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# Effective Use of Radiation Shields to Minimize Operator Dose During Invasive Cardiology Procedures

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**Objectives** This study sought to measure the protection from scatter radiation offered to the primary physician by a variety of available shields and to provide best practice guidelines for shield use during invasive cardiology procedures.

**Background** It is accepted that exposure to radiation includes a predicted increase in cancer risk. In the cardiac interventional laboratories, radiation shields are widely available; however, proper use of the shields to optimize protection during cardiac interventional procedures is not well understood.

**Methods** The protection from scatter radiation offered by a variety of shields used alone and in combination was measured. Protection was assessed from air-kerma measurements of scatter radiation from a phantom performed without and with the shields. Protection was assessed for 3 patient-access locations (right jugular vein, right femoral artery, and left anterior chest) and for elevations ranging from 25 to 175 cm from the floor. The influence of precise placement of the ceiling-mounted upper body shield was specifically assessed.

**Results** The utility and protection of shielding varied for the 3 access points and with elevation. For femoral artery access locations, the shields can provide at least 80% protection from scatter at all elevations; however, protection depends substantially on upper body shield position. A disposable radiation-absorbing pad can provide 35% to 70% upper body protection for procedures during which the upper body shield cannot be used effectively.

**Conclusions** Radiation shields can provide substantial protection from radiation during cardiac interventional procedures. Shields must be thoughtfully and actively managed to provide optimum protection. Best practice guidelines for shield use are provided. (J Am Coll Cardiol Intv 2011;4:1133–9) © 2011 by the American College of Cardiology Foundation

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X-ray radiation that interacts with patient tissue resulting in a change in direction (x-ray scatter) is the primary source of radiation exposure for workers in the cardiovascular interventional laboratory. It is widely accepted that exposure to even low radiation doses results in an increased cancer risk (1,2); therefore, international recommendations have been developed to maintain occupational radiation doses to permissible levels (3,4). To help minimize radiation dose, all persons working in interventional x-ray rooms are required to wear lead-equivalent radiation protection garments. Although these garments are effective at stopping radiation, a person's arms, head, and neck (without protective collar) are generally unprotected (5–8).

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Of all cardiovascular laboratory personnel, the performing physician is subject to the highest radiation dose (9,10). This is readily explained by the relative proximity of the primary physician to the patient and x-ray beam. The purpose of this work was to assess the potential for various available radiation shields to enhance protection of physicians performing cardiac interventional procedures. This work is specifically applicable to invasive cardiology procedures performed using right femoral artery (RFA), right jugular vein (RJV), or left anterior thoracic (LAT) (pacemaker implant) access points.

**Abbreviations and Acronyms**

**LAT** = left anterior thoracic

**RFA** = right femoral artery

**RJV** = right jugular vein

## Methods

As shown in Figure 1, shields investigated included a ceiling-mounted upper body shield with a patient contour cutout, a detachable lower body shield that mounts to the side rail of the patient table, an accessory shield that extends vertically from the lower body shield, and a radiation-absorbing disposable pad (6,11–15). The influence of precise placement of the upper body shield was specifically investigated.

Scatter radiation was created by directing an x-ray beam on an anthropomorphic phantom (anteroposterior thickness: 21 cm) with an additional 10-cm Solid Water (Gammex Inc., Middleton, Wisconsin) buildup material included to achieve patient thickness typical of a large adult patient. The x-ray beam was produced by a clinical interventional x-ray system (Siemens Axiom Artis, Siemens Medical Systems, Erlangen, Germany). The phantom was placed directly on the patient support table, with the top of the table fixed at an elevation of 85 cm from the floor. The x-ray source to image receptor distance was 110 cm and the nominal x-ray beam field of view was 25 cm (diagonal) throughout. All measurements were performed using a straight posterior-anterior projection (6,12). For all measurements, the x-ray system automatically selected a peak tube potential of 96 kV. The air-kerma (mGy) due to scatter during a 10-s cine acquisition was measured using a 10 × 5 −1,800 cc ionization chamber in conjunction with a Radcal 9015 meter (Radcal Corporation, Monrovia, California).

