

Efficacy of Radiation Safety Glasses in Interventional Radiology

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Received: 30 May 2013 / Accepted: 27 September 2013 / Published online: 2 November 2013

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Abstract

Purpose This study was designed to evaluate the reduction of the eye lens dose when wearing protective eyewear in interventional radiology and to identify conditions that optimize the efficacy of radiation safety glasses.

Methods The dose reduction provided by different models of radiation safety glasses was measured on an anthropomorphic phantom head. The influence of the orientation of the phantom head on the dose reduction was studied in detail. The dose reduction in interventional radiological practice was assessed by dose measurements on radiologists wearing either leaded or no glasses or using a ceiling suspended screen.

Results The different models of radiation safety glasses provided a dose reduction in the range of a factor of 7.9–10.0 for frontal exposure of the phantom. The dose reduction was strongly reduced when the head is turned to the side relative to the irradiated volume. The eye closest to the tube was better protected due to side shielding and eyewear curvature. In clinical practice, the mean dose reduction was a factor of 2.1. Using a ceiling suspended lead glass shield resulted in a mean dose reduction of a factor of 5.7.

Conclusions The efficacy of radiation protection glasses depends on the orientation of the operator's head relative to the irradiated volume. Glasses can offer good protection to the eye under clinically relevant conditions. However, the performance in clinical practice in our study was lower

than expected. This is likely related to nonoptimized room geometry and training of the staff as well as measurement methodology.

Keywords Radiation protection · Cataract · Eye lens dose · Glasses

Introduction

Interventional radiologists and cardiologists are exposed to high levels of radiation during routine clinical practice [1, 2]. Recently, the International Commission on Radiological Protection recommended reducing the equivalent dose limit for the lens of the eye from 150 to 20 mSv in a year [3]. This recommendation originates from a reevaluation of the sensitivity of the eye to radiation induced cataract.

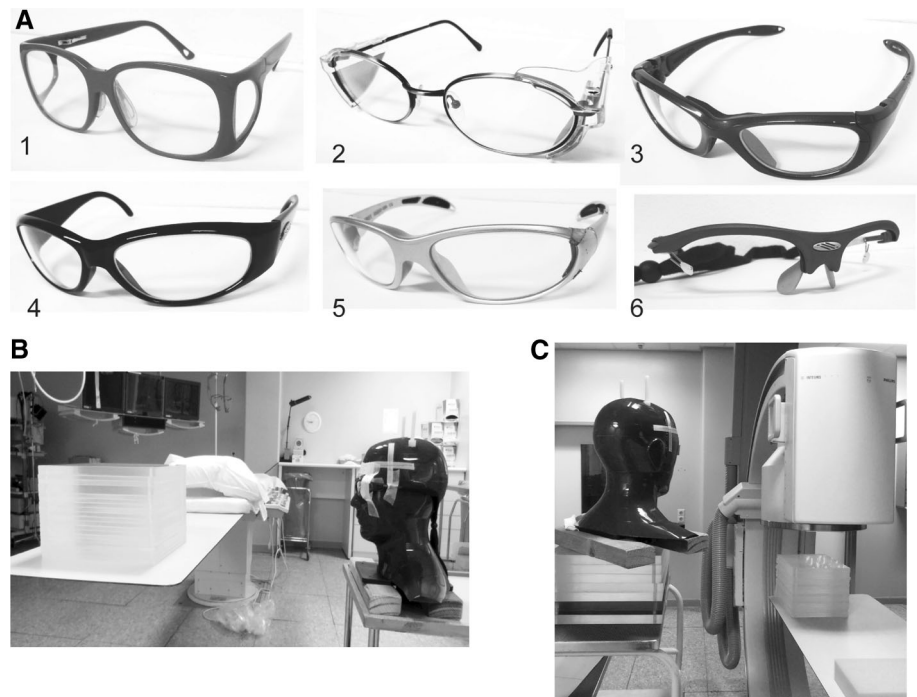
In the past, the occurrence of radiation induced cataract was classified as a deterministic effect with a threshold dose of 5 Gy for protracted exposures [4]. Recent work on reanalysis of atomic bomb survivors [5, 6], cataract incidence among medical staff [7–10], and other work (see [11, 12] for recent reviews) have resulted in updated risk estimates. More importantly, a growing body of evidence suggests that the threshold value for cataract formation is substantially lower than previously thought [5, 6, 11, 13]. These data highlight the importance of radiation protection of the eye for personnel performing X-ray-guided interventions [14].

