The choice of eyewear needs to include consideration of job task and orientation of the face to the radiation source as well as the possibility that face shape and eye glass fit may also impact the amount of scatter radiation that reaches the eye.

Protective Eyewear Selection for Interventional Fluoroscopy

Glenn M. Sturchio, Richard D. Newcomb,* Robin Molella,* Prathibha Varkey,* Philip T. Hagen,* and Beth A. Schueler*[†]

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Abstract: *Three protective eyewear models were evaluated to determine effectiveness in reducing radiation dose to a fluoroscopist's eyes. The performance of the protective eyewear was measured using radiation dosimeters in a fluoroscopy suite. An Eyewear Protection Factor was determined for each model in each of three exposure orientations. The protection was strongly influenced by the location of the radiation source. When the source was in front of the fluoroscopist, the lead equivalence was important. When the source was to the side of the fluoroscopist, the cross section of the side shield had a significant influence on protection. Protective eyewear selection needs to include consideration of job task and head orientation to the radiation source as well as the possibility that face shape and eyewear fit may also impact the radiation dose to the eye. Health Phys. 104(Supplement 1):S11–S16; 2013*

Key words: *operational topics; dose; scattered; exposure; occupational; fluoroscopy*

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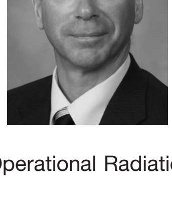
The authors declare no conflict of interest.

INTRODUCTION

The International Commission on Radiological Protection (ICRP) is an international body that recommends radiation safety standards and practices to regulatory agencies and practitioners around the world. The ICRP recommendations form the basis for the system of radiation limitation that regulates the occupational and non-occupational radiation exposures in the United States. In April 2011, the ICRP recommended lowering the equivalent dose limit for the lens of the eye to 20 millisievert (mSv) per year, averaged over a defined 5-y period, with no single year exceeding 50 mSv (ICRP 2012). The recommended reduction from the current 150 mSv per year limit is based on a review of recent epidemiological data that suggests that the threshold dose for causation of cataracts is lower than previously believed. As discussed by Vanhavere et al. (2011), if adopted by federal and state regulatory bodies, this seven-fold decrease in the occupational eye dose limit may limit the practice of certain interventional fluoroscopists unless they make a change in their practice or adopt the use of effective protective eyewear and other in-room shielding options. There are a number of eyewear products and styles available on the market. These vary in reported protection value and weight. Identifying the best eye protection options for providers may improve adherence and decrease lifetime risk of cataract.

Approximately 0.8% of people older than 40 y are blind worldwide, and 1.98% of the U.S. population has low vision. Cataracts are estimated to be the cause for 50% of these cases. Cataract is a common problem with estimates suggesting that it effects more than 22 million people in the United States; one in six over the age of 40 y. Other estimates suggest cataracts are the leading cause of blindness in the world (Michael and Bron 2011). Risk factors for cataracts are numerous, and include age, smoking status, alcohol consumption, sunlight exposure, low education, poor lifestyle habits including malnutrition and physical inactivity, metabolic syndrome, diabetes mellitus, ionizing radiation, systemic corticosteroid use, and possibly inhaled corticosteroids. While ultra violet radiation



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is thought to account for the majority of risk for cataract, occupational risks from exposure to ionizing radiation are well known. This is most pertinent to the U.S. and other developed countries that use ionizing radiation as sources for medical imaging, particularly in fluoroscopy and angiography. Prior estimates for cataract formation were based on Hiroshima and Nagasaki atomic bomb survivors as well as other highly exposed workers and patients. Research in the last 10 y have focused on mechanistic studies on laboratory animals, clinical studies in humans exposed to radiation for treatment of childhood hemangiomas in Sweden, and individuals exposed to radiation from the Chernobyl area as residents or those involved in clean up, as well as workers in the U.S. involved in occupational exposures, commercial and space flight (Ainsbury et al. 2009; Phelps 1997; Worgul et al. 2002; Hall et al. 1999; Day et al. 1995; Chodick et al. 2008; Rafnsson et al. 2005; Cucinotta et al. 2001). This research has suggested that there are genetic factors in which some individuals may be at higher risk for development of cataracts. Epidemiologic studies have suggested a strong likelihood that there is a threshold level of risk on the order of 1 Gy or lower for formation of cataracts in cumulative low dose exposures. Taken altogether, these studies and others have led the ICRP to recommend lowering the equivalent dose limit for the lens of the eye to 20 mSv y^{-1} (averaged over a 5-y period) from the prior 150 mSv per year limit.

