# Comparing Strategies for Operator Eye Protection in the Interventional Radiology Suite

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**PURPOSE:** To evaluate the impact of common radiation-shielding strategies, used alone and in combination, on scattered dose to the fluoroscopy operator's eye.

**MATERIALS AND METHODS:** With an operator phantom positioned at the groin, upper abdomen, and neck, posteroanterior low-dose fluoroscopy was performed at the phantom patient's upper abdomen. Operator lens radiation dose rate was recorded with a solid-state dosimeter with and without a leaded table skirt, nonleaded and leaded (0.75 mm lead equivalent) eyeglasses, disposable tungsten-antimony drapes (0.25 mm lead equivalent), and suspended and rolling (0.5 mm lead equivalent) transparent leaded shields. Lens dose measurements were also obtained in right and left 15° anterior obliquities with the operator at the upper abdomen and during digital subtraction angiography (two images per second) with the operator at the patient's groin. Each strategy's shielding efficacy was expressed as a reduction factor of the lens dose rate compared with the unshielded condition.

**RESULTS:** Use of leaded glasses alone reduced the lens dose rate by a factor of five to 10; scatter-shielding drapes alone reduced the dose rate by a factor of five to 25. Use of both implements together was always more protective than either used alone, reducing dose rate by a factor of 25 or more. Lens dose was routinely undetectable when a suspended shield was the only barrier during low-dose fluoroscopy.

**CONCLUSIONS:** Use of scatter-shielding drapes or leaded glasses decreases operator lens dose by a factor of five to 25, but the use of both barriers together (or use of leaded shields) provides maximal protection to the interventional radiologist's eye.

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**Abbreviations:** DSA = digital subtraction angiography, PA = posteroanterior

DURING the past decade there have been important advances in understanding the kinetics of radiation dose effects on the ocular lens. Studies of cataract incidence in Chernobyl cleanup workers (1) and radiologic technologists in the United States (2) have both questioned the accuracy of the current risk assumption of a 2–5-Gy threshold for lens opacity from protracted exposure (3,4) used to determine regulatory limits for lens exposure (5). Although the Chernobyl study (1) suggested a dose-effect threshold of less than 1 Gy for cataract formation, the study of radiologic technologists (2) suggested that risk increases linearly with radiation dose, with no apparent threshold. Work by Vano et al (6) demonstrated the importance of the use of radiation protection tools, without which doses to the lens of the eye were estimated to exceed allowable limits within several years of typical interventional radiology practice.

Leaded shields (rolling and ceiling-mounted), leaded eyeglasses, and scatter-shielding drapes are some of the most commonly available radiation protection devices likely to be found in the interventional radiology suite. Along with basic good radiation protection practices, these represent a well fortified collection of strategies to limit the exposure of the physician operator. However, not all protective methods are available in all suites, and it is possible that different tools might be found in different suites within the same unit. Understanding how to deploy locally available shielding methods for maximal effectiveness is therefore critical. The purpose of this study was to evaluate the impact on lens

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dose of commonly available shielding tools used alone and in various practical combinations.

## MATERIALS AND METHODS

Using an Integris Allura fluoroscopy system (Philips, Eindhoven, The Netherlands) with an image intensifier 3 cm above the upper abdominal skin surface of an anthropomorphic patient phantom (Real-bone Sectional Phantom; Radiology Support Devices, Long Beach, California) and a 15-cm field of view, low-dose fluoroscopy was performed using an under-table tube system in posteroanterior (PA; 70 kVp, 4.6 mA) and 15° left (75 kVp, 4.2 mA) and right anterior oblique (72 kVp, 4.4 mA) projections. An anthropomorphic operator phantom (model 702-D; Computerized Imaging Reference Systems, Norfolk, Virginia; **Fig**) was positioned 50 cm from an approximate patient midpoint near the patient's groin, upper abdomen, and neck in positions typical of transfemoral angiography, right-side biliary drainage, and transjugular interventions, respectively. In these operator positions, low-dose PA fluoroscopy was performed while radiation dose measurements were made at the phantom operator's left lens (groin and upper abdomen measurements) or right lens (neck measurements) at a height of 165 cm from the floor using a solid-state dosimeter (EDD-30; Unfors, Billdal, Sweden). Measurements were made with and without a (i) leaded table skirt, (ii) nonleaded and leaded (0.75 mm lead equivalent) eyeglasses (RayShield Sportwrap; Aadco Medical, Randolph, VT), (iii) disposable tungsten-antimony drapes (0.25 mm lead equivalent; X-drape; Aadco Medical) applied to the patient phantom, and (iv) suspended and rolling (0.5 mm lead equivalent) transparent leaded shields. Similar measurements were made with the operator phantom positioned at the upper abdomen in 15° right and left anterior oblique projections. Lens dose rate measurements were also obtained during digital subtraction angiography (DSA) at two images per second (83 kVp, 100 mA) with and without leaded glasses, a scatter-shielding drape, and leaded shields with the phantom operator positioned at the patient groin. Dose rates were measured in mR/h and converted to mSv/h with exposure–to–tissue dose conversion factors appropriate for the x-ray energies used in the study. Dose rate reductions were calculated relative to the unprotected scattered lens dose obtained during low-dose fluoroscopy with standard precautions of near image intensifier–to–patient technique in the presence of a leaded table skirt.