Protective eyewear containing leaded glass is a potential safety measure to reduce the eye lens dose. However, several factors negatively affect the dose reduction of wearing protective eyewear [15]. In this work, we have measured the reduction of the eye lens dose in radiological practice when wearing radiation safety glasses and when

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Fig. 1 A Images of the different models of radiation glasses that were tested in a phantom experiment. Model 6 is the frame without glasses that was used for the unprotected eye dose measurements during X-ray interventions.

B Determination of the maximal achievable dose reduction was performed in the geometry with the head at the same level and facing the irradiated volume of the slab. **C** Dose reduction factors achievable in practice were obtained with the phantom head at the position representative of that of a radiologist. In this picture the head was rotated -45° towards the tube



using a ceiling suspended radiation barrier. Additionally, we have assessed how spectacle design, layout of the intervention suite and positioning of the operator influence the efficacy of radiation safety glasses.

Materials and Methods

Radiation Safety Glasses

Radiation safety glasses were provided by Amray (Amray Medical, Drogheda, Ireland). The following models were used (Fig. 1A): 53 wrap (model 1), Metalite 553S (model 2), Maxi Designer Range (model 3), Icicles Designer Range (model 4) and Ultralite 99 (model 5). The lead equivalent thickness was 0.75 mm frontally and 0.5 mm for the sides.

Attenuation

The broad beam attenuation of the leaded glasses was measured on a digital X-ray system (Siemens Axiom, Siemens, Erlangen, Germany). A dosimeter (Unfors Xi, Unfors, Billdal, Sweden) was placed at 1 m from the X-ray tube. Two lead plates (thickness 3 mm) with a 1 cm circular aperture were placed 30 cm apart. The bottom plate was placed directly on the dosimeter to reduce scatter originating from the room walls and ceiling. The glasses were directly located above this aperture. Consequently, scatter originating from the glasses is included in the

attenuation measurement. The X-ray tube was set at 100 kV, 50 mAs, and 2 mm total aluminum filtration. The attenuation was calculated as the dose on the detector without glasses divided by the dose with glasses present.

Phantom Dose Measurements

Dose measurements were performed with LiF thermoluminescent dosimeters (TLDs) (TLD Poland, Krakow, Poland). TLD readout was performed with a Harshaw 3500 reader (Thermoscientific, Waltham, USA). TLDs were calibrated to the air Kerma free in air with a calibrated ionisation chamber (PM-30, Capintec, Ramsey, USA) with electrometer (192 A, Capintec, Ramsey, USA) as reference. Measurements were corrected for background radiation by subtracting the dose value of unirradiated TLDs. The irradiation duration in each experiment was adjusted to obtain an approximate minimum dose on the TLDs of around 0.2 mGy. Experiments were performed on a Philips Integris 3000 fluoroscopy system (Philips Healthcare, Best, The Netherlands) at 75 kV, 2 mm aluminum filter. A Perspex slab 20×30 cm with a thickness of 20 cm was placed in the beam and irradiated at full field size with the tube in the under couch position. A RANDO anthropomorphic head phantom (the Phantom Laboratory, Salem, USA), was placed in the scattered radiation field of the slab (Fig. 1B). For all measurements, sets of three TLDs were used to minimize the measurement error, average values were subsequently used for calculation of the dose reduction factor. Generally, the sets had a coefficient of variation

of approximately 3 %. TLDs were taped on the position of the eyes of the phantom. Dose values were divided by the dose on TLD placed at a fixed position, 50 cm away from the slab along the table long axis, to correct for exact tube output.

The dose reduction factor was determined by dividing the eye dose without glasses by the eye dose with glasses. Three different geometrical configurations were used: for frontal irradiation, the head phantom was placed 60 cm from the slab with the phantom facing the slab (Fig. 1B). Second, a geometry (operators position 0°) more representative of working conditions was used with the head phantom placed facing the table at a distance of 50 cm in the lateral and longitudinal direction from the beam axis and the top of the skull at a height of 1.85 m. The third geometry (operators position 45°) was identical to the second but with the head phantom rotated 45° sideways away from the slab. To establish in detail how head rotation influences eye protection, the dose reduction factor was measured in this position for several head angulations (Fig. 1C) and for an upward or downward tilting of the head with the head facing straightforward (0°). These measurements were performed for a single glass model (model 5) that performed well in the fixed positions.

