Effects of Real-Time Dosimetry on Staff Radiation Exposure in the Cardiac Catheterization Laboratory

Dilschad Murat, MD[1]; Christian Wilken-Tergau, MD[1*]; Uta Gottwald, MD[1]; Ole Nemitz, MD[1]; Thomas Uher, MD[1]; Eberhard Schulz, MD[1,2]*

The goal of our study was to quantify a possible reduction of radiation exposure by the use of real-time dosimetry with respect to individual operators and access site.

Abstract

Objectives. Radiation protection is essential for staff of cardiac catheterization laboratories in order to prevent long-term radiation-associated injury and disease. Instant feedback about the actual received dose may help operators to optimize the use of existing shielding devices. Therefore, the current study was designed to investigate whether routine use of real-time dosimetry may be able to reduce staff radiation exposure. **Methods and Results.** Over a period of 72 days, operators and assisting nurses were equipped with RaySafe i3 real-time dosimeters (Unfors RaySafe AB), but had no access to the dosimetry results during the first half of the study. This was followed by a second period that allowed operators to modify their behavior according to the dosimetry results. Compared with the first phase, the knowledge of real-time dosimetry results led to a uniform reduction in radiation exposure of all team members by approximately 60%, independent of the chosen vascular access. There were no significant changes in fluoroscopy time, dose-area product, or patient characteristics. **Conclusions.** Real-time dosimetry effectively reduced staff radiation exposure in the cardiac catheterization laboratory. This change was caused by optimized use of existing shielding equipment since no modifications of the general procedural approach or patient characteristics had occurred.

Reprinted with permission from J INVASIVE CARDIOL 2021;33(5):E337-E341. Epub 2021 April 5.

Key words: cardiac interventions, dosimetry, radiation protection

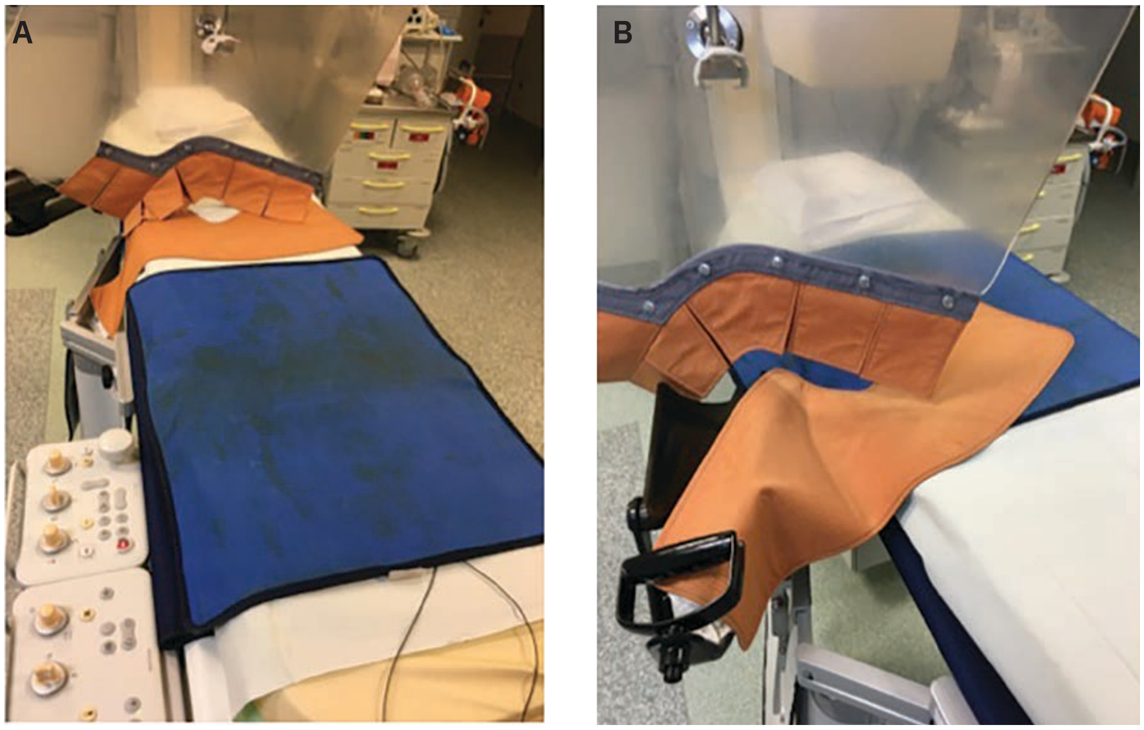

Figure 1. Arrangement of shielding drapes during (A) transfemoral and (B) transradial catheterization procedures.

