Comparison of fluoroscopic operator eye exposures when working from femoral region, side, or head of patient

M. Jordan Ray, MD, Fawzi Mohammad, MD, William B. Taylor, MD, Marco Cura, MD, and Clare Savage, MD

Operator radiation exposure is an important occupational hazard compounded over the course of an interventional radiologist's career. This study compared operator radiation dose to the eye and head for different positions around the patient. Compared with cases performed from the femoral region, exposures were 1.8 times higher at the side, and 1.6 times higher at the head, using conventional aprons, table shields, and mobile suspended shields. Exposures were 99% lower when using a suspended personal radiation protection system in all positions. In conclusion, standing at the side or head results in higher head exposures in a conventional setup.

Despite improvements in imaging equipment, advances in operator protection have been relatively stagnant, with the eyes and head remaining vulnerable to scatter (1, 2). Interposed shields may be cumbersome and leave gaps in protection, and lead glasses allow scatter to reach the eye from outside the area subtended by the lead lenses, permitting secondary scatter exposure to the lens (1–5). During the wide variety of interventional procedures, operators stand in different positions around the patient where shielding and scatter geometry vary drastically. When standing at the patient's side, such as during a biliary or nephrostomy procedure, the scatter source is a thick body part in close proximity to the operator, whose hands must reach into the scatter path where interposed hanging shields or attenuating blankets are obstructive to the work effort and are often repositioned, decreasing their effectiveness. Similar problems occur when the operator works at the patient's head, where the mobile suspended shield can obstruct the hands and must usually remain at least several inches above the patient's neck. The purpose of this study was to determine how much scatter radiation reached the operator's head and eyes during procedures performed from the side, femoral, or head position using either a standard lead apron with aggressive shielding or a suspended personal radiation protection system (SPRPS).

METHODS

The study was approved by the institutional review board. Exposure data were collected for three primary operators wearing a dosimeter adjacent to the left eye while performing a variety of procedures. The data were accumulated in one interventional suite to minimize variables related to different equipment design, age, or geometry. The suite included an Artis Zee unit (Siemens, Munich, Germany) equipped with three types of ancillary shields depicted in *Figure 1a:* a mobile suspended lead-acrylic shield, an under-table lead skirt, and a table-side shield that extended upwards from the under-table skirt (Mavig, Munich, Germany). The SHIELDS method of primary operator radiation protection is depicted in *Figure 1b.*

The suite also included an SPRPS (ZeroGravity Radiation Protection System, CFI Medical Solutions, Fenton MI) *(Figure 1c).* This overhead-suspended system had a curved lead-acrylic head shield (0.5 mm Pb) and lead apron (1 mm Pb in front) that extended to the distal calves with flaps hanging over the arms to the elbows, which may be covered with a sterile plastic drape to permit entry and exit. The SPRPS method of primary operator protection involved utilization of the suspended personal radiation protection system with the under-table lead skirt, occasional use of the table-side shield, and nonuse of the suspended lead-acrylic mobile shield. The use of the SHIELDS or SPRPS method was determined by preferences of the primary and secondary operators.

The dosimeter was a recently calibrated electronic direct dosimeter with manufacturer-reported sensitivity to 1 nSv (EDD-30, Unfors, Billdal, Sweden). Dosimetry measurements were recorded at the conclusion of each case using the electronic sensor worn near the left eye as depicted in Figure 1b and 1c. This measurement represents a separate exposure record from the standard monthly dosimeter typically worn on the leaded thyroid collar.

Procedures were performed in the standard manner with the primary operator positioned at the femoral region, the side, or the head of the patient *(Figure 2).* The method of protection (SHIELDS vs. SPRPS) was constant for each primary operator throughout each individual case. All primary operators at the institution aggressively utilize all three ancillary shields in all procedures when not using the SPRPS, and they practice patient-exposure reduction practices such as reduction of air

From the Department of Radiology, Baylor University Medical Center at Dallas.

Corresponding author: M. Jordan Ray, MD, Department of Radiology, Baylor University Medical Center at Dallas, 3500 Gaston Avenue, Dallas, TX 75246 (e-mail: Mjordan.ray@gmail.com).

