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Angular dependence of shielding effect of radiation protective eyewear for radiation protection of crystalline lens

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Abstract

Radiation protective (RP) eyewear effectively protects crystalline lenses from radiation exposure. A drawback of RP eyewear is the angular dependence of the shielding effect, which results from the design of the eyewear. In this study, 21 models of RP eyewear with different designs and lead equivalences were assessed. Each piece of RP eyewear was hung on a Styrofoam phantom that imitated the head, and a 0.125-cc ionization chamber dosimeter was placed at the position of the crystalline lens. The differences in angular dependence of the shielding effect were evaluated by changing the irradiation angle, and parameters that improved the angular dependence of the shielding effect—sufficient lead equivalence, large coverage design, and minimum gap between the crystalline lens and the RP eyewear—were identified. Thus, the findings highlight the importance of selecting RP eyewear according to the angular distribution and the nature of radiation exposure in the workplace for radiation workers.

Keywords Angular dependence · Crystalline lens · Interventional radiology · Radiation protective eyewear · Shielding rate

1 Introduction

The crystalline lenses of the eyes are highly sensitive to radiation, and this poses risks, such as the development of cataracts [1]. In a statement issued in April 2011 regarding tissue responses to radiation, the International Commission on Radiological Protection (ICRP) announced a decreased radiation threshold dose of 0.5 Gy to guard against cataracts and recommended a reduction in the annual dose-equivalent limit from 150 to 20 mSv for crystalline lenses. In August 2012, ICRP Publication 118 reported a re-evaluation of the sensitivity of the eye to radiation-induced cataracts [2]. The dose rate did not affect the incidence of cataracts. This implies that the injuries in these cases and at these low dose levels are caused by single-hit irreparable-type events. A threshold dose of 0.5 Gy is proposed herein for practical purposes, irrespective of dose rate, and future studies may elucidate this judgement further. Nevertheless, studies have reported that some healthcare workers are exposed to radiation levels beyond the new dose limit of 20 mSv per year [3–7]. Therefore, sufficient protection from radiation and periodic air kerma measurement of the crystalline lens is necessary.

There have also been reports about the conversion factor for radiation protective (RP) eyewear and the appropriate position for measuring the air kerma of the lens [8–11]. Some studies have reported that conversion factors differ among different types of RP eyewear [12–16]. For example, a study by Bart et al. confirmed that the difference in dose reduction

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between various models of RP eyewear ranged from 3.4 to 8.3 [12]. However, no study, to the authors' knowledge, has investigated the reasons behind the observed differences in the conversion factors. It is hypothesized that the differences in angular dependence of the shielding effect of the RP eyewear would play a role. In radiological examinations, where the positional relationship between the scattered radiation source and the crystalline lenses changes, the angular dependence of the shielding effect is thought to have important effects.

In this study, 21 models of RP eyewear were evaluated, and the angular dependence of the shielding effect was determined by changing the irradiation angle in the horizontal and vertical directions. By comparing the angular dependences of the shielding effect, the parameters that may be inducing the differences observed in the study were identified.

2 Methods

2.1 Classification of RP eyewear

In this study, 21 models of RP eyewear were classified by design, as shown in Table 1. The front type had RP glass, which contains lead only on the front to protect against radiation. The front and side types had RP glass on the front and sides. The panorama type had a three-dimensional lead acrylic lens, which extended to the sides and covered a large range. The screen type extended over 180° in the front and had a lead acrylic screen covering the whole face.

2.2 Measurement method

The geometry for the measurement is shown in Fig. 1. The source chamber distance (SCD) was set to 150 cm. An ionization chamber dosimeter N31005 (PTW; Freiburg, Germany) with a volume of 0.125 cc was positioned 100 cm above the floor. The useful tube voltage range of the ionization chamber dosimeter was 140 kV to 50 MV. In this study, a relative value was used. Therefore, this effect was minimal.