As shown in Figure 2, x-ray scatter air-kerma measurements were acquired at 3 floor locations within the procedure room, corresponding to physician position for femoral artery, jugular vein, and LAT (pacemaker implant) access sites. Note that for jugular vein procedures, physicians in our laboratory routinely stand along the right side of the patient's head. At each floor location, air-kerma was measured at elevations ranging from 50 to 175 cm in 25-cm increments. Scatter intensity measurements were acquired first without and then with a radiation shield in place.

The 0.5-mm Pb equivalent upper body shield (PT6290/6272, Mavig, Munich, Germany) was mounted on a longitudinal ceiling rail system on the patient's right side of the patient table. The upper body shield includes "flexible radiation protective strips" at the bottom of the shield that conform to patient contour, thereby providing direct contact between the shield (with sterile cover) and the patient. The


**Figure 1. Shields Investigated**

**(a)** Upper body shield, **(b)** lower body shield, **(c)** accessory vertical extension, and **(d)** radiation-absorbing disposable pad.

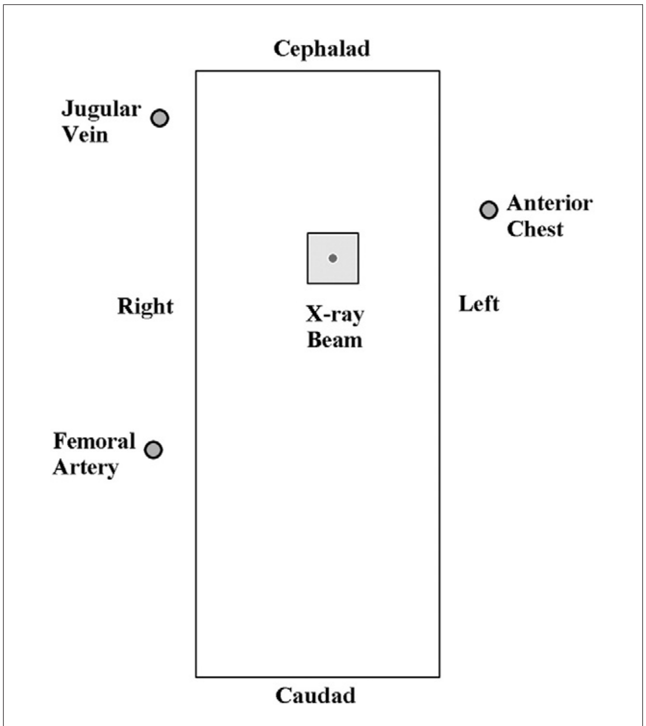


**Figure 2. Physician Location for the 3 Patient-Access Points**

Distances are with respect to the central axis of the patient-access x-ray beam and orientation with respect to supine patient: femoral artery: 60 cm caudad, 40 cm right; jugular vein: 40 cm cephalad, 40 cm right; anterior chest: 10 cm cephalad, 35 cm left.

mechanical arm onto which the upper body shield is attached has 4 articulating joints that allow both wide-ranging and precise adjustment of the spatial location and relative angular orientation of the shield. For all measurements involving the upper body shield, the shield was oriented such that the planar surface of the shield was perpendicular to the patient head-foot orientation.

Because the upper body shield must be specifically placed by the physician and can be (and often is) moved during the procedure, the influence of precise placement of this shield with respect to the x-ray beam and the patient (phantom) was measured. Protection offered by the ceiling shield was measured with the shield placed in 4 positions. Position of the upper body shield will be specified as the distance offset (in centimeters) from both the femoral access point in the head-foot orientation and from the anterior and right surfaces of the patient. For femoral artery access procedures, the furthest practical distance from the x-ray beam that the upper body shield can be placed is determined by the anatomical location of the femoral access point. In Figure 3, position e is just cephalad from the femoral access point and 34 cm from the x-ray beam central axis. The shield was also positioned 20 cm cephalad from the femoral access point (5 cm caudad from the detector housing) (Fig. 3, positions g and h). Finally, protection offered by the upper body shield was also measured with the shield offset from the phantom by 5 cm in both the anterior and lateral directions (Fig. 3, positions f and h).