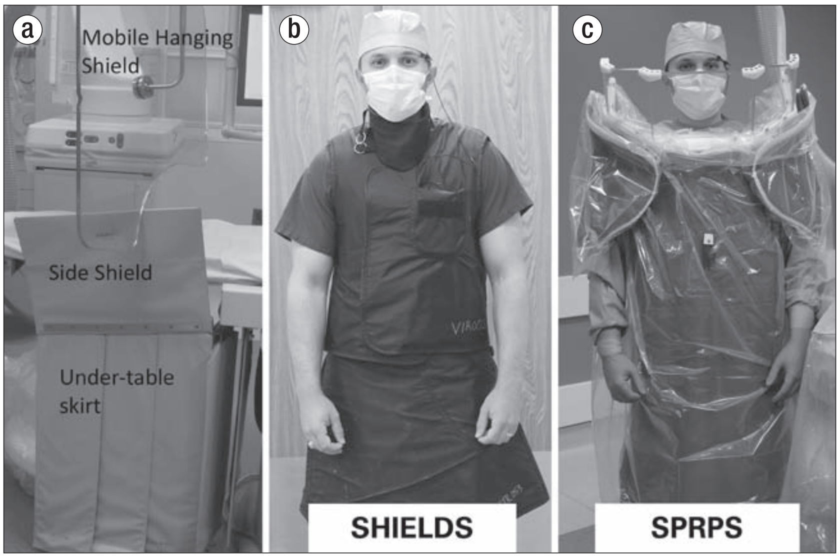

Figure 1. (a) Ancillary shielding including under-table, side-table, and mobile suspended lead shields. **(b)** Lead apron with thyroid collar worn by SHIELDS operators. The dosimeter sensor is shown near the left eye. **(c)** Suspended personal radiation protection system (SPRPS) (ZeroGravity). The sensor is again shown.

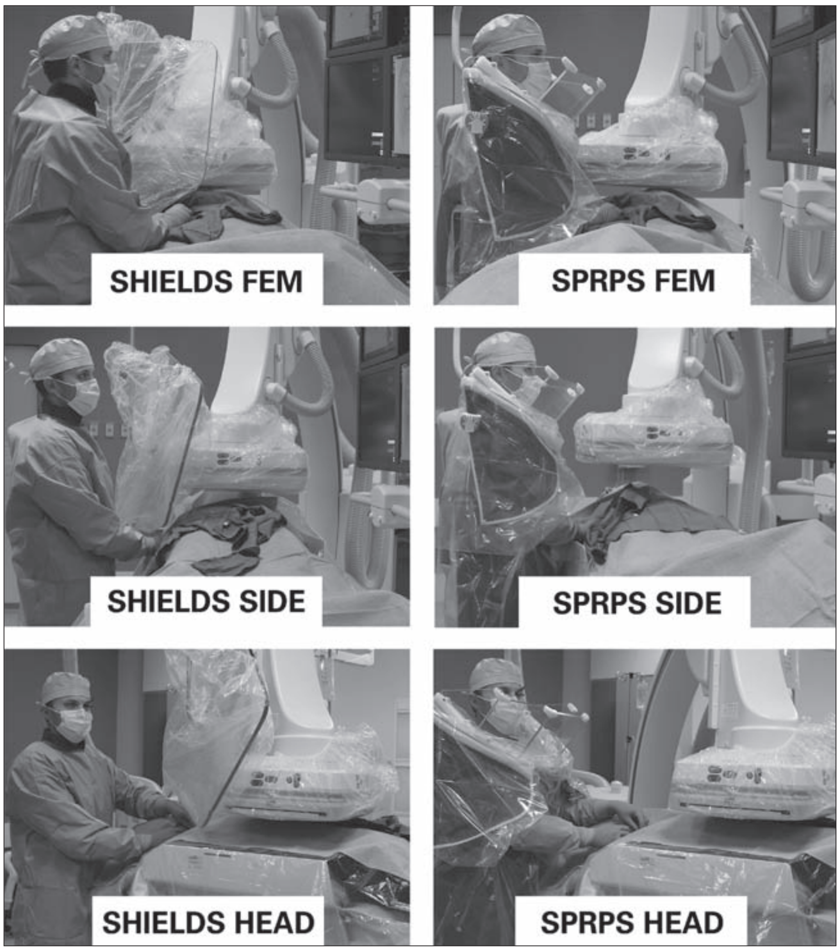

Figure 2. Demonstration of operator stance utilizing both the SHIELDS and SPRPS protection from the femoral (FEM), side, or head positions.

gaps, use of pulsed fluoroscopy, collimation, minimization of fluoroscopy times, and minimization of severely oblique or lateral receptor angles.