Eye Dose Measurements in Clinical Practice

Ethical approval for the clinical study was waived by the institutional review board. For the low dose measurements, LiF:Mg,Cu,P TLDs (TLD Poland, Krakow, Poland) were used. In the dose range of this study, these TLDs have a coefficient of variation of ~5 %. TLD Measurements were corrected for background radiation using unirradiated TLDs. Two TLDs were placed on the surgical cap directly above the eyes. A third TLD was placed centrally on the chest at the level of the collar bone. The eye lens dose was measured using a TLD close to the lateral corner of the eye. This TLD was attached to the frame of the glasses by means of a metal clip. Two different frames were used: One radiation safety glasses (model 5). Second, a spectacle frame with the lenses removed (model 6). In addition, the eye dose using a ceiling suspended barrier (no glasses) was assessed.

The dose reduction factor was calculated as the eye lens dose without protective glasses divided by the eye lens dose with protective glasses in the spectacle frame. In the case of radiation safety glasses, eye dose values were first corrected for tube output and distance of the radiologist to the source by dividing with the dose of the matching reference TLD on the surgical hat. In the case of the dose reduction factor of the ceiling suspended shield, eye dose values were corrected for tube output by dividing by the Kerma air product (KAP) values provided by the system.

Table 1 Summary of the performed procedures during the dose acquisitions in clinical practice

	No protection	Lead glasses	Ceiling suspended screen
Anatomical location			
Abdomen (number of procedures)	6 (1)	4 (2)	3 (1)
Lower extremities (number of procedures)	4	5 (1)	1
Upper extremities (number of procedures)	1 (1)	4 (2)	
Head (number of procedures)	1	1	1
Dosimetric characteristics			
Number of TLD sets	4	3	3
Mean left eye dose/procedure (μGy)	26.4	5.8	34.0
Mean chest dose/procedure (μGy)	38.0	19.4	57.5
Mean chest dose/KAP (μGy mGy ⁻¹ cm ⁻²)	2.5	3.5	0.6

The number of diagnostic angiographies is depicted between parentheses next to the total number of procedures. A summary of the dosimetric characteristics also is shown

For each measurement, the dose on the TLDs was accumulated during at least three half-day programs in normal interventional radiological practice (typically 2–4 procedures per acquisition). The vast majority of procedures performed in our department are vascular interventions using femoral access. A summary of the included procedures is given in Table 1. Additionally, the eye lens dose when wearing protective glasses during a single procedure (fenestrated aortic repair) was also measured. X-ray interventions were performed on a Toshiba (Toshiba, Otawara Tochigi, Japan) and a Philips Allura Xper FD 20 (Philips Healthcare, Best, the Netherlands) cardiovascular X-ray intervention system. The endovascular interventions were performed by four experienced (right-handed) interventional radiologists. Dose values were only acquired for the primary operators as these generally receive the highest dose.

Statistical Analysis

Data from the phantom experiment are reported as mean ± standard error for estimation of the mean. For the clinical measurements data are reported as mean, median, and range. Comparisons of continuous variables were performed using a two-tailed *t* test. Confidence intervals for the clinical dose reduction factor were calculated on log transformation of this ratio [16].

Table 2 Dose reduction factors from the phantom measurements for several geometries and spectacle models

Model	Eye	Broad beam attenuation factor	Frontal irradiation	Operator's position, 0°	Operator's position, 45°
1	L	87.6 ± 0.1	10 ± 0.6	5.1 ± 1	1.1 ± 0.1
	R			1.5 ± 0.2	1 ± 0.2
2	L	96.3 ± 0.1	9.1 ± 0.6	3.4 ± 1.1	1.6 ± 0.1
	R			2.2 ± 0.4	1.3 ± 0.3
3	L	105 ± 0.1	8 ± 0.7	5.6 ± 0.8	1.2 ± 0.1
	R			1.5 ± 0.3	1 ± 0.2
4	L	101.7 ± 0.5	8.4 ± 0.4	8.3 ± 1.7	2.5 ± 0.2
	R			2.3 ± 0.5	1 ± 0.2
5	L	99.1 ± 0.1	7.9 ± 0.9	7.5 ± 1.2	1.6 ± 0.2
	R			1.7 ± 0.3	1 ± 0.3

Data are reported as mean ± standard error ($n = 3$)

L left tube side, R right non-tube side eye

Results

Phantom Dose Measurements

The X-ray attenuation of the glasses in a broad beam configuration is shown in Table 2. For frontal irradiation (Fig. 1B) of the phantom head, the dose reduction factor at the eye of the phantom was in the range of 7.9–10.0 for different glasses. When the head phantom was positioned at a location typical for radiological interventions, the dose reduction varied among the different model in a range of a factor of 3.4–8.3 for the left (tube side) eye and 1.5–2.3 for the right eye. Upon rotating the phantom head 45° away from the tube in the axial plane, there was no significant dose reduction for the right eye and the protection of the left eye was 1.1–2.5.