When assessing the lower body shield (UT60) with detachable vertical extension for the femoral artery access point, the mechanical support arm for the apron was attached to the standard table rail on the patient right side and extended tableside toward the head of the table (Fig. 1). With this mounting system, the table apron could be expected to offer no protection for physicians standing at or near the patient's head, as is the case for both jugular vein and LAT access points. For these access points, the lower body shield was mounted to an accessory rail attached to the head of the table (Fig. 4). Also, our experience is that the manufacturer-provided vertical extension is too tall (35 cm), so it interferes with physician access to the patient and also with the upper body shield. Therefore, we have modified the vertical extension so that it extends 25 cm above the lower body shield support arm. Finally, the vertical extension impedes physician access to the jugular vein and anterior thoracic access points and therefore was not included for these locations.

Radiation-absorbing disposable pad models 5300-Y, 5500-O, and 5100-O (WorldWide Innovations and Technologies Inc., Kansas City, Kansas) were used for femoral artery, jugular vein, and left anterior chest access, respectively. For all access points, the pad was positioned to maximize radiation protection for the physician's upper body while still allowing unimpeded physician access to the vascular access point in such a way that the pad would not interfere with the primary x-ray beam (Fig. 4).

Others have shown that scatter dose rate is proportional to patient skin dose rate (7). Because the shape of the phantom does not accurately reflect that of a real patient (let alone a range of patients), the magnitude of the scatter measurements cannot be considered to accurately reflect clinical practice. However, the relative radiation protection offered by the shields can reasonably be expected to be independent of the shape of the phantom. Shield performance was measured as the fraction of scatter radiation that transmits through or around it. Preliminary measurements demonstrated that the combined influence of multiple shields could be estimated by multiplication of the transmission factors of individual shields. Shield performance is reported as the percentage of scattered x-ray air-kerma that is absorbed by the shield(s) or the relative protection from scatter radiation.

## Results

Select repeat measurements indicate that protection from scatter radiation measurements have an uncertainty of $<4\%$. Figure 5 demonstrates the influence of upper body shield placement on scatter transmission. From Figure 5, it is apparent that the best protection from scatter radiation occurs when the upper body shield is tight to the patient body and positioned just cephalad from the femoral access (point e). At

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**Figure 3.** **Upper Body Shield Positions for Which Protection Was Measured**

**Point e** is tight to the patient body and just cephalad from the femoral access point.

this position, upper body protection (125 to 175 cm) is at least 80%. Middle (75 to 125 cm) and upper body protection is compromised when the shield is offset 5 cm from the patient body (points f and h) and when the shield is positioned 20 cm cephalad from the femoral access point (points g and h). As might be expected, the upper body shield provides essentially no lower body (<75 cm) protection (<10%).

Figure 6 demonstrates the protection from scatter radiation provided by various shields that can be incorporated during RFA access procedures. Protection offered by the optimally placed upper body shield is replicated from Figure 5. As expected, the lower body shield provides good lower body protection (>90%), poor middle body protection (<30%), and essentially no upper body protection (<5%). The accessory vertical extension provides additional protection (25% to 90%) in the elevation range of 100 to 150 cm. The disposable pad can provide moderate protection of the upper body (55% to 70%). Also depicted in Figure 6 is the predicted protection provided by a combination of the table apron with vertical extension and the upper body shield. The combined influence of these shields results in at least 80% protection at all elevations and 90% protection for elevations below 150 cm.

Figure 7 demonstrates scatter protection provided by the various shields for the RJV access location. As expected, the lower body shield provides excellent lower body protection (>90%) but effectively no upper body protection (<5%). Similar to femoral artery access, the disposable pad offers no lower body protection but does provide modest upper body protection (55% to 70%).