Femoral procedures were generally transarterial and transvenous diagnostic and therapeutic procedures in the chest, abdomen, or pelvis. Side procedures included percutaneous nonvascular interventions involving the liver, kidneys, or fluid collection drainages in the abdomen or pelvis. Head procedures generally included transjugular procedures such as transjugular intrahepatic portosystemic shunt placements, inferior vena cava filter placements, and transjugular liver biopsies.

Reported data included operator exposure indicated by dosimeter readings, as well as fluoroscopy duration and patient dose-area-product (DAP) as reported by the fluoroscopy unit. As in other reports of occupational radiation in fluoroscopy suites, operator exposures were standardized to DAP because it is the best correlate for amount of scatter produced in the region of the operator (6, 7). Because our operators routinely exit the procedure area to stand behind a leaded wall during nonfluoroscopic imaging acquisitions, which contribute substantially to total patient DAP, operator exposures were standardized only to the relevant patient DAP corresponding to fluoroscopy. In other words, DAP corresponding to nonfluoroscopic imaging acquisitions, when the operator was not exposed to scatter radiation, was excluded. Standardized operator exposure (SOE) = operator exposure / fluoroscopic DAP and was reported in uSV/[g/cm^2].

SOEs corresponding to different operator positions were compared using the two-tailed *t* test. For each operator position, SOEs for SHIELDS and SPRPS were compared using a two-tailed *t* test.

RESULTS

Detailed results are depicted in *Table 1* and *Figure 3.* One hundred and thirty procedures were performed using a total of 1148 minutes of fluoroscopy time with total fluoroscopic patient DAP of 423,290 cGy/cm^2. When using conventional shielding (SHIELDS), SOE was highest when working at the patient's side, where it was 1.80 times the exposure when working at the femoral region. SOE when working at the patient's head was 1.62 times the SOE when working at the femoral region. These differences were both significant ($P < 0.001$ and <0.05, respectively).

When using SPRPS, SOE was greatly reduced in all positions, with a mean of 0.45% ($P < 0.0001$) of SOE for SHIELDS. These differences between SHIELDS and SPRPS were significant for all operator positions.

Although duration of fluoroscopy is a less suitable parameter than patient DAP for standardization of operator

Table 1. Fluoroscopy time, patient dose, and operator exposures for 130 interventional radiology cases for different operator stances using both SHIELDS and SPRPS operator protection methods

Shielding modality	Operator position	N	Fluoroscopy time (min)	Patient DAP (cGy/cm^2)	OE (uSV)	OE/fluoro time (uSV/min)	OE/DAP (SOE) (uSv/[Gy/cm^2])	SOE/ SOE$_{FEMSHIELDS}$ (%)	*P*	SOE$_{SPRPS}$/ SOE$_{SHIELDS}$*	*P*
SHIELDS†	Femoral	17	127	50,690	412	3.250	0.8137	100.00%	–	–	–
	Side	16	86	32,770	479	5.608	1.4631	179.80%	<0.001	–	–
	Head	16	145	59,062	781	5.399	1.3228	162.56%	<0.05	–	–
	Subtotal	49	357	142,521	1,673	4.686	1.1740	–	–	–	–
SPRPS	Femoral	41	463	150,510	9	0.020	0.0062	0.77%	<0.0001	0.77%	<0.0001
	Side	23	189	50,615	3	0.018	0.0066	0.82%	<0.0001	0.46%	<0.0001
	Head	17	139	79,644	2	0.015	0.0026	0.32%	<0.0001	0.20%	<0.0001
	Subtotal	81	791	280,769	15	0.019	0.0053	–	–	0.45%	<0.0001
Total	All	130	1,148	423,290	1,688	–	–	–	–	–	–

*For matched operator position.

†Shields used by this group included a mobile suspended lead-acrylic shield, an under-table lead skirt, and a table side shield that extended upwards from the under-table skirt.