Cardiac interventions are increasingly performed worldwide, driven in particular by the emerging field of valvular and structural heart interventions. However, coronary interventions remain the mainstay of all diagnostic and therapeutic interventions due to the high prevalence of atherosclerotic coronary artery disease. Nearly all cardiac interventions require x-ray based imaging, while increased procedure numbers and complexity create a potential hazard for the involved staff by accumulating exposure to scattered radiation. As a consequence, interventional cardiologists receive the highest amounts of radiation among medical personnel[1] and bear an increased risk for cataract[2,3] or even malignancies including brain or neck tumors.[4]

Besides advancements in the technology of fluoroscopy workplaces, the use of shielding devices and adequate behavior in the catheterization laboratory are most effective in reducing staff radiation exposure. Today, real-time dosimetry can provide information about the effective use of these measures and may uncover specific shielding needs in individual treatment scenarios with respect to access site (eg, femoral or radial) or the use of additional equipment (eg, optical coherence tomography, fractional flow reserve, rotablation, and circulatory support).

Since real-time dosimetry enables staff to adapt their behavior in order to minimize unnecessary radiation, we investigated whether adding this technique to our daily practice would result in lower radiation exposure. For this purpose, we recorded individual staff dosimetry data before and after access to the real-time dosimetry results. During the first period, interventionalists and assisting personnel wore individual real-time dosimeters, but the results were not displayed inside the catheterization laboratory. During the second period, the operating cardiologist as well as assisting staff had access to the results of online dosimetry during the procedure and were able to adapt their behavior and the use of shielding accordingly. The goal of our study was to quantify a possible reduction of radiation exposure by the use of real-time dosimetry with respect to individual operators and access site.

Methods

Cardiac catheterization laboratory set-up and description of included coronary procedures. From June 3, 2019 to August 14, 2019, a total of 270 coronary procedures were performed in one of the two cardiac catheterization laboratories at the General Hospital Celle, Germany. The laboratory is equipped with a monoplane Allura Xper FD 10 angiography unit (Philips) built in 2013. Procedures included diagnostic angiographies as well as percutaneous coronary interventions. The access site was left to the operator's discretion and included transfemoral or transradial approaches. All procedures were exclusively performed by experienced cardiologists with at least 500 cases as first operator. No educational angiographies or interventions were included. Importantly, no changes in procedural strategies were allowed in order to prevent changes in dosimetry results not related to optimized shielding and/or staff behavior.

For all patient data, ethical approval was waived by the local ethics committee of the Ärztekammer Niedersachsen (Bo/19/2020) in view of the retrospective nature of the study and all the procedures being performed were part of the routine care. Regarding staff dosimetry data, all team members gave their informed consent to participate in the study.

Radiation protection equipment. All staff members working inside the cardiac catheterization laboratory wore protective lead aprons including thyroid collars. Operators had individual leaded glasses. Shielding devices included table-mounted lead curtains with an upper shield, ceiling suspended lead-acrylic shields with x-ray protective strips (OT54001), as well as a separate, sterile covered and reusable shielding drape (ST-FS5AMM, all from MAVIG GmbH). For radial procedures, a large shielding drape (60 x 80 cm) was placed on the lower abdomen; for femoral procedures, the same shielding drape was placed on the legs just caudal to the access site (Figure 1).

Real-time dosimetry. For the duration of the investigation, the manufacturer (Unfors RaySafe AB) provided a RaySafe i3 system including 3 individual dosimeters and a separate screen to visualize real-time dosimetry results inside the catheterization laboratory. Each detector was worn at the outer side of the x-ray protective clothing (left side of the thyroid collar). Radiation exposure was analyzed every second during the time of each procedure and obtained cumulative dose (µSv) was transmitted wireless to the display. In the first part of the study, operators and assisting staff wore individual dosimeters without access to the results inside the catheterization laboratory ("blinded period"), while in the second period the system was used with instant visualization of the radiation exposure results for all staff members ("unblinded period").

Table 1. Patient and procedural data.

