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Radiation Exposure Among Scrub Technologists and Nurse Circulators During Cardiac Catheterization

The Impact of Accessory Lead Shields

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ABSTRACT

OBJECTIVES This study was performed to determine if the use of an accessory lead shield is associated with a reduction in radiation exposure among staff members during cardiac catheterization.

BACKGROUND Accessory lead shields that protect physicians from scatter radiation are standard in many catheterization laboratories, yet similar shielding for staff members is not commonplace.

METHODS Real-time radiation exposure data were prospectively collected among nurses and technologists during 764 consecutive catheterizations. The study had 2 phases: in phase I ($n = 401$), standard radiation protection measures were used, and in phase II ($n = 363$), standard radiation protection measures were combined with an accessory lead shield placed between the staff member and patient. Radiation exposure was reported as the effective dose normalized to dose-area product (E_{DAP}).

RESULTS Use of an accessory lead shield in phase II was associated with a 62.5% lower E_{DAP} per case among technologists (phase I: 2.4 [4.3] $\mu Sv/[mGy \times cm^2] \times 10^{-5}$; phase II: 0.9 [2.8] $\mu Sv/[mGy \times cm^2] \times 10^{-5}$; $p < 0.001$) and a 63.6% lower E_{DAP} per case among nurses (phase I: 1.1 [3.1] $\mu Sv/[mGy \times cm^2] \times 10^{-5}$; phase II: 0.4 [1.8] $\mu Sv/[mGy \times cm^2] \times 10^{-5}$; $p < 0.001$). By multivariate analysis, accessory shielding remained independently associated with a lower E_{DAP} among both technologists (34.2% reduction; 95% confidence interval: 20.1% to 45.8%; $p < 0.001$) and nurses (36.4% reduction; 95% confidence interval: 19.7% to 49.6%; $p < 0.001$).

CONCLUSIONS The relatively simple approach of using accessory lead shields to protect staff members during cardiac catheterization was associated with a nearly two-thirds reduction in radiation exposure among nurses and technologists. (J Am Coll Cardiol Intv 2018;11:206–12) © 2018 by the American College of Cardiology Foundation.

Recent reports of premature cataract formation, left-sided brain malignancies, subclinical atherosclerosis, and chromosomal damage among interventional cardiologists have heightened concerns over occupational radiation exposure in the cardiac catheterization laboratory (1-4). Recognition of these hazards has created demand for novel ways to reduce radiation exposure among interventional cardiologists (5-7). However, the hazards of radiation exposure in the catheterization laboratory are not limited to interventional cardiologists, as recent publications have suggested a possible increased risk for certain cancers, stroke, and cataracts among staff members (8-11). Considering these potential risks, additional studies are needed to better understand procedural characteristics that increase staff irradiation and to

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identify methods to reduce staff radiation exposure during cardiac catheterization.

It has been previously demonstrated that placing an accessory lead shield between the operating physician and patient effectively attenuates physician radiation exposure (12,13). Use of accessory shields to protect physicians from scatter radiation is now standard in many catheterization laboratories, yet similar shielding for staff members during cardiac catheterization is not commonplace. If using accessory shields to protect staff members were demonstrated to be effective, this approach might represent a relatively simple and inexpensive method to improve radiation safety in the catheterization laboratory. The present study was performed to identify procedural characteristics associated with radiation exposure among staff members during cardiac catheterization and to determine if the use of an accessory lead shield is associated with a reduction in radiation exposure among staff members.

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METHODS

STUDY POPULATION. The SHIELD (Combining Robotic-Stenting and Proactive Shielding Techniques in the Catheterization Laboratory to Achieve Lowest Possible Radiation Exposure to Physicians and Staff) study was a single-center prospective observational study designed to investigate radiation exposure to physicians and staff members in the cardiac catheterization laboratory. The study was conceived, designed, and conducted by investigators of the Frederik Meijer Heart & Vascular Institute of Spectrum Health (Grand Rapids, Michigan). The local Institutional Review Board approved the protocol, and all participants provided informed consent.