DAP indicates dose-area-product; OE, operator exposure; SOE, standardized operator exposure; SPRPS, suspended personal radiation protection system.

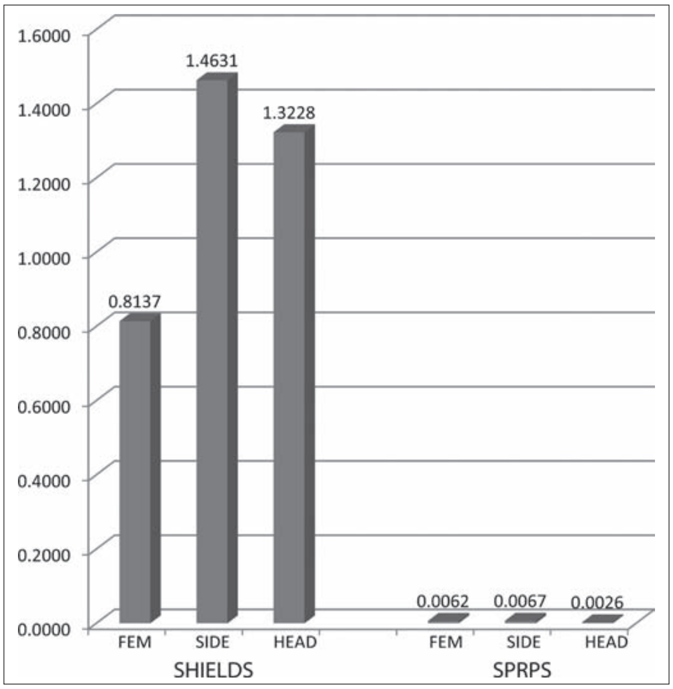

Figure 3. Standardized operator exposure, in uSv/[Gy/cm^2], from the femoral (FEM), side, or head position for both the SHIELDS and suspended personal radiation protection system (SPRPS) groups.

exposures, it is nevertheless conceptually simpler for operators. In the SHIELDS group, the mean operator exposure/fluoroscopy time was 4.69 uSv/min (0.469 mRem/min). Exposure at the head and side positions was 1.73 and 1.66 times, respectively, the exposure for FEM—roughly similar to the pattern for the DAP-standardized results described above. When using SPRPS, the mean exposure was 0.02 uSv/min (0.002 mRem/min).

DISCUSSION

Shielding of interventionalists' head and eyes during fluoroscopically guided procedures is problematic. Cataract formation is a known side effect with lens opacities occurring at significantly lower doses than previously believed (1, 2, 3, 8). The upward direction of scatter to the head enables a portion of scatter to pass underneath lead glasses, or enter from the side to reach the eye (4, 5). Secondary scattered radiation from the operator's head contributes substantially to ocular exposure (4, 5). In one study, the best glasses of 32 tested types yielded eye exposures amounting to 44% of the incident radiation, even with the head directly facing the scatter source (5). The findings of another study indicated that lead glasses could reduce eye exposures 2- to 3-fold (4). Although imperfect, such reductions are substantial and lead to recommendations to use lead eyewear in conventional setups lacking a face shield (1, 2).

Operator-supported face shields provide superior protection and obviate the need for lead eyewear but are uncommonly used due to their bulk (5, 9). By protecting much of the head, they also address concerns about neural tumors, which have been associated with even moderate doses of radiation (10).

When using SHIELDS, there are always gaps in the shielding, most notably at the level of the operator's arms, permitting scatter to pass upwards underneath the mobile suspended lead acrylic shield to the operator's upper body and head (Figure 2). The significantly higher exposures for the side position relative to both the femoral and head positions is likely due to the operator's proximity to the scatter source in addition to the gaps between the shields that are required to permit operator access to the patient. Working at the head or femoral positions provides some additional distance from the scatter sources; however, gaps in shielding persist.

The SPRPS group had substantial reductions in exposure for all operator positions compared with the SHIELDS group, presumably because the SPRPS moves with the operator and is therefore always positioned optimally with regard to scatter geometry. The height of the lead-acrylic head shield provides a barrier to scatter to the head while permitting direct, unimpeded line of sight to the monitor over its top. This is possible because the scatter source is lower than the operator's head, creating a substantial upward vector from scatter source to operator head (3).