	Blinded	Unblinded	*P*-Value
Procedures (n)	122	148	
Patient height (cm)	171.1 ± 0.8	171.1 ± 1.0	.94
Patient weight (kg)	82.7 ± 1.6	81.3 ± 1.5	.50
Body mass index (kg/m^2)	28.7 ± 0.7	27.7 ± 0.4	.63
Transradial access	48.4%	32.4%	—
Transfemoral access	52.5%	67.6%	—
Coronary angiogram	90.2%	92.6%	—
PCI of right coronary artery	13.9%	9.5%	—
PCI of left coronary artery	29.5%	36.5%	—
Fluoroscopy time (minutes)	7.0 ± 0.6	8.2 ± 0.6	.07
Dose area product (Gy•cm^2)	15.2 ± 1.3	15.4 ± 1.2	.49

Data presented as count, percentage, or mean ± standard deviation. PCI = percutaneous coronary intervention.

TABLE 2. Real-time dosimetry data from individual operators.

	Blinded	Unblinded	% of Blinded	*P*-Value
Operator 1				
Procedures (n)	35	23	—	—
Dosage (µSv)	0.54 ± 0.17	0.22 ± 0.05	40.7	.78
Operator 2				
Procedures (n)	19	17	—	—
Dosage (µSv)	3.29 ± 0.74	0.79 ± 0.2	24.0	<.01
Operator 3				
Procedures (n)	19	29	—	—
Dosage (µSv)	1.10 ± 0.23	0.56 ± 0.09	50.9	.10
Operator 4				
Procedures (n)	21	18	—	—
Dosage (µSv)	1.70 ± 0.74	0.43 ± 0.13	25.3	.05

Data presented as count, percentage, or mean ± standard deviation.

In the first part of the study, operators and assisting staff wore individual dosimeters without access to the results inside the catheterization laboratory ("blinded period"), while in the second period the system was used with instant visualization of the radiation exposure results for all staff members ("unblinded period").

Statistical analysis. Continuous variables are presented as mean ± standard error of the mean, significance was tested by an unpaired t-test or Mann-Whitney test as applicable. D'Agostino-Pearson test was used to assess normal distribution. Discrete variables are displayed as counts and percentages and were compared with the Chi-squared test. *P*-values of <.05 were considered statistically significant.

Results

Patient and procedural data. We analyzed data from 270 consecutive coronary catheterization procedures between June 3, 2019 and August 14, 2019 at our institution (General Hospital Celle, Germany). Of all included patients, 121 (44.8%) underwent coronary interventions. Transradial access was performed in 106 cases (39.3%), while transfemoral access was performed in 163 patients