Data were prospectively collected on consecutive cases in a single fluoroscopy suite with an Allura Xper FD10 x-ray system (Philips, Amsterdam, the Netherlands). All cases with start times between approximately 8 AM and 5 PM, Monday through Friday, were included in the study. Cases that did not require any radiation were excluded as specified in the study protocol. Radiation exposure data were collected on procedural staff members, including nurse circulators and scrub technologists. At the study institution, the nurse circulator is responsible for monitoring the patient, administering medications, and obtaining equipment requested by the operating physician. The technologist, who typically stands to the right of the operating physician, serves as a second operator during the case, assists the operating physician in device exchanges, performs all injections using a contrast delivery system (Acist CVi, Acist Medical Systems, Eden Prairie, Minnesota), and inflates angioplasty and stent balloons.

RADIATION MONITORING. Real-time radiation exposure data were collected using a commercially available dosimetry system that contains a bedside monitor capable of displaying real-time radiation exposure data (RaySafe i2, Unfors RaySafe, Billdal, Sweden). Physicians and staff members were blinded to the monitor display and to the radiation data collected by the dosimeters for the duration of the study. During the study, each staff member wore an outer dosimeter, located on either the left anterior side of the glasses or on the left anterior side of the thyroid collar, and a body dosimeter, located underneath the lead apparel on the V-neck of the scrub shirt.

ABBREVIATIONS AND ACRONYMS

CI = confidence interval

DAP = dose-area product

E = effective dose

E_{DAP} = effective dose normalized to the dose-area product

FFR = fractional flow reserve

H_{os} = dose recorded by outer dosimeter

H_{osDAP} = dose recorded by outer dosimeter normalized to dose-area product

H_u = dose recorded by body dosimeter

H_{uDAP} = dose recorded by body dosimeter normalized to dose-area product

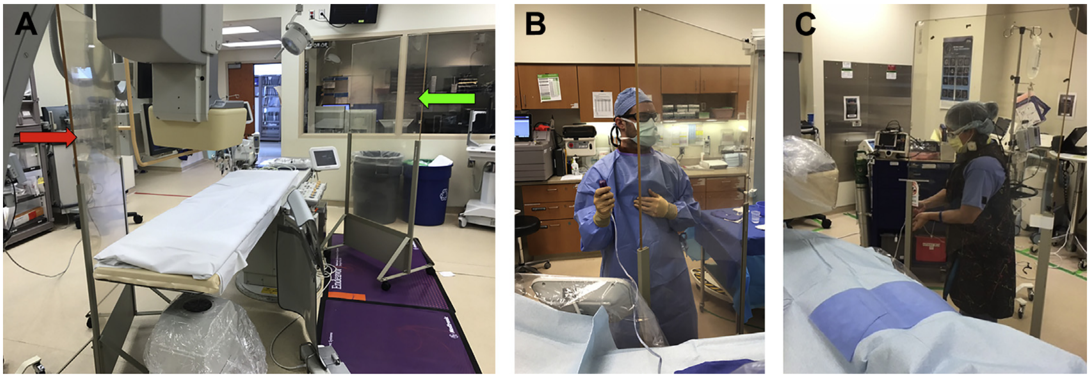
PCI = percutaneous coronary intervention

RADIATION PROTECTION. According to standard operating procedure at the study institution, 2 shields were positioned between the patient and operating physician in all cases: a ceiling-mounted upper body lead shield with a patient contour cutout and a lower body lead shield attached to the side of the operating table extending from table to floor (12). A radiation-absorbing disposable pad (RadPad, Worldwide Innovations & Technologies, Kansas City, Missouri) was used at the discretion of the operating physician and staff members. Staff members wore traditional lead apparel, consisting of a lead skirt, apron, and thyroid collar.

To determine the impact of accessory shields on staff radiation exposure, the study was divided into 2 phases. During phase I, all cases were performed using the standard radiation protective measures described previously. In phase II, all cases were performed using standard radiation protective measures in combination with a dedicated accessory lead shield for each staff member. The accessory lead shields used in this study (height 1.8 m, width 0.7 m) had an effective lead thickness of 0.5 mm Pb. For nurse circulators, the shield was positioned between the patient and the intravenous medication pole. For scrub technologists, the shield was positioned near the foot of the bed, enabling them to stand behind the shield whenever possible, including while performing injections with the contrast delivery system (**Figure 1**).