Figure 8 demonstrates the protection offered by the various shields for the LAT access location. For this access location, the lower body shield can provide excellent lower body protection (>90%) and the radiation absorbing towel can provide modest upper body protection (45% to 60%).

## Discussion

Multiple radiation shields, used alone or in concert, can provide effective operator protection when used appropriately. Operators should be cognizant of the fact that operator radiation exposure depends on several factors; importantly, the portion of the operator's body (lower to upper body) in question and the patient access site. Radiation shields may be used in a judicious manner in this context. A major finding of this work is that the upper body protection provided by the ceiling-mounted upper body shield is highly dependent on precise positioning (Table 1). Protection provided by the upper body shield is substantially compromised if the shield is not thoughtfully and precisely positioned. To achieve maximum protection from the upper body shield, it must be positioned just cephalad to the femoral access point and with the patient cutout contour tight to the patient surface (Fig. 3, point e). Note that conventional wisdom is that shields should be placed close to the source of radiation to maximize the size of the protective "radiation shadow" of the shield. Properly positioning the upper body shield requires the opposite mindset. The upper body shield should be located relatively far from the

**Figure 4. Shield Positioning for Left Anterior Chest Access**

Lower body shield attached to accessory rail mounted on the table. Radiation-absorbing disposable pad is positioned to maximize physician upper body protection yet avoid interfering with access to the patient or with the primary x-ray beam.

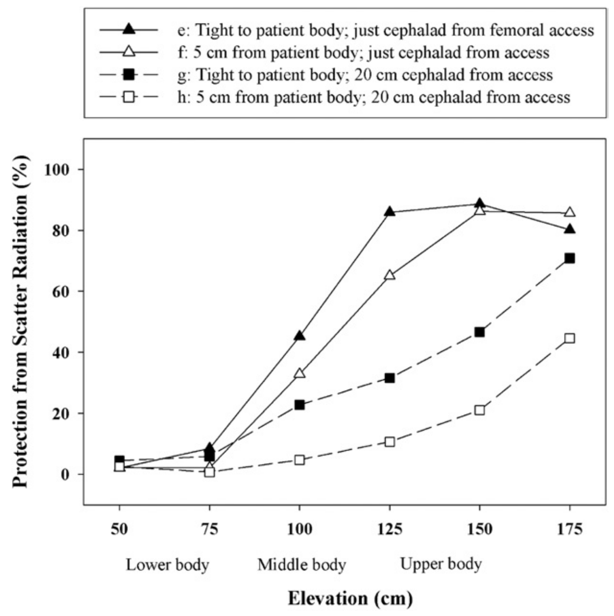


**Figure 5. Influence of Upper Body Shield Position on Protection From Scatter Radiation**

Letter designations **(e to h)** correspond to equivalent labels in Figure 3.

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. This gap is accentuated by moving the shield away from the patient surface or further cephalad from the femoral access point. 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. 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.

For femoral artery access, the lower body shield with the vertical extension can and should be routinely used to minimize radiation dose to the physician's lower and middle body. Used in combination with protective garments, the lower body shield will result in a minimal radiation dose to the lower body. For the femoral artery access location, the disposable radiation-absorbing pad can provide modest upper body protection in conditions that prevent effective use of the upper body shield.

For radial artery access procedures, the physician stands at a location that is similar to that for femoral