The differences in the dose reduction may be caused by the fit of the protective eyewear to the shape of the phantom head. Figure 2 shows an X-ray image of the phantom

head from a 45° double oblique angulation (left oblique, caudal-cranial position). The location of the right eye is much closer to the shadow projected by the edge of the leaded glass compared with the left eye. Furthermore, differences in the distance between the position of the eye and the edge of the shielding are observed for different models (Fig. 2A, B).

Figure 3A shows the reduction factor of the eye dose of the right and left eye for different head rotations in the axial plane for glasses model 5. The dose reduction was smaller when the head was rotated away from the tube. For the right (non-tube side) eye, this effect occurred at a smaller angle compared with the left eye. Relative dose values for the protected and unprotected case are shown in Fig. 3B. When wearing protective glasses, the dose to both eyes is lowest when facing the tube. By rotating the head away from the tube, the eye dose increases and approach the eye dose in the unprotected case. Especially for the left eye this leads to high eye doses, the dose to the right eye is much lower. Tilting the phantom head upwards 15° also resulted in lower dose reductions while a downward tilt improved the dose reduction (Fig. 3C). The effect of tube voltage on the dose reduction for a single geometry is shown in Fig. 3D. The dose reduction was smaller at higher tube voltages.

Dose Reduction in Clinical Practice

The average eye dose per unit KAP for different scenarios is summarized in Table 3. Wearing leaded glasses resulted in an average dose reduction factor of around 2.1 for the left (tube side) eye and no reduction for the right eye. For individual procedures, the dose reduction of radiation protection glasses can be higher than the average value. For instance, during fenestrated endovascular aortic repair wearing radiation protective eyewear resulted in a mean dose reduction factor of 5.6 for the left eye and 7.7 for the right eye. The use of a ceiling suspended radiation barrier led to a mean reduction for the left and right eye of a factor of 5.7 and 4.8 respectively.

Fig. 2 X-ray image of the phantom head from a 45° double oblique angulation (left oblique, caudal-cranial position) with an overlay containing the image with the phantom head wearing radiation protection glasses. The position of the eye lens was marked with 1 mm X-ray opaque markers. These are denoted in the images with an *arrowhead*. Two different models are shown: model 5 (A), model 2 (B)

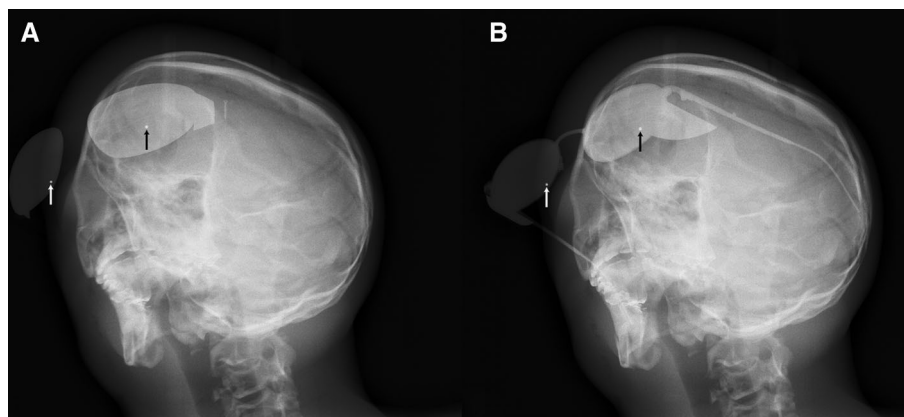


Fig. 3 Phantom dose measurements at different angular positions of the head. **A** The dose reduction of the protective eyewear (model 5) for both the *left* (tube side) and *right* (non-tube side) eye. The angle of 0° was defined as the head was facing the table and a positive rotation as rotating the head away from the tube. A schematic top view of the phantom head rotation in the axial plane relative to the tube is shown on *top*. **B** Relative dose values in the protected and unprotected case. **C** In a similar way the effect of looking down (−15°) and up (15°) on the dose reduction was measured with an axial rotation of 0°. **D** The effect of tube voltage on the dose reduction in a single geometry