STATISTICAL ANALYSIS. Using radiation exposure data collected from the outer dosimeter (H_{os}) and body dosimeter (H_u), the effective dose (E) per case

FIGURE 1 **Positioning of Accessory Lead Shields for Technologists and Nurses**



The positions of the accessory lead shields for nurses **(red arrow)** and technologists **(green arrow)** used in phase II of the study are shown **(A)**. For technologists, the shield was positioned near the foot of the bed, enabling them to stand behind the shield while performing injections with a contrast delivery system **(B)**. For nurses, the shield was positioned between the patient and the intravenous medication pole **(C)**.

for the nurse circulator and scrub technologist was calculated using the method of Niklason et al. (14,15). According to this method, $E = 0.02(H_{os} - H_u) + H_{os}$. To control for the amount of radiation used in each case, E was normalized to the dose-area product (DAP) and is reported as E_{DAP}. The DAP, which is automatically calculated in each case by the fluoroscopy imaging system, was recorded at the completion of all cases. H_{os} normalized to DAP (H_{osDAP}) and H_u normalized to DAP (H_{uDAP}) are also reported as raw estimates of radiation exposure measured by dosimeters at the head level and chest level, respectively.

Descriptive statistics were used to summarize baseline characteristics and outcome measures. Normally distributed continuous variables are expressed as mean ± SD. Non-normally distributed continuous variables are shown as median (interquartile range). Categorical variables are shown as count (percentage frequency). The p values for comparison of continuous variables were derived from 2-sample independent Student *t*-tests if data were normally distributed or from Wilcoxon rank sum tests if data were not normally distributed. P values for comparison of categorical variables were generated using chi-square analysis or the Fisher exact test if the expected cell counts were lower than 5 in more than 20% of the cells. Univariate analyses were performed to determine procedural characteristics associated with E_{DAP} among nurses and technologists. Multivariate linear regression modeling with backward selection was performed to identify procedural variables independently associated with log of E_{DAP}. Log transformation was performed because of the non-normal distribution of the data. The procedural variables included in the multivariate model were accessory lead shielding, right heart catheterization, radial access, fractional flow reserve (FFR), presence of bypass grafts, percutaneous coronary intervention (PCI), and a radiation-absorbing pad. All statistical analyses were generated using SAS Enterprise Guide version 7.1 (SAS Institute, Cary, North Carolina).

RESULTS

STUDY POPULATION. Between August 3, 2015, and February 26, 2016, staff radiation exposure was measured in 764 consecutive cases, the baseline characteristics of which are shown in **Table 1**. Of these, 401 cases (52.5%) were performed during phase I, in which standard radiation protection measures were used, and 363 cases (47.5%) were performed in phase II, in which standard radiation protection measures were combined with proactive shielding of staff members. There were no significant differences in the procedural characteristics of cases performed during phase I and phase II, except that cases in phase II were characterized by lower radiation metrics, including lower fluoroscopy time, air kerma, and DAP (**Table 1**). As a result of these differences in radiation metrics, effective doses among staff members in phase I and phase II were compared only after doses were normalized to DAP.

SCRUB TECHNOLOGIST RADIATION EXPOSURE. Technologists had an E_{DAP} of 2.4 [4.3] $\mu Sv/(mGy \times cm^2) \times 10^{-5}$ per case in phase I. With the introduction of accessory lead shields in phase II, the E_{DAP} for technologists was 0.9 [2.8] μSv/(mGy × cm²) × 10^{-5}, which represents an observed 62.5% lower dose per case compared with phase I ($p < 0.001$) (Figure 2, Table 2). Compared with the median doses recorded by the outer dosimeter among technologists in phase I, H_{osDAP} was 54.2% lower in phase II (phase I: 2.4 [4.3] μSv/[mGy × cm²] × 10^{-5}; phase II: 1.1 [3.1] μSv/[mGy × cm²] × 10^{-5}; $p < 0.001$). Low doses were recorded by the inner dosimeter in both phases, as the median H_{uDAP} was 0.0 [0.1] μSv/[mGy × cm²] × 10^{-5} in phase I and 0.0 [0.0] μSv/[mGy × cm²] × 10^{-5} in phase II.