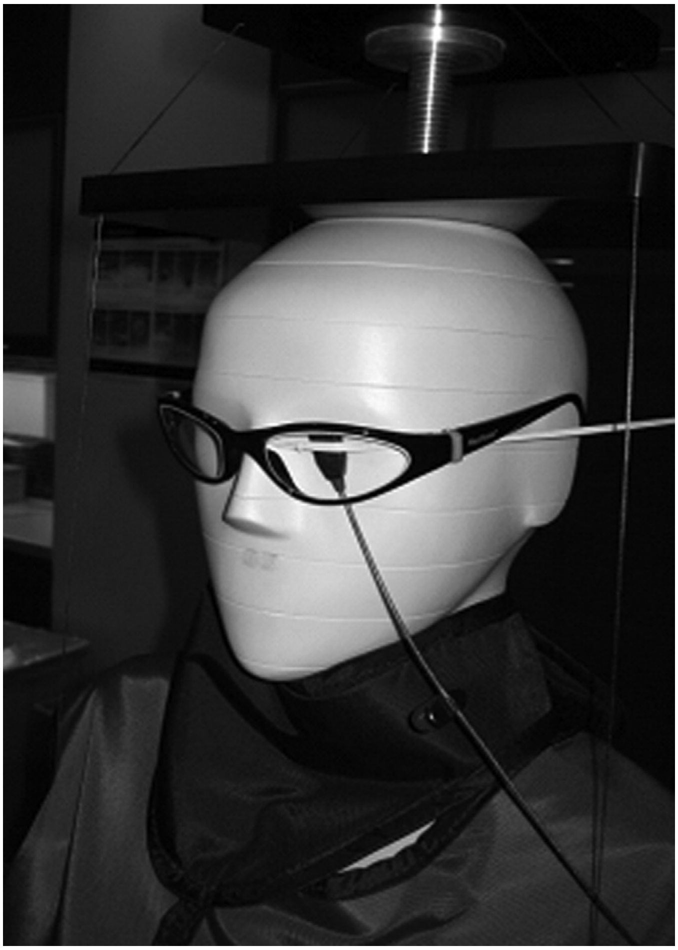

**Figure.** The dose detector is fixed at the left eye, behind leaded glasses, in this image of the operator phantom.

## RESULTS

### Operator Position at the Groin

During low-dose fluoroscopy (**Table 1**), the reference lens dose rate obtained with the image intensifier situated 3 cm above the upper abdominal skin surface with a leaded table skirt in place was 0.49 mSv/h (56.2 mR/h). Low-dose fluoroscopy with an inappropriately high position of the image intensifier (20 cm above upper abdominal surface, such as might be encountered when observing early trainee operations) was associated with a twofold increase in lens dose rate versus the reference dose rate. In the operator position typical for visceral angiography, use of leaded glasses or a scatter-shielding drape substantially reduced lens dose by factors of 9.5 and 12, respectively. Maximal eye protection was achieved by the combined use of leaded glasses and a scatter-shielding drape or use of appropriately positioned rolling or ceiling-suspended shields.