Exposures in the SHIELDS arm of this study are in range with previous studies that used rigorous shielding, corroborating our operators' aggressive shielding technique (11–13). Unfortunately, in some labs, the table side-shield (Figure 1a) may be intermittently or never used since it must be removed for each patient transfer. Likewise, the mobile hanging shield is sometimes neglected. Despite the gaps in protection with these devices, they provide substantial protection, and their rigorous use is strongly advised when not using a more comprehensive system such as the SPRPS or a radioprotective cabin.

Limitations of this study include absence of randomization. Randomization may have improved comparison between standard lead shielding and SPRPS, but remains irrelevant to the position analysis, the primary focus of this manuscript. Due to dramatic differences between conventional shields and SPRPS, randomization was not believed necessary.

Acknowledgments

The authors thank the laboratory technology and research nursing staff for their contributions in data collection.

1. Miller DL, Vañó E, Bartal G, Balter S, Dixon R, Padovani R, Schueler B, Cardella JF, de Baère T; Cardiovascular and Interventional Radiology Society of Europe; Society of Interventional Radiology. Occupational radiation protection in interventional radiology: a joint guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology. *J Vasc Interv Radiol* 2010;21(5):607–615.
2. Kleiman NJ. Radiation cataract. In *Radiation Protection 145. EU Scientific Seminar 2006: "New Insights in Radiation Risk and Basic Safety Standards*." Brussels: European Commission, 2007:81–95. Available at ec.europa.eu/energy/nuclear/radioprotection/publication/doc/145_en.pdf.
3. Prater S, Rees CR, Bruner A, Savage C. Determination of minimum effective height of transparent radiation face shielding for fluoroscopy. *Health Phys* 2011;101(Suppl 3):S135–S141.
4. Moore WE, Ferguson G, Rohrmann C. Physical factors determining the utility of radiation safety glasses. *Med Phys* 1980;7(1):8–12.
5. Cousin AJ, Lawdahl RB, Chakraborty DP, Koehler RE. The case for radioprotective eyewear/facewear. Practical implications and suggestions. *Invest Radiol* 1987;22(8):688–692.
6. Kuon E, Dahm JB, Empen K, Robinson DM, Reuter G, Wucherer M. Identification of less-irradiating tube angulations in invasive cardiology. *J Am Coll Cardiol* 2004;44(7):1420–1428.
7. Servomaa A, Karppinen J. The dose-area product and assessment of the occupational dose in interventional radiology. *Radiat Prot Dosimetry* 2001;96(1–3):235–236.
8. Worgul BV, Kundiyev YI, Sergiyenko NM, Chumak VV, Vitte PM, Medvedovsky C, Bakhanova EV, Junk AK, Kyrychenko OY, Musijachenko NV, Shylo SA, Vitte OP, Xu S, Xue X, Shore RE. Cataracts among Chernobyl clean-up workers: implications regarding permissible eye exposures. *Radiat Res* 2007;167(2):233–243.
9. Marshall NW, Faulkner K, Clarke P. An investigation into the effect of protective devices on the dose to radiosensitive organs in the head and neck. *Br J Radiol* 1992;65(777):799–802.
10. Preston DL, Ron E, Yonehara S, Kobuke T, Fujii H, Kishikawa M, Tokunaga M, Tokuoka S, Mabuchi K. Tumors of the nervous system and pituitary gland associated with atomic bomb radiation exposure. *J Natl Cancer Inst* 2002;94(20):1555–1563.
11. Zorzetto M, Bernardi G, Morocutti G, Fontanelli A. Radiation exposure to patients and operators during diagnostic catheterization and coronary angioplasty. *Cathet Cardiovasc Diagn* 1997;40(4):348–351.
12. Williams JR. The interdependence of staff and patient doses in interventional radiology. *Br J Radiol* 1997;70(833):498–503.
13. Koukorava C, Carinou E, Simantirakis G, Vrachliotis TG, Archontakis E, Tierris C, Dimitriou P. Doses to operators during interventional radiology procedures: focus on eye lens and extremity dosimetry. *Radiat Prot Dosimetry* 2011;144(1–4):482–486.