Eye protection strategies from occupational ionizing radiation exposure include engineering controls, dosimetry monitoring, and protective eyewear. It is well known that reliance on personal protective equipment as a risk reduction strategy should be thought of as the protection of last resort. NIOSH (2012) gives the following guidance: "The eye protection chosen for specific work situations depends upon the nature and extent of the hazard, the circumstances of exposure, other protective equipment used, and personal vision needs. Eye protection should be fit to an individual or adjustable to provide appropriate coverage. It should be comfortable and allow for sufficient peripheral vision. Selection of protective eyewear appropriate for a given task should be made based on a hazard assessment of each activity, including regulatory requirements when applicable." Lack of comfort is one reason cited for failure to use personal protective devices. Lightweight protective eyewear is available for protection from ionizing radiation, though these glasses have not been reported as having the same protection factors as heavier eyewear. Previous studies have evaluated leaded eyewear for its efficacy (Moore et al. 1980; Cousin et al. 1987). The primary objective of this study evaluates newly available lightweight safety glasses, using facial angle towards the source as a factor in the efficacy of protection. Although not an objective of the study, the results highlighted the importance of considering job tasks and eyewear fit in selecting protective eyewear for ionizing radiation exposure.

MATERIALS AND METHODS

To create as realistic an environment as possible to test the protection afforded the lens of the eye by commercially available leaded eyewear, the measurements were made in an interventional fluoroscopy procedure room and phantoms were used to represent the patient undergoing the examination and the operator wearing the protective eyewear. A C-arm angiography system (Multistar; Siemens Medical Solutions, 51 Valley Stream Parkway, Malvern, PA 19355) equipped with a 40-cm image intensifier was used to simulate a clinical abdominal imaging configuration with the x-ray tube positioned under the patient table. The scattered x-ray field used for the experiments was generated by directing the primary x-ray beam into a cube of material—a patient phantom—consisting of a 25 cm polymethyl methacrylate layer, a 5 mm aluminum layer, and a 0.25 mm copper layer. The operator was represented by a RANDO phantom (Alderson Research Laboratories, Stamford, CT), which is made of tissue equivalent material and contains skeletal structures, so photon transport is representative of actual conditions. The RANDO phantom used in this study corresponds to a 175 cm male weighing

Fig. 1. The RANDO phantom and patient phantom used for measurements (not in measurement geometry).

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73.5 kg. The two phantoms used for these measurements are shown in Fig. 1.

An optically stimulated luminescent (OSL) dosimeter, 1 cm × 1 cm × 0.2 cm, was placed on the eye of the RANDO phantom to record the lens of the eye dose. The OSL dosimeter uses aluminum oxide material, which absorbs x-ray energy and is later analyzed to determine the amount of radiation dose. These dosimeters were analyzed locally using a MICROSTAR reader (Landauer, Inc., 2 Science Road, Glenwood, IL 60425).

The new lightweight protective eyewear (XR-700 extra wide, Toray Medical Co., Toray International America Inc., 140 Cypress Station Dr., Suite 120, Houston, TX 77090) was compared to two older models that are readily available from commercial vendors and are frequently in use at our facility. The eyewear is described in Table 1. Our initial assessment of the effectiveness of the protective eyewear was to determine the attenuation provided when the scattered x-ray source was directly in front of the operator (0 degree orientation)—a geometry that is typical for claimed protection but not representative of typical clinical practice. This was accomplished by making measurements of the radiation reaching the eye with and without protective eyewear in place, while the operator phantom was 50 cm from the edge of the patient phantom with eye level approximately 30 cm above table height and looking directly at the scatter phantom. For each exposure condition, the patient phantom was exposed to a digital acquisition series of 120 images at 91 kVp with 3.5 mm aluminum filtration. Kerma-area-product for each exposure condition was measured to ensure consistent exposure levels to within 3%. All measurement conditions were performed twice and OSL values averaged.