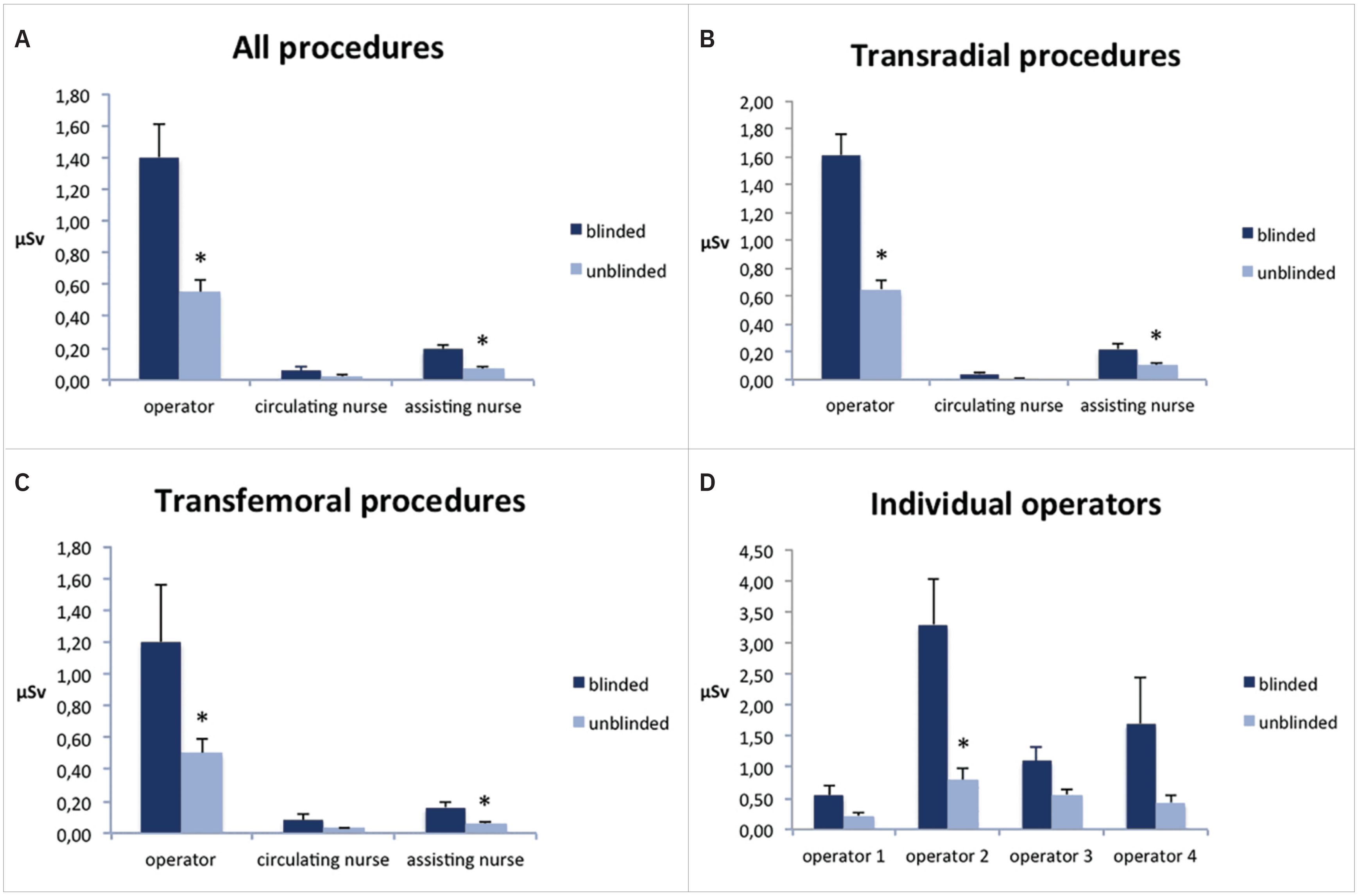

Figure 2. Overall change in radiation exposure by real-time dosimetry among different members of the cardiac catheterization laboratory team. (A) Average cumulated radiation exposure data (per procedure) are displayed for individual staff members during the blinded period (black bars) and unblinded period (grey bars). Staff exposure is separately shown for all (B) transradial and (C) transfemoral procedures. (D) Individual cumulated radiation exposure data (per procedure) from 4 different operators who performed the majority of all cases. *Indicates *P*<.05 vs blinded.

(60.4%). The majority of procedures included a diagnostic angiogram, while coronary interventions were performed in 43.4% of all cases during the blinded period and in 46% during the unblinded period (Table 1). Biometric data of patients, including weight, height, or body mass index, were comparable between the two periods. Even more important, no significant difference was observed regarding fluoroscopy time (7.0 ± 0.6 minutes during the blinded period vs 8.2 ± 0.6 minutes during the unblinded period) or dose area product (15.2 ± 1.3 Gy•cm^2 during the blinded period vs 15.4 ± 1.2 Gy•cm^2 during the unblinded period), indicating that no change in radiation protocols or strategies occurred between both observation periods (Table 1).

Effects of real-time dosimetry on overall staff radiation exposure. Real-time dosimetry led to ~60% reduction in operator and assisting nurse radiation exposure during the unblinded period, as illustrated in Figure 2A (operator, 0.55 ± 0.08 µSv vs 1.40 ± 0.21 µSv during the blinded period [*P*<.01]; assisting nurse, 0.07 ± 0.02 µSv vs 0.19 ± 0.03 µSv during the blinded period [*P*<.01]). A similar trend was observed for circulating nurses (0.02 ± 0.01 µSv vs 0.06 ± 0.02 µSv during the blinded period; *P*=.23).

Radiation exposure with respect to access route. Different access routes change the set-up and shielding options in the catheterization laboratory and might therefore affect staff radiation exposure. We analyzed our data separately for transradial vs transfemoral procedures and found a similar magnitude of staff dose reduction by the use of real-time dosimetry. Again, these results were significant for operators and assisting nurses while the same trend was observed for circulating nurses (Figures 2B and 2C). Importantly, no change was observed in patient radiation exposure as indicated by the comparable dose-area product (transradial access, 15.7 ± 1.06 Gy•cm^2 during the blinded period vs 15.1 ± 1.00 Gy•cm^2 during the unblinded period [*P*=.99]; transfemoral access, 14.9 ± 1.98 Gy•cm^2 during the blinded period vs 15.6 ± 1.36 Gy•cm^2 during the unblinded period [*P*=.29]).