During DSA at two images per second with the image intensifier 3 cm above the simulated skin surface, and with use of the leaded table skirt (**Table 1**), lens dose rates were 4.3 mSv/h (500 mR/h) without leaded glasses and 0.03 mSv/h (3.5 mR/h) with leaded glasses and a scatter-shielding

**Table 1**
**Left Lens Exposure while Operating at Patient's Groin during Low-dose PA Fluoroscopy and In-room PA DSA of Upper Abdomen**

| | Low-dose PA Fluoroscopy | | | PA DSA | | |
|---|---|---|---|---|---|---|
| | Lens Dose Rate | | Lens Dose Reduction Factor | Lens Dose Rate | | Lens Dose Reduction Factor |
| Shielding Strategy | mSv/h | mR/h | | mSv/h | mR/h | |
| Image intensifier at 20 cm | 1.18 | 135 | — | — | — | — |
| Image intensifier at 3 cm (close) | 0.54 | 62 | — | — | — | — |
| Plus leaded table skirt | 0.492 | 56.2 | RM | 4.3 | 500 | RM |
| Plus unleaded eyeglasses | 0.489 | 55.8 | 1.0 | 4.3 | 500 | 1.0 |
| Plus leaded eyeglasses | 0.052 | 5.9 | 9.5 | 0.64 | 74 | 6.8 |
| Plus scatter-shielding drape | 0.041 | 4.7 | 12.0 | 0.18 | 20.3 | 24.6 |
| Plus leaded eyeglasses and scatter-shielding drape | LLD | LLD | > 1,000 | 0.032 | 3.5 | 143 |
| Plus ceiling-suspended shield | LLD | LLD | > 1,000 | 0.028 | 3.2 | 132 |
| Plus ceiling-suspended shield and scatter-shielding drape | LLD | LLD | > 1,000 | LLD | LLD | > 1,000 |
| Plus rolling shield | LLD | LLD | > 1,000 | LLD | LLD | > 1,000 |

Note.—LLD = below the lower limit of detection (0.001 mSv/h); RM = reference measurement.

**Table 2**
**Right Lens Exposure while Operating at Patient's Neck under Low-dose PA Fluoroscopy of Upper Abdomen**

| | Right Lens Dose Rate | | |
|---|---|---|---|
| Shielding Strategy | mSv/h | mR/h | Lens Dose Reduction Factor |
| Image intensifier at 3 cm | 0.48 | 55 | |
| Plus leaded table skirt | 0.46 | 53 | RM |
| Plus unleaded glasses | 0.35 | 40 | 1.3 |
| Plus leaded glasses | 0.045 | 5.2 | 10.2 |
| Plus scatter shielding drape | 0.088 | 10.1 | 5.2 |
| Plus leaded glasses and scatter-shielding drape | 0.012 | 1.4 | 37.9 |
| Plus ceiling-suspended shield | LLD | LLD | > 1,000 |

Note.—LLD = below the lower limit of detection (0.001 mSv/h); RM = reference measurement.

drape. This dose rate was eight times higher than that received from low-dose fluoroscopy under the same conditions. While the use of both leaded glasses and a scatter-shielding drape provided substantial dose reduction at the operator's lens in the configuration typical of an in-room DSA run, the combined use of a ceiling-suspended shield and a scatter-shielding drape or use of the rolling shield were the configurations required to achieve an undetectable dose rate at the operator's eye.

### Operator Position at the Neck

With the operator in the position typical of transjugular intrahepatic portosystemic shunt creation, transjugular liver biopsy, or jugular inferior vena cava filter placement and retrieval, the ceiling-suspended shield provided maximal eye protection (**Table 2**). The combination of leaded glasses and scatter-shielding drape was more effective than either device used alone. Leaded glasses used alone permitted a 10-fold reduction in lens dose rate, whereas the use of a scatter-shielding drape alone reduced dose rate by a factor of five.

### Operator Position at the Upper Abdomen

With the operator in the position typical of a right-sided biliary drainage with PA fluoroscopy (**Table 3**), the reference dose rate to the lens was lower than in either of the two preceding operator configurations, which is consistent with positioning of the operator's eyes closer to the image intensifier and away from the scatter field. Maximal reduction in lens dose rate was achieved by use of the ceiling-suspended shield. The combination of leaded glasses and a scatter-shielding drape led to greater dose rate reduction than either device used alone. When the image intensifier is moved 15° into left anterior obliquity over the upper abdomen, the scatter field opens toward the operator's face, leading to a nearly fourfold increase in the reference lens dose compared with PA fluoroscopy at the upper abdomen. Maximal lens protection was again provided by the ceiling-suspended shield, followed by the combination of leaded glasses and a scatter-shielding drape. In a 15° right anterior obliquity, the scatter field is projected away from the operator's face, leading to the lowest baseline lens dose rate in this operator position. Both the ceiling-suspended shield and the combination of leaded glasses and scatter-shielding drape were maximally protective for this geometry.