More realistic evaluations of the protective eyewear were accomplished by positioning the operator phantom as would be typical for either a femoral access procedure or a gastro-intestinal procedure with the operator looking at the fluoroscopy image display during x-ray exposure and not at the patient. For a femoral access procedure, the operator's head was positioned at a 45-degree angle relative to the scatter radiation source and for a gastro-intestinal procedure, the operator's head was positioned at a 90-degree angle. For both configurations, presented in Fig. 2, the operator phantom was positioned 70 cm from the edge of the patient phantom with eye level 70 cm above the tabletop.

To evaluate the efficacy of the protective eyewear, we calculated an Eyewear Protection Factor for each measurement geometry. The protection factor is the ratio of the measured eye dose without eyewear to the measured eye dose with eyewear—the higher the protection factor the more protection afforded by the eyewear.

RESULTS

The results of the eye dose measurements using the OSL dosimeters are presented in Table 2. It is interesting to note that the

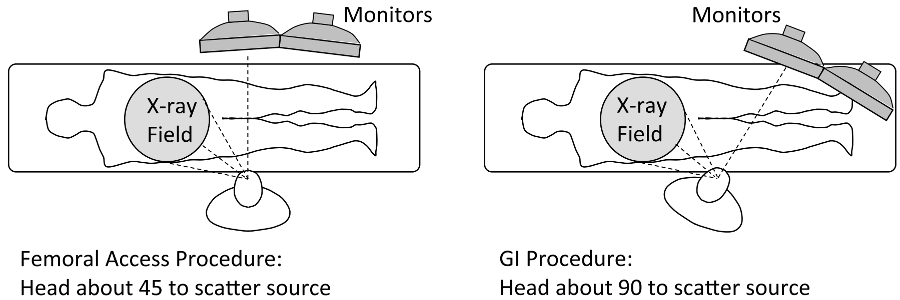

Fig. 2. Monitor location impact on incidence angle of radiation.

Table 1. Eyewear selection evaluated.

Eyewear	Lead equivalence[a] (mm)	Weight (g)	Approximate eyeglass lens cross section (cm^2)	Image
Lightweight	0.07	48	50	
Sportwrap	0.75	59	16	
Classic	0.75	120	28	

[a]Lead equivalence — the thickness of a pure lead sheet needed to provide the same level of radiation protection as the subject material.

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Table 2. Measured eye doses and calculated eyewear protection factors.

	Average eye dose (μSv)			Eyewear protection factor		
Eyewear	0 degree	45 degree	90 degree	0 degree	45 degree	90 degree
None	980	380	350	1.0	1.0	1.0
Lightweight	380	215	135	2.6	1.8	2.6
Sportwrap	120	85	245	8.2	4.5	1.4
Classic	105	75	90	9.3	5.1	3.9

eye dose increases significantly as the Sportwrap eyewear moves from 45 degree to 90 degree. This is likely attributed to the lack of substantial side shields on this type of eyewear design.

Eyewear Protection Factors at 0 degrees are presented in Fig. 3. The Lightweight eyewear provides the lowest Eyewear Protection Factor because it has the lowest lead content; therefore, it provides the least shielding. Although the Sportwrap eyewear and the Classic eyewear have the same lead content, the Sportwrap eyewear has a smaller lens cross section. The smaller cross section allows more incident x-rays to interact with tissue around the eye and potentially be scattered into the eye increasing radiation dose.

The Eyewear Protection Factors at 45 degree presented in Fig. 4 show a significant drop as compared to the 0 degree protection factors. This is due to the radiation source being located below the eyewear in the 45 degree orientation as compared to being in front of the eyewear in the 0 degree orientation. In this orientation, it is possible that x rays may pass unattenuated through gaps between the face and the eyewear frame, directly irradiating the eye and causing an increase in the eye dose. It is also possible that x rays will interact with head tissue just outside the area protected by the eyewear and be scattered into the eye increasing eye dose.

The relative position for Lightweight eyewear and Sportwrap eyewear switches in the graph of Eyewear Protection Factor at 90 degree presented in Fig. 5. The drop in Sportwrap eyewear protection factor and increase in Lightweight protection factor is likely related to the cross sectional area of the side shields on each model.