Individual radiation exposure of different operators. Protective behavior and the use of protection devices varies among individual operators and could therefore attenuate the beneficial effects of real-time dosimetry. We separately analyzed radiation exposure data from 4 operators who performed the highest number of cases during the observation period. For all operators, a similar degree of dose reduction by real-time dosimetry was observed despite a variation in baseline levels (Table 2; Figure 2D).

Discussion

Interventional cardiology is one of the most dynamic fields in medicine and has made dramatic progress over the last 2 decades. With increasing procedure numbers, radiation exposure to the catheterization laboratory personnel accumulates[1] and may result in serious adverse health effects including cataract formation[3] or malignancies.[4] Therefore, all preventive measures leading to a sustained reduction of radiation exposure should be utilized. Technological advances have led to excellent visibility despite low

We found that the use of real-time dosimetry led to a 60% reduction of staff radiation exposure, which is similar to the results reported in an interventional radiology setting.[7,8] This change was significant in personnel with the highest exposure dose (operators, assisting nurses), while the same trend was seen in the less-exposed circulating nurses.

x-ray dose levels, and applications such as "last image hold" or fusion imaging have further diminished necessary fluoroscopy times and intensity. However, the major part of radiation protection is based on continuous educational efforts in order to avoid any unnecessary radiation. This will reduce both the effective dose applied to the patient as well as staff exposure by less scattered radiation.[5] Regarding the latter, keeping maximal possible distance to the table as well as the use of personal and installed shielding devices[6] are important factors. Real-time dosimetry has been introduced as a tool to visualize radiation exposure immediately, thereby allowing users to adapt their behavior and the use of shielding accordingly.[7]

In the current study, we analyzed the effects of implementing a real-time dosimetry system (RaySafe i3) on staff radiation exposure during routine procedures in the cardiac catheterization laboratory. We found that the use of real-time dosimetry led to a 60% reduction of staff radiation exposure, which is similar to the results reported in an interventional radiology setting.[7,8] This change was significant in personnel with the highest exposure dose (operators, assisting nurses), while the same trend was seen in the less-exposed circulating nurses. Importantly, the applied patient dose in terms of dose-area product or fluoroscopy time was not significantly different between both observation periods. Since no changes in procedural strategies (eg, the use of angulations with less exposure, abandoned cine sequences) were allowed, the observed staff dose reduction must be attributed to the optimized use of existing shielding devices and adequate behavior in the catheterization laboratory.

We found that the degree of dose reduction by real-time dosimetry was independent of the chosen access site. This is important and shows a particular strength of instantaneous dose feedback as it allows a quick adaptation to different set-ups and individual procedural settings. Moreover, individual operators achieved a similar reduction of radiation exposure, although baseline levels were quite different (up to 6 times compared with the lowest operator dose). This result indicates that a further dose reduction is still possible even for operators who already incorporated radiation protection as a fundamental part of their daily practice.

Study limitations. Despite these clear and encouraging results, our study has several limitations. First, the number of included patients is limited and may have prevented statistical significance for some of the observed trends. Moreover, the amount of dose reduction by real-time dosimetry depends on individual availability of shielding devices and motivation of all team members and may be less prominent in other settings. Our study did not assess effects of individual strategies or procedural preferences, although real-time dosimetry may also be used to modify the general procedural approach in future investigations. All procedural details and settings such as access route or standard angulations were left to the operator's discretion in order to allow a broad translation of our results for varying settings. However, all operators were instructed to maintain their general procedural approaches during the course of the study. Although we demonstrate a significant effect of real-time dosimetry on individual radiation exposure, we cannot predict whether this effect may be maintained over time (even without further use of real-time dosimetry) as staff members may have been "educated" by the system regarding their deficiencies in radiation protection.[8]

Conclusion

Our study is the first to identify real-time dosimetry as an effective concept to reduce staff radiation exposure in the cardiac catheterization laboratory. Hospitals that offer invasive cardiology should consider the implementation of this technique to protect their employees from radiation-associated health hazards. ■

Acknowledgments. We thank the nursing staff of the cardiac catheterization laboratory at the General Hospital Celle for excellent technical assistance and MD Solutions/Unfors RaySafe for providing the i3 real-time dosimetry device for this study. Data of the present study are part of the medical thesis of co-author Dilschad Murat, MD.