## DISCUSSION

The lens is a biconvex structure of the eye, suspended by its attachments

**Table 3**
**Lens Exposure while Operating at Patient's Upper Abdomen during Low-dose PA, RAO, and LAO Fluoroscopy**

| | PA | | | 15° LAO | | | 15° RAO | | |
|---|---|---|---|---|---|---|---|---|---|
| | Lens Dose Rate | | Lens Dose Reduction Factor | Lens Dose Rate | | Lens Dose Reduction Factor | Lens Dose Rate | | Lens Dose Reduction Factor |
| Shielding Strategy | mSv/h | mR/h | | mSv/h | mR/h | | mSv/h | mR/h | |
| Image intensifier at 3 cm (close) | 0.32 | 37 | — | 0.946 | 108 | — | 0.171 | 19.5 | — |
| Plus leaded table skirt | 0.217 | 24.8 | RM | 0.79 | 90 | RM | 0.156 | 17.8 | RM |
| Plus unleaded eyeglasses | 0.205 | 23.5 | 1.0 | 0.74 | 85 | 1.1 | 0.153 | 17.5 | 1.0 |
| Plus leaded eyeglasses | 0.040 | 4.6 | 5.4 | 0.101 | 11.5 | 7.8 | 0.024 | 2.7 | 6.6 |
| Plus scatter-shielding drape | 0.033 | 3.8 | 6.5 | 0.087 | 10 | 9.0 | 0.035 | 4.0 | 7.2 |
| Plus leaded eyeglasses and scatter-shielding drape | 0.007 | 0.77 | 32.2 | 0.014 | 1.6 | 56.3 | LLD | LLD | > 1,000 |
| Plus ceiling-suspended shield | LLD | LLD | > 1,000 | LLD | LLD | > 1,000 | LLD | LLD | > 1,000 |

Note.—LAO = left anterior oblique; LLD = below the lower limit of detection (0.001 mSv/h); RAO = right anterior oblique; RM = reference measurement.

to the ciliary muscles between the iris and the vitreous body. Contraction or relaxation of the ciliary muscles alters the thickness of the lens, permitting accommodation—the ability to sharply focus on objects near or far. The lens fibers are continuously renewed throughout life by progenitor epithelial cells located at the lens periphery. Opacities in the normally transparent lens are termed cataracts. Whether associated with diabetes, trauma, medication, exposure to UV light, or radiation, the common pathway of cataract formation is believed to be related to impaired proliferation of the progenitor epithelial cells and/or oxidative denaturation of lens fiber proteins (7). A spectrum of clinical importance ranges from asymptomatic peripheral opacities to slight decreases in visual acuity and contrast discrimination to complete clouding of the lens, obstructing passage of light and causing blindness.

The association of radiation exposure and cataractogenesis is well documented, having been studied in a variety of populations including atomic bomb survivors, radiation workers, radiation therapy patients, and radiologists. In atomic bomb survivors, a significant correlation has been shown between radiation dose and development of cortical and posterior subcapsular lens opacities (7). Among 8,607 Chernobyl cleanup workers, 25% had detectable subcapsular or cortical cataracts characteristic of radiation exposure 20 years after the 1986 disaster. On the contrary, patients treated with radiation therapy for hemangioma as infants developed contralateral lens opacities 30–45 years after exposure (8). A 20-year prospective cohort study of radiologic technologists in the United States showed that the dose response for occupational radiation exposure to the lens of eye and cataract risk was nearly linear, with no apparent threshold level. Haskal (9) reported finding posterior subcapsular cataracts in five of 59 screened interventional radiologists (8%), with 22 others (37%) showing signs of early radiation damage to the lens. Working with Vano et al (6), Haskal further demonstrated that the dose threshold for cataract formation may be exceeded within several years of typical interventional radiology work if radiation protection tools are not used.

Basic radiation safety practice represents the first step in eye protection for the practicing interventional radiologist. The impact of maintaining the image intensifier as close as reasonably possible to the patient is illustrated by **Table 1**, which shows that the difference between a large and short distance between patient and image intensifier produces a twofold difference in the dose rate to the operator's lens. Routine use of low-dose fluoroscopy, last-image hold, and archiving last-image hold screens rather than exposing new images all contribute to lower dose to the patient and decreased scatter to the radiologist's eye. Moving away from the patient, when possible, has a powerful impact on exposure to scattered radiation dose through the well known inverse square law. Perhaps the most important application of this principle would be to avoid acquisition of hand-injected angiograms when machine injection can be used, freeing the operator to leave the procedure room for maximal radiation shielding. According to the present measurements, the lens dose rate associated with acquiring hand-injected DSA images without protection was eight times higher than the dose obtained during low-dose fluoroscopy.