DISCUSSION

Recognizing that ICRP is advocating reduced eye lens exposure in the occupational setting, occupational health and safety experts may be called upon to assist in policy formation regarding eye protection strategies, choice of devices and fit testing. In this study of three protective eyewear models in three different exposure orientations, we found that the Eyewear Protection Factor was strongly influenced by the radiation source location. When the source is in front of the fluoroscopist, the lead equivalence of the protective eyewear is important. However, when the source was to the side of the fluoroscopist, the cross section of the side shield had a significant influence on protection. Our work suggests that organizations should establish a systematic process for selecting eyewear based on task and fit.

This study has focused on evaluation of protection factors by using a phantom and modeling the activities of those at risk for exposure. By taking this approach we were able to identify that different eyewear styles afforded different protection based on the angle of the wearer to the scatter

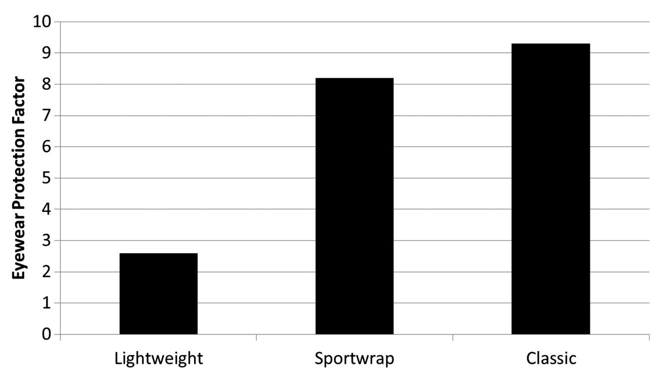

Fig. 3. Eyewear Protection Factors for 0 degree exposure geometry.

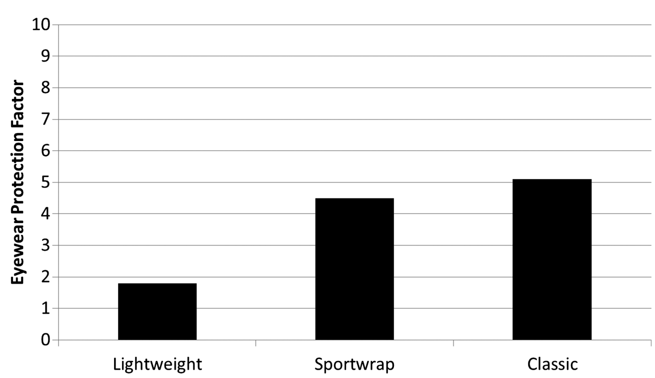

Fig. 4. Eyewear Protection Factors for 45 degree (femoral access) exposure geometry.

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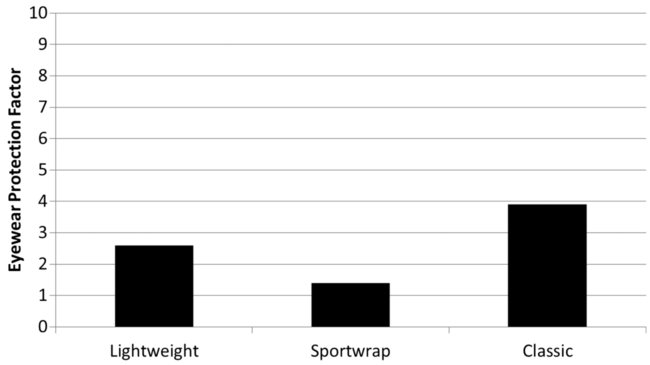

Fig. 5. Eyewear Protection Factors for 90 degree (GI procedure) exposure geometry.

source. This approach highlights the fact that eyeglass design and fit may both have significant impacts on the effectiveness of eyewear protection. It is valuable to note that due to the potential significant contribution from backscatter and side exposure, lead equivalent thickness values and associated radiation attenuation values specified by eyewear manufacturers should not be used as correction factors for eye dose estimation. Manufacturer data may not report protection factors or attenuation data for all possible angles to the radiation source, and it would appear that this information is important in choosing appropriate eyewear. As demonstrated in Fig. 6, protection factor combined with workload mix—25% to 75% femoral access procedures—provides a more accurate picture of the effectiveness of eyewear in the clinical setting.