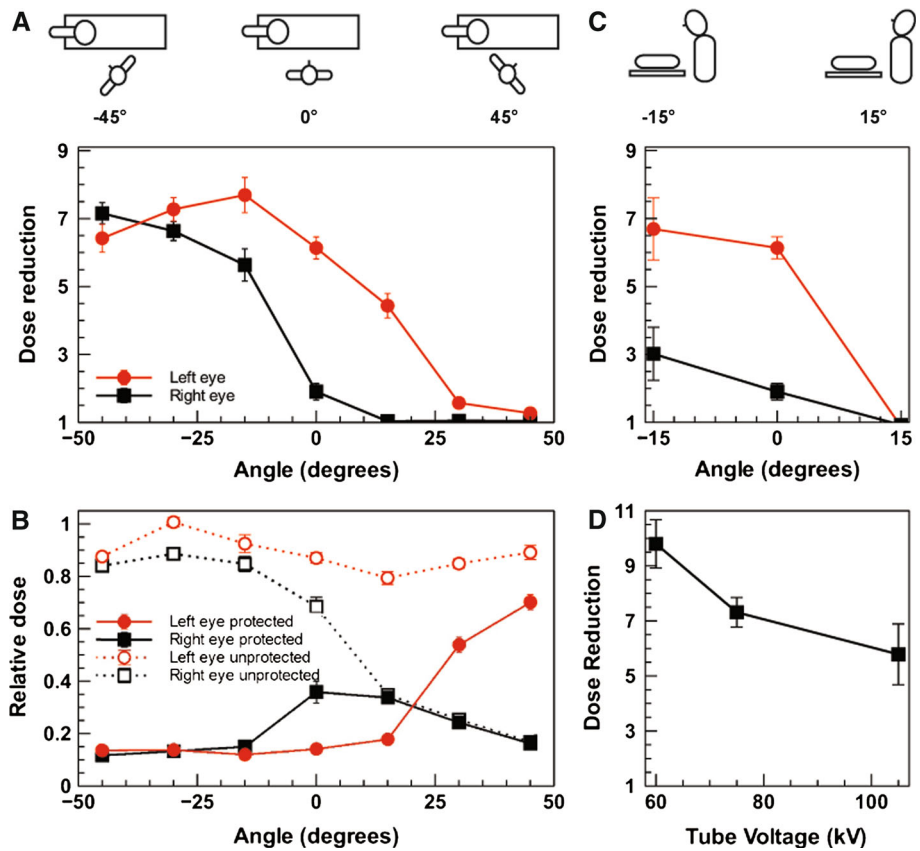


Table 3 Eye lens exposures in routine radiological practice and the dose reduction factor achieved by protective eyewear

Eye	Eye dose/KAP ($\mu\text{Gy mGy}^{-1}\text{cm}^{-2}$)			Eye dose/dose on cap			Dose reduction factor	
	Mean	Range	Median	Mean	Range	Median	Mean	95 % CI
Unprotected								
L	1.7	0.9–2.5	2.2	1.3	1.1–1.7	1.3		
R	1.0	0.2–2.1	1.6	1.4	1.3–1.6	1.4		
Protective eyewear								
L	1.0	0.4–2.0	0.7	0.6*	0.6–0.8	0.6	2.1	1.1–3.8
R	0.7	0.4–1.1	0.6	1.7	1.2–2.5	1.5	**	**
Ceiling suspended barrier								
L	0.3*	0.2–0.4	0.3				5.7	1.5–22.5
R	0.2	0.1–0.4	0.2				**	**

* Eye dose in the protected case is significantly different from the unprotected case against $p < 0.05$

** No significant dose reduction could be measured

Discussion

When wearing protective eyewear three dose contributions to the eye are present. First, some radiation leaks through the leaded glasses. Second, radiation that enters the head of the radiologist can be scattered towards the eye. Third, radiation that enters where no shielding is present can contribute directly to the eye dose.

Radiation protective glasses typically contain ~0.75 mm of lead equivalent material. At the tube voltages commonly used in interventional radiology, the shielding effectively attenuates the radiation. We measured an attenuation factor of 87.6–105.0 at 100 kV for several glass models. When the phantom head faced the radiation source, we measured a dose reduction factor of ~8–10 for the tested models. Thus, the maximum achievable dose

reduction is limited by the contribution from radiation scattered inside the head of the operator. Finally, the position and viewing direction of the operator relative to the imaged area of the patient determine if the radiation can directly reach the eye. Both looking upward and looking away from the irradiated volume resulted in smaller dose reductions in the phantom experiment, which corresponds well with earlier studies [17]. For the non-tube side eye the glasses failed at smaller axial angles, because there is no shielding on the side of the tube for this eye. In terms of absolute dose, the tube side eye is more important because it is closer to the source [18].