References

1. Venneri L, Rossi F, Botto N, et al. Cancer risk from professional exposure in staff working in cardiac catheterization laboratory: insights from the National Research Council's biological effects of ionizing radiation VII report. *Am Heart J*. 2009;157:118-124.
2. Karatasakis A, Brilakis HS, Danek BA, et al. Radiation-associated lens changes in the cardiac catheterization laboratory: results from the IC-CATARACT (CATaracts Attributed to RAdiation in the CaTh lab) study. *Catheter Cardiovasc Interv*. 2018;91:647-654.
3. Buchanan GL, Chieffo A, Mehilli J, et al. The occupational effects of interventional cardiology: results from the WIN for safety survey. *EuroIntervention*. 2012;8:658-663.
4. Roguin A, Goldstein J, Bar O, Goldstein JA. Brain and neck tumors among physicians performing interventional procedures. *Am J Cardiol*. 2013;111:1368-1372.
5. Gutierrez-Barrios A, Camacho-Galan H, Medina-Camacho F, et al. Effective reduction of radiation exposure during cardiac catheterization. *Tex Heart Inst J*. 2019;46:167-171.
6. Heidbuchel H, Wittkampf FH, Vano E, et al. Practical ways to reduce radiation dose for patients and staff during device implantations and electrophysiological procedures. *Europace*. 2014;16:946-964.
7. Poudel S, Weir L, Dowling D, Medich DC. Changes in occupational radiation exposures after incorporation of a real-time dosimetry system in the interventional radiology suite. *Health Phys*. 2016;111:S166-S171.
8. Baumann F, Katzen BT, Carelsen B, Diehm N, Benenati JF, Pena CS. The effect of real-time monitoring on dose exposure to staff within an interventional radiology setting. *Cardiovasc Intervent Radiol*. 2015;38:1105-1111.

Dilschad Murat, MD[1*]; Christian Wilken-Tergau, MD[1*]; Uta Gottwald, MD[1]; Ole Nemitz, MD[1]; Thomas Uher, MD[1]; Eberhard Schulz, MD[1,2]

[*]*Joint first authors.*

From the [1]Department of Cardiology, Allgemeines Krankenhaus Celle, Celle, Germany; and the [2]Department of Cardiology 1, Center for Cardiology, Universitätsmedizin Mainz, Mainz, Germany.

Disclosure: The authors have completed and returned the ICMJE Form for Disclosure of Potential Conflicts of Interest. The authors report no conflicts of interest regarding the content herein.

Manuscript accepted November 5, 2020.

Address for correspondence: Eberhard Schulz, MD, Department of Cardiology, Allgemeines Krankenhaus Celle, 29223 Celle, Germany. Email: eberhard.schulz@akh-celle.de.

Proper Shielding Technique in Protecting Operators and Staff From Radiation Exposure in the Fluoroscopy Environment

Lloyd W. Klein, MD

Radiation shielding can provide effective protection from scatter radiation during cardiac interventional procedures, but the individual shields must be thoughtfully and precisely arranged to achieve optimum protection.[1] Since the employment of fluoroscopic shielding continues to be operator-dependent,[2-4] its effectiveness varies considerably. Current catheterization laboratory design requires the operator to coordinate the placement of the x-ray tube, the image intensifier, and both ceiling and table-mounted shields to obtain the best images and protect those who work in the lab. Proper positioning by the primary operator is considered voluntary even though the occupational hazards of unnecessary exposure affect the health of the entire staff in the working environment.

> **Correct shielding practices are well known, but actually employing them once the case is underway sometimes takes lower precedence.**

Scatter radiation is the principal source of radiation exposure to interventional physicians and fluoroscopy suite staff.[3,4] Scatter radiation is secondary radiation spreading in various directions when a beam interacts with objects, causing the x-rays to be dispersed. In the catheterization laboratory, the patient's body is the primary object that deflects radiation, causing it to distribute around the room. The operator is at highest risk consequent to relative proximity to the patient and x-ray beam.

