluoroscopic time) of patients undergoing percutaneous coronary intervention, because the correlation coefficient for WFP was higher than that for fluoroscopic time alone. In percutaneous coronary intervention, DAP correlated reasonably well with the maximum radiation skin dose ($r = 0.724$).

DAP is one of the rough predictors of the maximum radiation skin dose in percutaneous coronary intervention procedures. The correlation coefficient between DAP and the maximum radiation skin dose was lower for percutaneous coronary intervention procedures than for RFCA procedures. The major cause of this reduction in the correlation coefficient was the use of different angles and views while performing percutaneous coronary intervention. Few studies have examined the correlation between the maximum radiation skin dose and factors such as DAP in percutaneous coronary interventions. In their study, van de Putte et al. [11] reported that the maximum radiation skin dose measured using a TLD was correlated with DAP in percutaneous coronary intervention and diagnostic procedures ($r = 0.77$). Our results are similar to theirs. By contrast, den Boer et al. [6] reported that the maximum radiation skin dose was correlated with KAP (KERMA [kinetic energy released per unit mass]–area product, which is roughly equivalent to DAP) in percutaneous coronary intervention ($r = 0.90$); their correlation [6] was much better than ours. One of the most likely reasons for their superior correlation is that many of their patients received higher radiation doses (e.g., maximum radiation dose, > 4 Gy). If the extreme values (> 4 Gy) are excluded, their correlation coefficient was 0.81.

The WFP (i.e., weight × fluoroscopic time) is another rough predictor of the maximum radiation skin dose in percutaneous coronary intervention procedures. Fluoroscopic time, a factor that the FDA and ICRP recommend be recorded for fluoroscopy procedures [2, 3], had a weak correlation with the maximum radiation skin dose, especially in percutaneous coronary intervention procedures ($r = 0.628$). By contrast, for percutaneous coronary intervention procedures, WFP correlated reasonably well with the maximum radiation skin dose ($r = 0.709$). One cause of this improvement in the correlation coefficient might be the increase in the radiation skin dose with patient weight. Furthermore, WFP correlated well with DAP ($r = 0.736$). Therefore, for percutaneous coronary intervention procedures, WFP might be more useful for estimating the maximum skin dose than fluoroscopic time alone.

During a cardiac intervention procedure, the patient skin dose may occasionally exceed the dose that causes transient erythema and skin burns. A number of cases involving skin injuries in cardiac intervention procedures have been reported [12–20]. To avoid radiation skin injuries in patients undergoing cardiac intervention procedures, it is necessary to keep the exposure doses as low as can be reasonably achieved [1, 18, 21]. To reduce the risk of a patient receiving a skin injury, the FDA and ICRP have suggested that physicians record the radiation skin dose of patients undergoing such procedures [2, 3]. Unfortunately, real-time maximum dose monitoring of the skin is unavailable for many cardiac intervention procedures. The skin dose monitor (SDM) (SDM model 104-101, McMahon Medical) is useful for measuring skin radiation in real time [22]. However, the SDM measures the skin dose at only a single point on the skin surface, because an SDM responds only when the sensor is irradiated. Therefore, to be effective, the SDM sensor must be placed in the field of maximum X-ray exposure; however, it is impossible to predict the site of maximum X-ray exposure before a cardiac intervention procedure commences. The Caregraph skin-dose-mapping software used in this study is useful for measuring the maximum skin radiation in real time [6, 8, 9], but Caregraph is expensive and can only be used with Siemens machines (Bicor or Multistar angiographic units). In addition, Caregraph is no longer available on newer Siemens equipment. Therefore, Caregraph is not widely used to measure skin dose [8].

Because the radiation dose varies greatly with each X-ray machine and laboratory [1], to estimate the maximum skin dose the radiation dose must be calibrated for each X-ray machine and each laboratory.

In conclusion, because real-time monitoring of the maximum skin dose is unavailable on many X-ray machines, we recommend that physicians record DAP when it can be monitored and that physicians record the fluoroscopic time when DAP cannot be monitored for estimating the maximum patient skin dose in RFCA procedures. For estimating the maximum patient skin dose in percutaneous coronary intervention procedures, we also recommend that physicians record DAP when it can be monitored and that physicians record WFP (i.e., weight × fluoroscopic time) when DAP cannot be monitored. This information could be used to help prevent skin injuries during cardiac intervention procedures. This article is an important addition to interventionalists' knowledge and understanding about how to evaluate radiation exposure to their patients.

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