In this study, the main beam was focused directly at the position of the eye to clarify the irradiation direction. The ionization chamber dosimeter was placed at the position of the crystalline lens of the right eye of a Styrofoam head phantom, and the ionization chamber surface matched the lens phantom. The ionization chamber dosimeter coincided with the center of the rotating table. This positioning helped

Table 1 Classification of RP eyewear

Product name	Manufacturer, Country	Design type	Lead equivalence (mm Pb)	Weight (g)	Length of RP glass (cm): horizontal	Length of RP glass (cm): vertical
Sporty	Uniray Medical, India	Front	0.75	84	7	4
Front	Uniray Medical, India	Front	0.75	74	5.5	4.5
Maxx	Uniray Medical, India	Front	0.75	62	5	3.5
PT-99AL	Protech, USA	Front	0.75	77	5.5	3.5
PT-99	Protech, USA	Front	0.75	69	6	3.4
FP-6	Hoshina, Japan	Front	0.6	73	6	4
PT-NIKE-BRAZEN	Protech, USA	Front	0.5	84	5.7	3.7
LG-N700B	AADCO Medical, USA	Front	0.5	75	6	3.6
PT-COMET	Protech, USA	Front and Side	0.75	80	6	3.5
PT-53	Protech, USA	Front and Side	0.75	94	5.5	5.5
PT-70S	Protech, USA	Front and Side	0.75	92	5	4
PT-90	Protech, USA	Front and Side	0.75	114	6.5	5
Front and Side	Uniray Medical, India	Front and Side	0.75	86	5	4.5
Fitover	Uniray Medical, India	Front and Side	0.75	96	6	4
LG-N190	AADCO Medical, USA	Front and Side	0.6	84	6	4.5
FG50-770	MAEDA & CO LTD., Japan	Front and Side	0.5	102	6.5	5
EC-06	AOYAMAKOUGAKU, Japan	Front and Side	0.15	47	5	3
FP-3	Hoshina, Japan	Screen	0.1	278	15	40
LG-800	AADCO Medical, USA	Screen	0.1	432	10	30
HF-350B	Toray Medical, Japan	Panorama	0.07	41	9	5
HF-400S	Toray Medical, Japan	Panorama	0.07	47	11	5.6

Twenty-one models of RP eyewear were classified by design

The front type has RP glass only on the front. The front and side type has RP glass on the front and the sides. The screen type covers 180° at the front using lead acrylic. The panorama type has a three-dimensional lead acrylic lens that extends to cover the sides

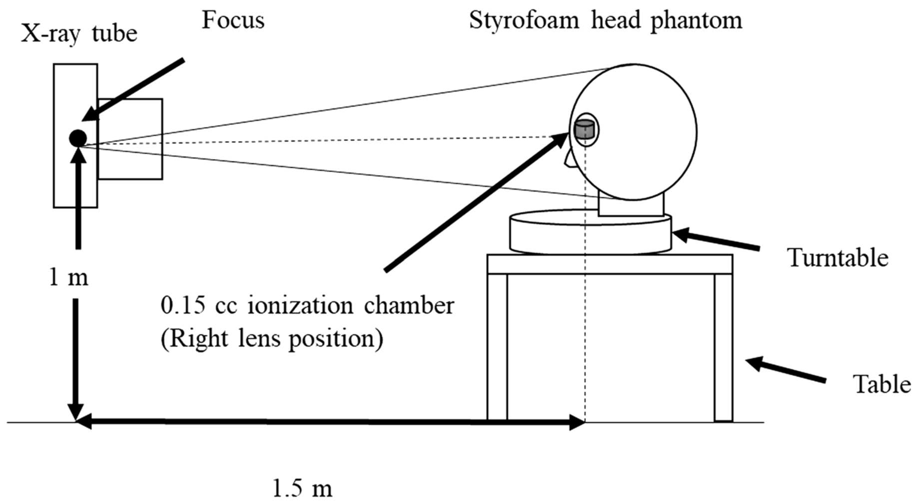

Fig. 1 Geometry for measurement. The source–chamber distance (SCD) was set to 150 cm. The ionization chamber dosimeter N31005 (PTW; Freiburg, Germany), with a volume of 0.15 cc, was positioned 100 cm above the floor to reduce the effects of radiation scattered against the floor