Standard catheterization suite shielding combines a movable ceiling suspended and fixed table-side shielding to significantly reduce scatter radiation exposure.[5] Minimizing the area of the vertical gap between these shields minimizes scatter radiation "leakage" through the gap and reduces operator exposure. This gap is accentuated by moving the shield away from the patient's body surface and further away from the access site. Therefore, the best protection from scatter radiation is provided when the upper body shield is located relatively far from the scatter source and close to the physician to minimize the effective size of the gap in protection that is created by the patient contour cutout.[3] The most common error is positioning the shield close to the image detector and x-ray tube and directly over the patient (ie, farther from the operator). Although this position is commonly taught as being the correct one, in fact, positioning the ceiling shield closer to the x-ray tube to maximize its radiation "shadow" is less effective than using the shield as one would use an umbrella in wind-driven rain, that is, as close to the operator as possible.[1] When correctly placed, shields can provide at least 80% protection from scatter at all table elevations.[4] Use of accessory soft extensions along the bottom edge of the upper body shield helps to maintain contact between the patient and shield, thereby minimizing the amount of scatter directed toward the physician.

In the May 2021 of the *Journal of Invasive Cardiology*, Murat and colleagues[6] evaluate how real-time dosimetry providing on-the-spot radiation exposure feedback motivated modifications in the use of shielding equipment available in the catheterization laboratory. During the first 36 days, dosimetry was measured but the staff had no access to the results, while in the second phase, knowledge of their exposure motivated behavioral changes sufficient to produce a 60% reduction. Despite a variation in baseline levels, this feedback resulted in better use of protection devices in the highest-volume operators. Real-time dosimetry is therefore an effective teaching tool to motivate better shielding technique to reduce staff radiation exposure in the cardiac catheterization laboratory.

Most importantly, Murat et al[6] demonstrate how much more can be done practically to protect staff and ourselves once attention is called to the subject. Correct shielding practices are well known, but actually employing them once the case is underway sometimes takes lower precedence. To maintain effective protection during procedures, the upper body shield requires continual repositioning when the patient table height is adjusted, when the table is moved longitudinally or laterally, or when it must be moved to avoid collision with the x-ray system for steep caudal angles. Because the upper body shield must be specifically placed by the physician and often is moved during the procedure, it must be continually readjusted. The sense of nuisance this creates must be consciously overcome; although we know intellectually that shielding works and is important, it is an annoyance to be concerned with it when our minds are focused on the patient. That the most advantageous shield positioning can have a greater than 4-fold relative reduction in scatter radiation exposure supports its use even when inconvenient, and suggests that learning to coordinate multiple shields should be among the fundamental principles taught in every interventional cardiology training program.[7-9]

The basic radiation protection principles of radiation safety are time, distance, and shielding. Time means limiting exposure to the minimum amount possible. Distance means staying as far from radiation sources as possible as a best practice. The intensity of radiation generally follows the inverse-square law, meaning that it decreases with the square of the distance from the source. Moving twice the distance away from a source of radiation reduces the intensity of exposure by a factor of (one-half)^2 or one-fourth the value. Unfortunately, increasing the distance from the scatter source may be awkward for operators, who are working close to the patient.

Beyond time and distance, making use of effective shielding is the best approach to managing exposure to radiation. Radiation shield protection products are lead-lined glass or latex/plastic. Shielding means placing something that will absorb radiation between the source of the radiation and the area to be protected. The concept of shielding is based on the principle of

> **The future interventional laboratory must be designed so that radiation safety is not predicated on the voluntary cooperation, sensitivity, and education of operators, but rather is constructed into the design of the laboratory.[7,12]**

attenuation, which is the loss in intensity of a beam of radiation as it traverses through barrier material. Attenuation is the result of interactions between x-ray and matter from a combination of absorption and scatter. The differential absorption increases as kVp decreases. Lead is particularly well-suited for lessening the effect of x-rays due to its high atomic number, which refers to the number of protons within an atom; a lead atom has a relatively high number of protons along with a corresponding number of electrons. These electrons “block” the x-ray photons that are projected through a lead barrier by absorbing their energy. The degree of protection can be enhanced by using thicker shielding barriers. Because of the heavy weight of lead, layers of bismuth and some lightweight synthetic materials are often used in garments.[10,11]

The meticulous application of established radiation protection techniques is essential to minimize exposure. Personal protective garments, eyeglasses, and head protection are necessary accoutrements. Collimation of the beam to the specific area being treated is another effective measure, as the larger the amount of tissue the beam is penetrating, the greater the amount of scatter radiation. Selecting judicious table height and angulation to minimize scatter is sensible practice; using high kVp and low mAs techniques reduces scatter and also improves image quality. Mobile lead shields of at least 0.25 mm lead equivalency are recommended to be used by anyone working near the table during fluoroscopy procedures when possible.