By univariate analysis, procedures that included right heart catheterization were associated with increased E_{DAP} among technologists (Table 2). In contrast, cases involving radial access, FFR, and the use of a radiation-absorbing pad were all associated with lower E_{DAP} among technologists by univariate analysis (Table 2). By multivariate analysis, the only variables independently associated with E_{DAP} among technologists were accessory lead shields (dose reduction 34.2%; 95% confidence interval [CI]: 20.1% to 45.8%; $p < 0.001$) and radiation-absorbing pads (dose reduction 47.0%; 95% CI: 36.2% to 55.9%; $p < 0.001$) (Table 3).

NURSE RADIATION EXPOSURE. Nurses had an E_{DAP} of 1.1 [3.1] μSv/(mGy × cm²) × 10^{-5} per case in phase I. With the introduction of accessory lead shields in phase II, the E_{DAP} for nurses was 0.4 [1.8] μSv/(mGy × cm²) × 10^{-5}, which represents an observed 63.6% lower dose per case compared with phase I ($p < 0.001$) (Figure 2). Compared with the median doses recorded by the outer dosimeter among nurses in phase I, H_{osDAP} was 60.0% lower in phase II (phase I: 1.0 [3.1] μSv/[mGy × cm²] × 10^{-5}; phase II: 0.4 [1.6] μSv/[mGy × cm²] × 10^{-5}; $p < 0.001$). Low doses were recorded by the inner dosimeter in both phases, as the median H_{uDAP} was 0.0 [0.1] μSv/[mGy × cm²] × 10^{-5} in phase I and 0.0 [0.0] μSv/[mGy × cm²] × 10^{-5} in phase II.

By univariate analysis, right heart catheterization was associated with decreased E_{DAP} among nurses, whereas PCI, FFR, and a radiation-absorbing pad were all associated with increased E_{DAP} among nurses (Table 2). By multivariate analysis, the use of an accessory lead shield was the only variable associated with a reduction in E_{DAP} among nurses (dose reduction 36.4%; 95% CI: 19.7% to 49.6%; $p < 0.001$) (Table 3). By multivariate analysis, PCI (dose increase 112%; 95% CI: 66.2% to 171%; $p < 0.001$) and FFR (dose increase 41.9%; 95% CI: 0.7% to 100.1%; $p = 0.046$) were the only variables independently associated with an increase in nurse E_{DAP} (Table 3).

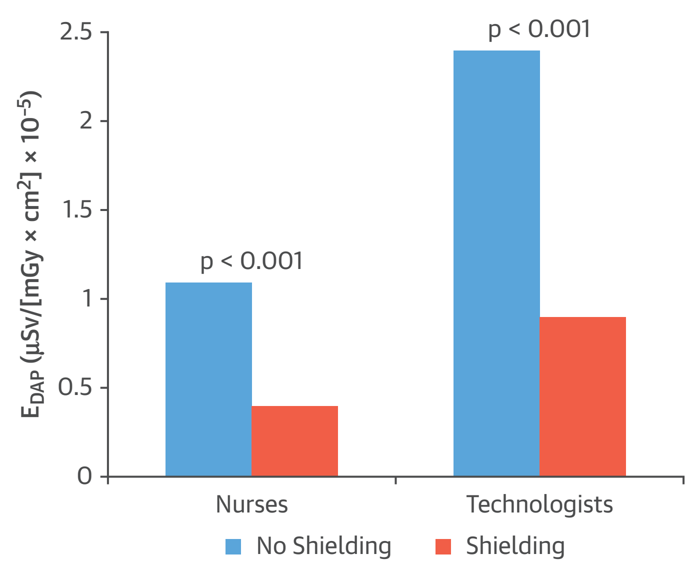
TABLE 1 Patient and Procedural Characteristics