prevent the SCD from changing, even if the angle of the center of the rotating table was changed to alter the irradiation angle. Thus, the ionization chamber was always placed on the rotation axis of the turntable. The RP eyewear was fitted to the nose and the ears of the phantom. The gap between the crystalline lens (ionization chamber) and the RP glasses was 1.5–2 cm in most models of the RP eyewear.

The irradiation angle was changed by rotating the turntable to evaluate the angular dependence of the shielding effect of the RP eyewear (Fig. 2). In the horizontal direction, the irradiation angles were − 90°, − 75°, − 60°, − 30°, 0°, 30°, 60°, 75°, and 90°. In the vertical direction, the irradiation angles were − 75°, − 60°, − 45°, − 30°, 0°, 30°, 45°, 60°, and 75°.

The radiological parameters employed were as follows: 120 kV, 100 mA, and 0.1 s, with a radiation field measuring 20 × 20 cm and an SCD of 150 cm. The

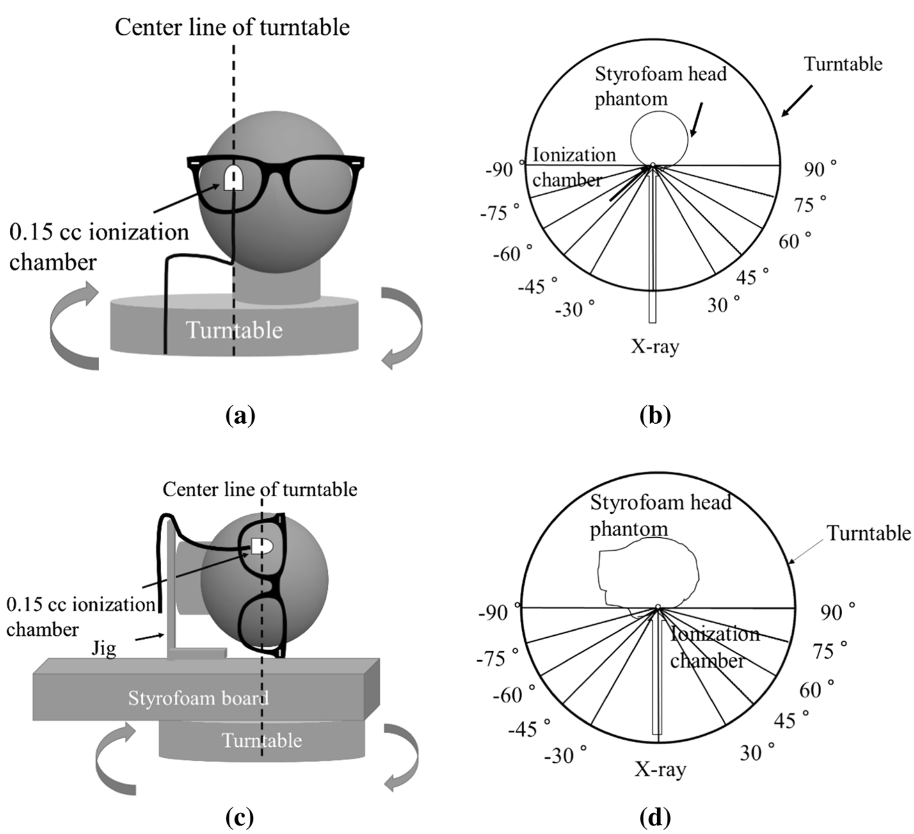

Fig. 2 Illustration of rotation phantom. **a** View from the front in the horizontal direction. **b** View from above in the horizontal direction. **c** View from the front in the vertical direction. **d** View from above in the vertical direction. The irradiation angle was changed by rotating the turntable. In the horizontal direction, the irradiation angles were − 90°, − 75°, − 60°, − 30°, 0°, 30°, 60°, 75°, and 90°. In the vertical direction, the irradiation angles were − 75°, − 60°, − 45°, − 30°, 0°, 30°, 45°, 60°, and 75°

highest allowable tube voltage in interventional radiology (120 kV) was used to ensure overestimation [17].