Both Classic and Lightweight eye protection had side shields, and it appears that these shields may have been important and superior in reduction of exposure depending on the percentage of time spent in a particular work orientation. This could be relevant in practices such as invasive cardiology where the physician tends to stand at 45-degree angles to the radiation source, compared to invasive fluoroscopy for gastroenterological and other procedures where the physician tends to stand at 90 degrees to the radiation source. As noted in Fig. 6, depending on workload mix, the choice of glasses impacts the protection provided. Individual practitioners would benefit from knowing transmission reduction at multiple angles so they could choose appropriate protection for their method of practice and range of exposure angles.

Practitioners may choose eye protection based on many factors, but lightweight protection is often an important consideration for those that may require long hours of usage each day. We would encourage wearers also consider effectiveness for reducing transmission based on practice style and angles of exposure. This study agrees with the findings of Geber et al. (2011) that some face shapes and eyewear types might not be ideally paired, allowing for more radiation to reach the eye. Further research is necessary to identify the best method to fit test and correct for this.

The strength of this study was providing data on transmission attenuation using a known methodology and testing to provide comparisons for standard leaded safety glasses, and two newer commonly used leaded eyewear selections that are often chosen because of their light weight properties. The testing was completed by examiners who have no overt conflict of interest in brand options. Limitations of this study included the limited number of eyewear models available for testing, and lack of data on frequency of usage for these models. Additionally, data for the general acceptance and frequency of use for eye protection is lacking. While the ICRP is promulgating new standards for protective eyewear, it is unclear whether physicians that use fluoroscopy for procedures are concerned about the long term effect of radiation exposure at current levels, and whether risk for development of cataracts is problematic, given effective medical interventions available to treat cataracts and the likelihood that occupational exposure likely represents only a small percentage of overall risk. Another limitation of the study is that the angular response of the OSL dosimeter on the phantom was not evaluated.

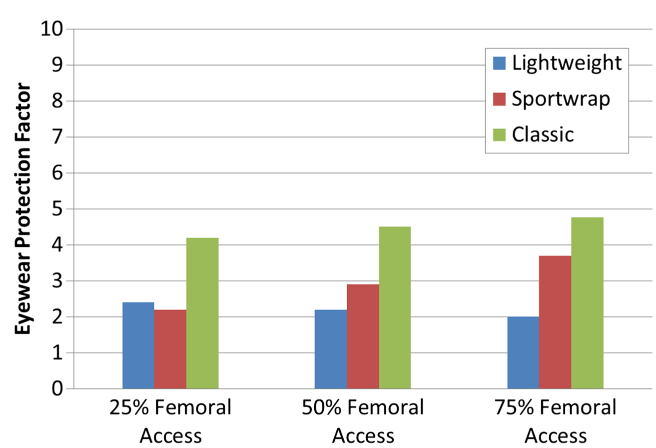

Fig. 6. Eyewear Protection Factors for a range of Femoral Access:GI procedure ratios.

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Lavoie et al. (2011) has shown that the in-air angular response is fairly constant (0.96–1.03) except at 90 degrees were it dips to 0.78, as well as that there is no significant difference when exposed in a phantom. The angular response may not be a significant issue operationally, because of the significant contribution of scattered radiation from the phantom and eyewear; however, it could be the topic of future research.

Future work needs to be done to assess why individuals may not be compliant with eyewear use. This is a key factor in this protection strategy. In addition, there continues to be new technologies and additional products to be evaluated including 0.5mm lead equivalent eyewear as well as other systems for protection (e.g., in room shielding). Again the acceptance of other protection systems as functional in the clinical setting needs to be evaluated. Eyewear fit and comfort remain a concern.

CONCLUSION

The ICRP recommendation to lower the annual eye dose limit to 20 mSv may increase interest in finding the most effective eyewear product available. Some interventional fluoroscopists may not be within these recommendations using current strategies. Multiple styles of eyewear are available, and the choice of eyewear is often made based on comfort and not protection afforded. Our data suggest that the choice of eyewear needs to include consideration of job task and orientation of the face to the radiation source as well as the possibility that face shape and eye glass fit may also impact the amount of scatter radiation that reaches the eye. Further research is required to answer important questions about compliance, additional eyewear technologies, the feasibility of alternate protection strategies in some circumstances and the possible need for formal fit testing programs for radiation safety eye protection.

Acknowledgments—The authors would like to thank Mark Hindal, Rodney Landsworth, and Dixon Magnuson for their assistance in collecting the data for this project.

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