	Total (n = 764)	Phase I (n = 401)	Phase II (n = 363)	p Value
Age, yrs	64.8 ± 12.4	65.1 ± 12.0	64.4 ± 12.9	0.42
Height, cm	172.9 ± 10.2	173.3 ± 9.9	172.5 ± 10.6	0.26
Weight, kg	91.3 ± 21.9	92.0 ± 21.6	90.6 ± 22.3	0.39
BMI, kg/m²	30.5 ± 6.7	30.6 ± 6.5	30.3 ± 6.8	0.65
BSA, m²	2.1 ± 0.3	2.1 ± 0.3	2.1 ± 0.3	0.28
Coronary angiography ± LHC	643 (84.2)	349 (87.0)	294 (81.0)	0.66
Femoral access	231 (30.2)	125 (31.2)	106 (29.2)	
Radial access	410 (53.7)	222 (55.4)	188 (51.8)	
Brachial access	2 (0.3)	2 (0.5)	0 (0.0)	
FFR	67 (8.8)	36 (9.0)	31 (8.5)	0.83
PCI	181 (23.7)	101 (25.2)	80 (22.0)	0.32
RHC	275 (36.0)	136 (33.9)	139 (38.3)	0.95
Femoral access	81 (10.6)	40 (10.0)	41 (11.3)	
Jugular access	193 (25.3)	95 (23.7)	98 (27)	
Brachial access	1 (0.1)	1 (0.2)	0 (0.0)	
Radiation-absorbing pad	452 (59.4)	244 (61.3)	208 (57.3)	0.26
Fluoroscopy time, min	4.5 [7.2]	5.1 [7.4]	4.2 [6.8]	0.026
Air kerma, mGy	644 [709]	701 [678]	581 [680]	0.001
DAP, mGy × cm²	53,408 [58,119]	57,540 [60,712]	47,239 [56,088]	0.001

Values are mean ± SD, median [interquartile range], or n (%). The p values are for comparisons between phase I and phase II.

BMI = body mass index; BSA = body surface area; DAP = dose-area product; FFR = fractional flow reserve; LHC = left heart catheterization; PCI = percutaneous coronary intervention; RHC = right heart catheterization.

FIGURE 2 Impact of Accessory Lead Shielding on Radiation Exposure Among Nurses and Technologists During Cardiac Catheterization



The median values of effective dose normalized to the dose-area product (E_{DAP}) per case as experienced by nurses and technologists during cardiac catheterization procedures are shown with and without the use of accessory lead shields.

TABLE 2 Effective Dose Normalized to Dose-Area Product per Case Among Technologists and Nurses According to Various Procedural Characteristics

	E_{DAP} When Variable Present (μSv/[mGy × cm^2] × 10^{-5})	E_{DAP} When Variable Absent (μSv/[mGy × cm^2] × 10^{-5})	p Value
Scrub technologist			
Accessory lead shield	0.9 [2.8]	2.4 [4.3]	<0.001
Right heart catheterization	2.8 [9.0]	1.4 [2.9]	<0.001
Radial access	1.1 [2.7]	1.9 [3.4]	<0.001
Fractional flow reserve	1.0 [2.1]	1.8 [4.2]	0.017
Bypass graft angiography	1.6 [2.7]	1.7 [4.1]	0.507
PCI	1.8 [3.5]	1.7 [4.4]	0.557
Radiation-absorbing pad	1.2 [2.8]	2.8 [7.8]	<0.001
Nurse circulator			
Accessory lead shield	0.4 [1.8]	1.1 [3.1]	<0.001
Right heart catheterization	0.3 [2.2]	0.9 [2.6]	<0.001
Radial access	0.8 [2.5]	0.8 [2.3]	0.794
Fractional flow reserve	1.9 [3.2]	0.7 [2.4]	<0.001
Bypass graft angiography	0.8 [2.6]	0.7 [2.6]	0.811
PCI	2.1 [3.5]	0.4 [1.9]	<0.001
Radiation-absorbing pad	0.9 [2.6]	0.4 [2.3]	0.001

Values are median (interquartile range).
E_{DAP} = effective dose normalized to the dose-area product; PCI = percutaneous coronary intervention.