2.3 Visualization of positional relation between RP eyewear and crystalline lens

To visualize the positional relationship between the RP eyewear and the crystalline lens, a metal marker was placed at the position of the lens of the phantom's head, and X-ray images were obtained, as shown in Fig. 3. These X-ray images allowed clear visualization of the gap between the RP eyewear and the crystalline lens, and the area protected by the lead shields.

2.4 Analysis

Using the phantom, the lens air kerma dose was measured at each irradiation angle with and without the RP eyewear. The shielding rate was calculated using Eq. (1)

$$\mathrm{SE}(\theta) = \frac{D(\theta)_{\mathrm{without}} - D(\theta)_{\mathrm{wearing}}}{D(\theta)_{\mathrm{without}}} \times 100 \tag{1}$$

where $\mathrm{SE}(\theta)$ is the shielding efficiency, $D(\theta)_{\mathrm{without}}$ is the lens dose without the RP eyewear, and $D(\theta)_{\mathrm{wearing}}$ is the lens dose while wearing the RP eyewear.

In this study, the relationship between the lead equivalence and the shielding rate at each irradiation angle was assessed, and the angular dependence of the shielding rate was compared between various models of RP eyewear. Additionally, a relationship between the shielding effect and the length of the front of the RP eyewear was identified. These relationships were assessed with the coefficient of determination (R^2), which shows the degree of correlation, and its value ranges from 0 to 1. The correlation is stronger as the value near 1.

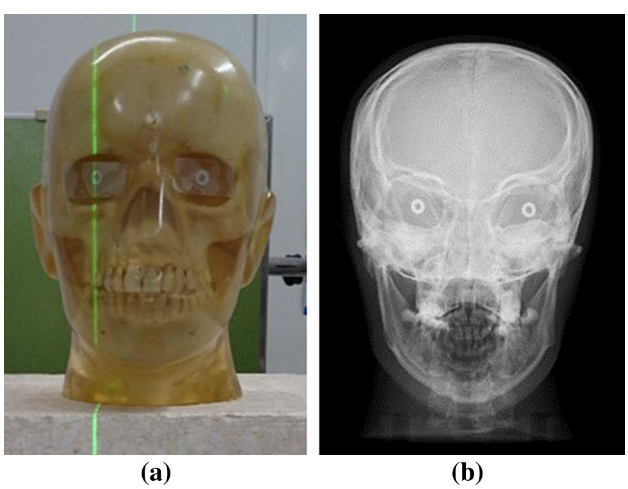

Fig. 3 **a** Photograph and **b** radiograph of the head phantom, with metal markers denoting the position of the lens

2.4.1 Relationship between lead equivalence and shielding rate

The relationship between the shielding rate and the lead equivalence, which is the main factor indicating the shielding ability of RP eyewear, was considered. It was confirmed how the correlation between lead equivalence and shielding rate is altered when the irradiation angle changes horizontally or vertically using R^2.

2.4.2 Comparison of angular dependence of shielding rate by design type

The angular dependences of the shielding rates of the four types of eyewear classified by design (front type: Maxx, front and side types: PT-COMET, panorama type: HF-350 B, and screen type: LG-800) were compared for the horizontal and vertical directions.

2.4.3 Relationship between length of RP glass and shielding effect

It was hypothesized that the length of the RP glass at the front affects the shielding coverage. Increasing the shielding coverage leads to improvement in the overall shielding ability of RP eyewear. Therefore, the correlation between the length of the front RP glass and the overall shielding ability of the RP eyewear was assessed using R^2.