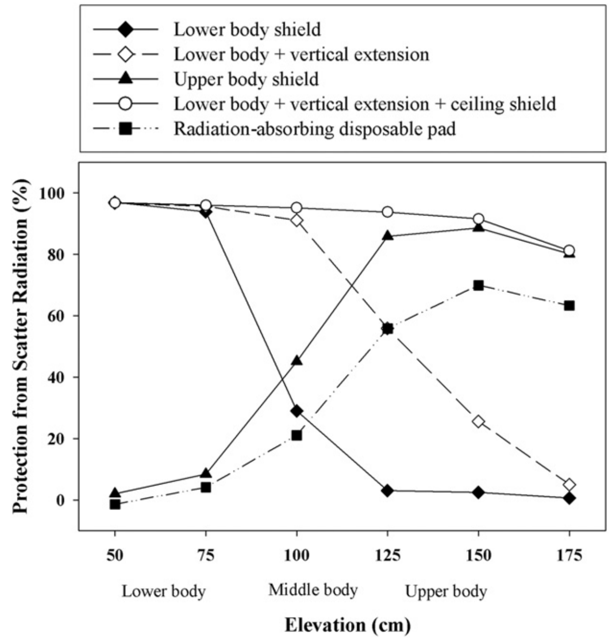


**Figure 6. Protection From Scatter Radiation Offered by Various Shields for Right Femoral Access Procedures**

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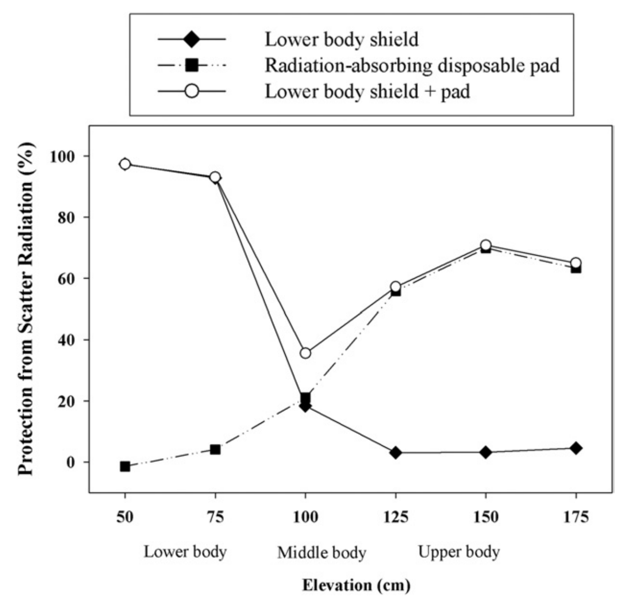


**Figure 7. Scatter Transmission Fraction of Radiation Protection Shields Used for Right Jugular Vein Access Procedures**

artery access procedures. Therefore, protection for radial artery access procedures can be inferred from measurements for femoral artery access. For radial artery access procedures, the lower body shield can and should be routinely used. Whether the vertical extension from the table drape can be used ultimately depends on the structure and placement of the patient arm board, but it is expected to be of limited practical use. Further, radial artery access does not lend itself well to typical placement of the upper body shield, although it can often be creatively positioned to provide protection for at least a portion of most procedures. Especially given that the frequency of radial artery access procedures is increasing, there is a need for novel radiation protection devices to be used for radial artery access procedures (16,17).

For the RJV and LAT access locations, an accessory rail mounting system attached to the head of the table allows use of the lower body shield for improved lower body radiation protection. The vertical extension to the lower body shield tends to impede patient access and, therefore, is generally not useful. For both the jugular vein and anterior thoracic access locations, a disposable pad could be used to provide at least some upper body protection (18).

Even though radiation protection shields are widely available in cardiovascular procedure rooms, these shields require active management to be of any useful consequence. Of the shields described here, only the lower body shield used for RFA access can be considered a standard implementation. All other shields and uses require accessory mounting systems (table head mount of lower body shield) and/or active pre-procedure and intraprocedure management (upper body shield, vertical extension from lower body shield, disposable towel).

**Study limitations.** Certainly, the clinical use of radiation and practice of radiation protection is spatially and temporally complex. Recognized limitations of this work include that only a posterior-anterior x-ray projection was used and that only the radiation protection offered to the primary operator at a fixed location was specifically measured. A wide range of x-ray system gantry angles are used in invasive cardiology procedures. It is well known that the angular scatter distribution is not uniform and that absolute scatter intensity is greatest in the direction back toward the x-ray tube and least in direction forward to the x-ray detector (19). However, others have reported that the relative protection offered by shields is largely independent of the angle of incidence of the primary beam (6,12). So although scatter radiation dose rate is highly dependent on x-ray beam angle, optimal use of radiation shields is not. In practice, the spatial relationship between the source of x-ray scatter, radiation shields, and primary physician may vary between patients and even during a procedure on a single patient. Shields need to be thoughtfully positioned to accommodate this variability. Also, procedures performed in the cardiac interventional laboratory increasingly involve treatment of abdominal and peripheral vessels. This work provides no specific recommendation for protection for this type of procedure. Given the complexities of clinical implementation, specific investigation of the potential for the findings and recommendations of this work to affect real-world radiation dose to physician operators is warranted.