DISCUSSION

The principal finding of the present study is that the simple and relatively inexpensive approach of providing staff members with a dedicated accessory lead shield during cardiac catheterization was associated with a nearly two-thirds reduction in radiation exposure among both nurses and technologists. This proactive approach to shielding staff members from radiation remained associated with a significant reduction in E_{DAP} by multivariate analysis. Whereas use of accessory shields has previously been shown to effectively attenuate physician radiation exposure (12,13), the present study is the first, to our knowledge, to observe a similar benefit among nonphysician staff members, an observation that may have important implications for occupational safety in the cardiac catheterization laboratory.

RADIATION EXPOSURE IS OCCUPATION SPECIFIC. Although proactive shielding was associated with a reduction in radiation exposure among both nurses and technologists, it is notable that other procedural variables associated with radiation exposure were occupation specific. These occupation-specific differences may be partly attributable to the location and mobility of the staff member during cardiac catheterization. Technologists, who stand at the procedure table adjacent to the operating physician, are relatively stationary during cardiac catheterization and often remain at a somewhat fixed distance from the radiation source throughout the procedure. Because of this fixed distance, the radiation exposure of technologists depends upon the amount of radiation used during the case, which was controlled for in the present study by normalizing effective doses to the DAP, and the degree of shielding. This concept likely explains why use of an accessory lead shield and radiation-absorbing pad were the only procedural variables independently associated with a reduction in radiation by multivariate analysis.

In contrast to technologists, who remain relatively stationary during cardiac catheterization, nurse circulators are often mobile throughout the procedure. As a result of this mobility, the distance between the nurse and radiation source fluctuates during cardiac catheterization. Hence, procedures that require the nurse to be in closer proximity to the patient during catheterization likely result in higher radiation exposures. This concept may account for the observation that PCI was not associated with an increase in exposure among technologists, yet PCI was associated with a striking 425% increase in E_{DAP} among nurses by univariate analysis, a finding that remained highly significant by multivariate analysis. It is important to note that the observed increase in E_{DAP} with PCI was not attributable to an increase in radiation use during PCI cases, as the E_{DAP} variable normalizes the effective dose for the amount of radiation used during each case. Rather, the observed association between PCI and an increase in E_{DAP} among nurses likely indicates that nurses are performing certain occupational duties during PCI that place them in closer proximity to the patient and thereby dramatically increase their radiation exposure. These PCI-related duties may include approaching the patient while fluoroscopy is in use to administer oral antiplatelet therapy, provide supplemental oxygen, or administer intravenous medications. Similar duties, such as administering intravenous heparin or adenosine, are performed during FFR and may account for

TABLE 3 Variables Independently Associated With Log of Effective Dose Normalized to Dose-Area Product Among Technologists and Nurses by Multivariate Linear Regression Analysis

	Δ% Exposure	β	p Value
Scrub technologists			
Accessory lead shield	−34.2 (−45.8 to −20.1)	−0.4 (−0.6 to −0.2)	<0.001
Radiation-absorbing pad	−47.0 (−55.9 to −36.2)	−0.6 (−0.8 to −0.4)	<0.001
Nurse circulators			
Accessory lead shield	−36.4 (−49.6 to −19.7)	−0.5 (−0.7 to −0.2)	<0.001
Fractional flow reserve	41.9 (0.7 to 100.1)	0.4 (0.0 to 0.7)	0.046
PCI	112.2 (66.2 to 171.0)	0.8 (0.5 to 1.0)	<0.001

Values in parentheses are 95% confidence intervals.
Δ% Exposure = percentage change in the log of E_{DAP} between groups; other abbreviations as in Table 2.

the observed 171% increase in E_{DAP} among nurses in cases in which FFR was performed. The observations in the present study indicate that PCI and FFR may represent targets through which future efforts could be made to improve occupational radiation exposure among nurses.