Despite proof that shielding is an effective remedy and prudent practice, its correct use is not mandatory and remains operator-dependent. The future interventional laboratory must be designed so that radiation safety is not predicated on the voluntary cooperation, sensitivity, and education of operators, but rather is constructed into the design of the laboratory.[7,12] We may need an automated mechanism to place the shields correctly, or a surrounding shell around the patient. More expansive and encompassing lead shielding systems are commercially available.[13]

Moreover, attitudes about personal protection must change; this ought not be a matter of courtesy, but rather a required labor practice.[7] Common physician opinion is that more rules and regulations are the last thing we need; yet, here is an example of a behavior that appears amenable to change, but never does. Interventional cardiologists must accept the challenge to adopt healthier attitudes and new technologies for the reduction of occupational hazards.[7-9] The study by Murat demonstrates that we are teachable if given positive feedback in a manner that reminds us what adequate protection entails in real time. ■

References

1. Klein LW, Maroney J. Optimizing operator protection by proper radiation shield positioning in the interventional cardiology suite. *JACC Cardiovasc Interv*. 2011; 10: 1140-1141.
2. Klein LW, Miller DL, Balter S, et al. on behalf of the members of the Joint Inter-Society Task Force on Occupational Hazards in the Interventional Laboratory. Occupational hazards in the interventional laboratory. Time for a safer environment. *Catheter Cardiovasc Interv.* 2009; 73: 432-436.
3. Fetterly KA, Magnuson DJ, Tannahill GM, Hindal MD, Mathew V. Effective use of radiation shields to minimize operator dose during invasive cardiology procedures. *JACC Cardiovasc Interv*. 2011; 10: 1133-1139.
4. Kim KP, Miller DL, Balter S, et al. Occupational radiation doses to operators performing cardiac catheterization procedures. *Health Phys.* 2008; 94: 211-227.
5. Kuon E, Schmitt M, Dahm JB. Significant reduction of radiation exposure to operator and staff during cardiac interventions by analysis of radiation leakage and improved lead shielding. *Am J Cardiol.* 2002; 89: 44-49.
6. Murat D, Wilken-Tergau C, Gottwald U, Nemitz O, Uher T, Schulz E. Effects of real-time dosimetry on staff radiation exposure in the cardiac catheterization laboratory. *J Invasive Cardiol.* 2021; 33: E337-E341.
7. Klein LW, Goldstein JA, Haines D, et al. Multispecialty Society Position Statement. Occupational hazards of the catheterization laboratory: shifting the paradigm for healthcare workers’ protection. *J Am Coll Cardiol.* 2020; 75: 1718-1724.
8. Chambers CE, Fetterly KA, Holzer R, et al. Radiation safety program for the cardiac catheterization laboratory. *Catheter Cardiovasc Interv*. 2011; 77: 546-556.
9. Fetterly KA, Mathew V, Lennon R, Bell MR, Holmes DR, Rihal CS. Radiation dose reduction in the invasive cardiovascular laboratory: implementing a culture and philosophy of radiation safety. *JACC Cardiovasc Interv*. 2012; 5: 866-873.
10. A guide to the use of lead for radiation shielding. Accessed on April 10, 2021. Available at https://www.canadametal.com/wp-content/uploads/2016/08/radiation-shielding.pdf
11. USEPA. Protecting yourself from radiation. Accessed on April 10, 2021. Available at https://www.epa.gov/radiation/protecting-yourself-radiation.
12. Klein LW, Miller DL, Goldstein J, et al; on behalf of the members of the Multispecialty Occupational Health Group. The catheterization laboratory and interventional vascular suite of the future: anticipating innovations in design and function. *Catheter Cardiovasc Interv.* 2011; 77: 447-455.
13. Fattal P, Goldstein JA. A novel complete radiation protection system eliminates physician radiation exposure and leaded aprons. *Catheter Cardiovasc Interv*. 2013; 82: 11-16.

Lloyd W. Klein, MD
From the University of California, San Francisco, Cardiology Section, San Francisco, California.

Disclosure: The author has completed and returned the ICMJE Form for Disclosure of Potential Conflicts of Interest. The author reports no conflicts of interest regarding the content herein.

Address for correspondence: Lloyd W. Klein, MD, University of California, San Francisco, Cardiology Section, 505 Parnassus Ave, M1177A, San Francisco, CA 94143. Email: lloydklein@comcast.net