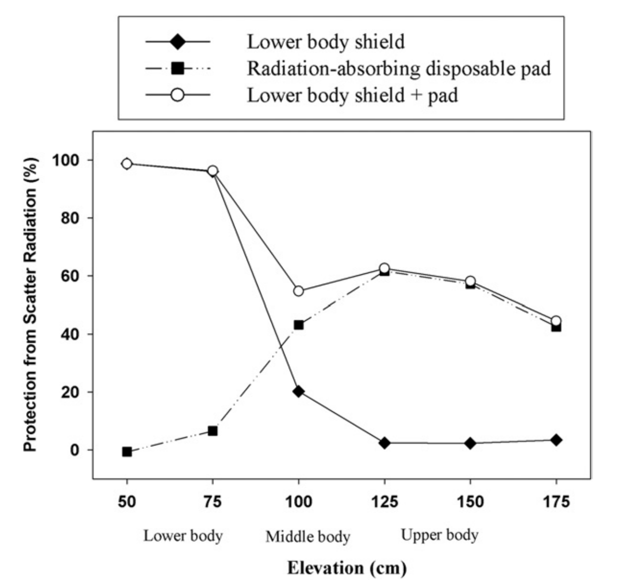


**Figure 8. Scatter Transmission Fraction of Radiation Protection Shields Used for Left Anterior Thoracic Procedures**

**Table 1. Recommended Use of Protective Shields**

| | Upper Body Shield | Lower Body Shield | Vertical Extension From Lower Body Shield | Disposable Radiation Absorbing Towel |
|---|---|---|---|---|
| Femoral artery | Position just cephalad to the access point and tight to the patient surface | Should be used routinely; attach using standard table rail | Should be used routinely; consider modifying to shorter height | Provides modest upper body protection |
| Radial artery | Useful positioning likely possible for at least portions of procedures | Should be used routinely; attach using standard table rail | Interferes with patient arm board | Provides modest upper body protection |
| Jugular vein | Interferes with x-ray receptor and patient access | Should be used with accessory mount at the head of the table | Interferes with patient access | Provides modest upper body protection |
| Anterior thoracic | Interferes with patient access | Should be used with accessory mount at the head of the table | Interferes with patient access | Provides modest upper body protection |

Regardless of the x-ray system gantry angle, physician position, or scatter radiation intensity, the principles of radiation shielding remain unchanged. Specifically, shields offer radiation protection only when they are positioned between the source of x-ray scatter and the body of the physician. When positioning any radiation shield for any imaging condition, consider the patient volume irradiated by the primary x-ray beam and position the shield to intercept the scatter radiating from this volume. Finally, it must be recognized that successful radiation shielding requires active management both before and during procedures.

## Conclusions

Radiation shields must be thoughtfully placed and actively managed both before and during the procedure to be effective. Of great importance is that the typical upper body shield with patient contour cutout is most effective for providing upper body protection during right femoral access procedures when it is positioned just cephalad to the access site and is tight to the anterior and right surfaces of the patient. Typical lower body shields that mount to the table rail offer excellent lower body protection during femoral access procedures. For jugular vein or anterior thoracic patient-access procedures, an accessory mount at the head end of the table can be used to move the lower body shield to a useful position. Disposable radiation pads can provide upper body protection from radiation and their use should be considered in situations where practical limitations preclude effective use of the upper body shield.

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**Key Words:** radiation protection ■ radiation safety ■ radiation shield.