Our purpose was to experimentally demonstrate the efficacy of commonly available radiation shielding strategies used alone and in combination. The reference condition was one we believe must be universally available to all practicing interventional radiologists—namely, a fluoroscopy unit with a source situated beneath the patient operated with the image intensifier as close as practical to the surface of the patient's body in the presence of a leaded table skirt. Not surprisingly, unleaded eyeglasses provided no substantial protection versus this reference condition. Leaded glasses, on the contrary, reduced dose rate to the lens by factors of five to 10 depending on operator position and beam angulation.

The use of a scatter-shielding drape produced five- to 25-fold reductions in the dose rate to the lens. These drapes provide maximal protection when they are interposed between the patient (ie, the scatter source) and the operator. However, care must be taken to keep the drape out of the beam, as this can lead to substantial increases in energy output from the radiation source. For the simulation of visceral angiography recorded in **Table 1**, the drape was positioned to span the lateral aspect of the patient phantom from the lower abdomen to the hip, peripheral to the imaging field. In this orientation, there was a 12-fold reduction in the rate of scatter to the operator's lens. A similar position of the drape produced smaller dose rate reductions when the operator was at the jugular position, leading to a fivefold reduction in scatter rate to the lens. Positioning of the drape in a simulated right-sided biliary drainage was most challenging, as the area one hopes to shield is in the working field. We placed the drape just superior to the location of a low intercostal puncture and observed scatter rate reductions from 6.5- to ninefold, depending on beam obliquity. Use of these drapes does incur incremental cost for each procedure. The type of drape costs between $27 and $32, depending on the style selected (10).

In all our experiments, the combination of leaded glasses and a scatter-shielding drape was substantially more protective than the use of either implement alone. In three instances, the combination provided dose rate reductions of 25–132 fold; and in two instances, no detectable dose could be registered at the lens detector when both devices were present.

In all the geometries we studied, the leaded ceiling-suspended shield uniformly provided maximal dose rate reduction for the operator's eyes during low-dose fluoroscopy. Despite having only 0.5 mm lead equivalent—compared with 0.75 mm lead equivalent in the tested lead glasses—the protection afforded by the suspended shield was always as good or better than that afforded by the leaded glasses. This is almost certainly a result of the broader size of the shield compared with the glasses. When the operator was positioned at the phantom patient's groin, the rolling leaded shield also provided maximal reduction in scatter rate to the operator's lens. The rolling shield was the only single barrier associated with an undetectable lens dose rate during in-room DSA. However, we found no practical way to position such a shield with the operator positioned at the mid-abdomen or the neck.

For simplicity, we did not design our experiment to evaluate multiple variations in the use of each radiation protection implement. For example, only one sports-style wraparound, non–goggle type of leaded eyeglass was evaluated at a specific height above the floor. Leaded goggles or leaded eyeglasses used at different heights would be expected to have different performance profiles. Only a single type of scatter-shielding drape was used, although several are available. We positioned the leaded drapes in a manner that simulated typical placement during our clinical cases, but different drape positions are possible and could lead to different results. Additionally, we used an analog fluoroscopy system in our experiment. Use of digital fluoroscopy should lead to lower doses to the patient and lower used scattered doses to the operator. However, by dealing in dose rates and factor reductions to scattered dose rates rather than absolute doses, we believe we have demonstrated reproducible and applicable general principles. In fact, Vano et al (6) similarly showed that leaded goggles and suspended screen shields can result in significantly reduced scattered radiation doses at eye lens level.

In summary, exposure of the lens to radiation increases the risk of cataract formation and visual impairment. Modern evidence suggests that the risk accrues, without a threshold dose, in an apparently linear relation to radiation exposure. Understanding the efficacy of available methods of eye protection is therefore essential. The combination of scatter-shielding drapes and leaded glasses provides substantial reduction in scattered dose to the operator's eyes, and the use of both is more effective than the use of either alone. Ceiling-suspended leaded shields were routinely maximally effective in reducing the lens dose rate and should be made available in all interventional radiology suites. Because use of the scatter-shielding drape also reduces scattered dose to others in the working area, we believe drapes should be routinely considered for use in conjunction with leaded glasses or suspended shields.

The preservation of visual acuity is a key component in the longevity of a career in interventional radiology. Understanding the synergy of available shielding implements should assist the interventional radiologist in choosing the barrier system most appropriate for each case to minimize occupational risk to the lens.

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