From these findings, it is clear that the efficacy of lead glasses in practice is mainly dependent on geometrical factors and thus depends on the position of the physician relative to the source and the model of the glasses. In the phantom experiment, differences between models were especially apparent for the measurements at the position of the operator. The difference in performance of the glass models is related to the range of angles that are shielded by the model. This is illustrated by the X-ray images of the phantom head from a 45° double oblique angulation (left oblique, caudal-cranial position), where the distance from the center of the eye lens to the edge of the glasses is different for the shown models. This difference corresponds to a difference in dose reduction factor at the position of the operator (model 5: 7.5 ± 1.1 vs. model 2: 3.4 ± 1.2 , difference significant at $p = 0.06$). This illustrates the importance of the fit of the glasses relative to the shape of the head. Note that the fit of the glasses should be assessed on an individual basis and that the optimal glass model may be different for different operators.

In addition to the model of the glasses, the achieved dose reduction depends on the nature of the procedure, the posture and length of the radiologist, and layout of the angiosuite. Because of the large variations in these parameters, a single value for the dose reduction of radiation safety glasses cannot be provided. Averaged over different radiologists and procedures, we found a dose reduction factor of 2.1 for the tube side eye and 0.8 the non-tube side eye. The average dose reduction measured here was lower than previously reported in literature. Moore et al. [15] reported a dose reduction with a factor of 5.3 for a wrap around model. Challa et al. [19] reported a dose reduction of approximately 3.3. The different values reported could be related to the applied methodology. In our study, the dose reduction for the left eye lens is underestimated, because we measure next to the eye at a position that is less well shielded. More importantly, the dose reduction may be lower due to suboptimal room layout. Operators were not instructed on the use of radiation safety glasses before the study. Placement of the monitor relative to the irradiated area was not adjusted to optimize the dose reduction.

Another limitation is the uncertainty in the estimate of the dose reduction. The eye dose varies considerably between procedures due to difference in tube-operator distance and operator posture as evidenced by the differences in chest dose/KAP for the different scenarios (glasses, screen, and unprotected). The estimate of the dose reduction factor thus has large uncertainty. Using the TLD on the hat instead of KAP, reduced some of the variation by compensating for the differences in average tube-operator distance between the unprotected and protective eyewear group. Additionally, there is a large variation in the dose reduction between different procedures. For instance, during endovascular aortic repair we measured a high dose reduction (a factor of 5.6, tube side eye) for the radiologist. During these procedures, the radiologist was positioned differently with respect to the patient to work together with the vascular surgeon.

An important measure for reducing the eye lens dose is the use of a ceiling suspended radiation barrier. The ceiling suspended screen lead to an average dose reduction factor of 5.7. Other studies have reported dose reductions of a factor of 5–20 [20, 21]. However, a ceiling suspended screen cannot be used during every procedure. Protective surgical drapes placed over the patient to reduce scattered radiation have also been reported to reduce staff exposures [22, 23]. In addition to protective barriers, minimizing patient exposure and keeping distance when possible are also vital to reduce eye lens exposures.

Conclusions

The results in this study show that wearing protective eyewear is an important measure for radiation protection of the eye tool. In an optimal geometry, a high dose reduction factor is achievable. However, if the geometry of the intervention suite and design of the glasses is not optimal the dose reduction may be lower. Radiation that enters from the side or below, which is not shielded by the glasses, causes a much lower dose reduction than is expected on the basis of lead equivalent thickness alone. Careful attention to the way these glasses are used is critical in ensuring their efficacy. Adequate training and advice to interventional radiologists and X-ray technicians is thus of the utmost importance to ensure effective radiation protection. Based on our results, we have the following advice for effective radiation protection of the eye:

- Whenever possible place a ceiling suspended screen between the source of the radiation and the eyes.
- Protective eyewear should block radiation from wide angles: Adequate shielding for radiation from the side and below is a necessity.

- Reducing the angle at which the radiation enters the head maximizes the dose reduction of the glasses. This can be achieved by optimizing posture and layout of the intervention suite (such as positioning the monitor at an appropriate position).

Conflict of interest The authors declare that they have no conflict of interests.

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