MITIGATING STAFF RADIATION EXPOSURE. The ability of staff members to optimally protect themselves from scatter radiation during cardiac catheterization is hindered by several factors. It is important to note that reducing the patient dose during cardiac catheterization will result in less scatter radiation and less exposure for physicians and staff members. However, unlike physicians, who often singularly control the amount of radiation administered during a case, nurses and technologists may have no control over radiation use. Although increasing one's distance from the radiation source can substantially reduce exposure, technologists are not often able to increase their distance from the radiation source, as their presence is frequently required at the operating table. Similarly, nurses are often required to be in close proximity to the patient to administer medications and attend to the patient's needs, which are job-related activities that might carry substantial occupational risk.

STUDY LIMITATIONS. The single-center, observational study design represents the most significant limitation. The impact of accessory lead shields on staff radiation exposure could be more vigorously evaluated in the context of a randomized controlled trial. Because the 2 study phases were conducted serially, the potential influence of a learning effect among nurses and technologists on the study results cannot be excluded. Hence, nurses and technologists could have become increasingly focused on radiation protection during the course of the study and may have consciously or subconsciously enhanced their protective behaviors. Such actions would favor lower radiation exposures in phase II. The difference in radiation use in the 2 study phases, evident in a lower fluoroscopy time, air kerma, and DAP in phase II, represents another limitation and occurred despite the absence of significant differences in other procedural characteristics in the 2 study phases. This limitation was addressed by normalizing staff radiation exposures to DAP when making comparisons between phases. The lower radiation use in phase II might suggest a secondary benefit attributable to accessory shields, namely, that their presence might have heightened radiation awareness and inadvertently lead physicians to use less radiation per case. Such an effect could have secondary beneficial effects on the radiation exposure to physicians and patients. Considering that nurses and technologists were often the same individuals in phases I and II, their data were not independent, and the optimal statistical approach would have accounted for this. However, identifiable data on the individual staff members involved in each case were not collected.

That higher levels of radiation reduction were not observed with shielding in the present study likely reflects that neither technologists nor nurses were able to maintain a constant position behind the accessory shield for the entire case. Because technologists in this study performed coronary injections using a contrast delivery system, it is unclear whether the present results can be extrapolated to centers at which technologists do not perform injections. The contrast delivery system used in this study limited the ability of technologists to maximize their distance from the radiation source. Hence, whether accessory lead shields would effectively reduce radiation exposure at centers at which technologists can further increase their distance from the radiation source remains unknown. The fact that radiation-absorbing pads were used in 59% of cases limits the ability to extrapolate the present results to institutions that do not routinely use radiation-absorbing pads. Considering that steeper angulation of the x-ray system increases scatter radiation, the present study is limited because angulation of the system was not recorded and accounted for in this analysis. Finally, the use of accessory lead shields, which might be effective to reduce staff radiation exposure, will not likely reduce other occupational hazards of working in the catheterization laboratory related to wearing heavy lead garments, including the risks for orthopedic injuries and experiencing chronic work-related pain (16,17).

CONCLUSIONS

The present study demonstrates that use of an accessory lead shield during cardiac catheterization is associated with a nearly two-thirds reduction in radiation exposure among nurses and scrub technologists. This simple and relatively inexpensive approach to shielding staff members from radiation exposure may have important implications for occupational safety in the cardiac catheterization laboratory.

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PERSPECTIVES

WHAT IS KNOWN? It was formerly demonstrated that placing an accessory lead shield between the operating physician and patient effectively attenuates physician radiation exposure, yet the effectiveness of similarly shielding staff members during cardiac catheterization was previously unknown.

WHAT IS NEW? The present study demonstrates that use of an accessory lead shield during cardiac catheterization is associated with a nearly two-thirds reduction in radiation exposure among nurses and scrub technologists.

WHAT IS NEXT? Although the use of accessory lead shields is associated with a reduction in staff radiation exposure, shielding will not likely reduce other occupational hazards of working in the catheterization laboratory, including the risks for orthopedic injuries and experiencing chronic work-related pain. Additional studies will be required to address these other occupational hazards.

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KEY WORDS cardiac catheterization, occupational hazard, radiation safety