As an index for evaluating the overall shielding ability of RP eyewear, the sum of shielding efficiency (SSE) in the horizontal and vertical directions was calculated using the following equation:

$$\mathrm{SSE} = \int_{-90^\circ}^{90^\circ} \mathrm{SE}(\theta)\mathrm{d}A \tag{2}$$

SSE is the sum of the shielding efficiency, $\mathrm{SE}(\theta)$ is the shielding efficiency, and A is the irradiation angle. The SSE in the vertical direction was used for the vertical length of the front the RP glass. The SSE for the horizontal direction was used for the horizontal length of the front RP glass. The SSE is equal to the sum of the shielding rates at all angles. When the shielding rate is 100% in all directions along a 180° angle, the SSE is at its maximum, which is 180. In this analysis, only the front-type RP eyewear with a lead equivalence of 0.75 mm Pb was used to confirm the relationship between the shielding effect and only the length of the front RP glass.

3 Results

3.1 Relationship between lead equivalence and shielding rate

3.1.1 The relationship between lead equivalence and shielding rate from the front

The lead equivalence indicated by the manufacturers denotes the value for irradiation from the front, at 0°. Before confirming whether the relationship between the lead equivalence and the shielding rate varies depending on the irradiation angle, the correlation between the lead equivalence and the shielding rate at the front was confirmed. A correlation diagram of lead equivalence–shielding rate in the front is shown in Fig. 4. The coefficient of determination is 0.97, which indicates a strong correlation between the lead equivalence and shielding rate at the front.

3.1.2 Lead equivalence–shielding rate changes at various angles

Table 2 shows the approximation and the coefficient of determination of the relationship between lead equivalence and shielding rate at each horizontal irradiation angle. In the horizontal direction, the irradiation angles for which a correlation was confirmed between the lead equivalence and shielding rate were −60°, −30°, 0°, 30°, and 75°. In the vertical direction, the irradiation angles for which a correlation was confirmed between the lead equivalence and shielding rate were −45°, −30°, and 0°. These results show that the relationship between lead equivalence and shielding rate changes markedly with the irradiation angle.

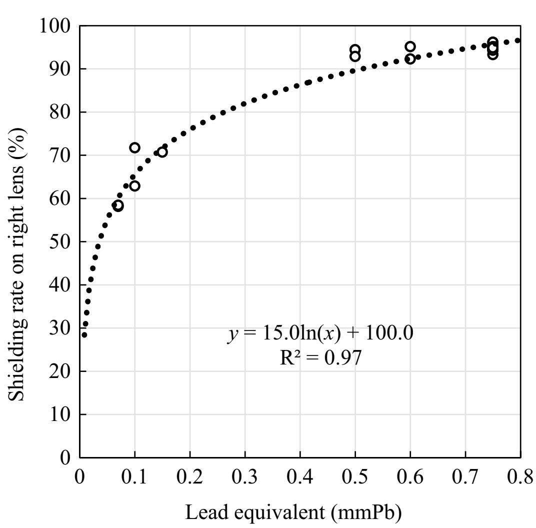

Fig. 4 Relationship between lead equivalence and shielding rate from the front. A strong correlation exists between the lead equivalence and the shielding rate at the front

Table 2 Approximation and coefficient of determination between lead equivalence and shielding rate

Irradiation angle	Approximation	Coefficient of determination
a) Horizontal direction		
−90°	$y = -3.0\ln(x) + 47.7$	$R^2 = 0.01$
−75°	$y = 9.3\ln(x) + 78.7$	$R^2 = 0.08$
−60°	$y = 12.8\ln(x) + 98.9$	$R^2 = 0.96$
−30°	$y = 13.3\ln(x) + 95.9$	$R^2 = 0.66$
0°	$y = 15.0\ln(x) + 100.0$	$R^2 = 0.97$
30°	$y = 14.6\ln(x) + 98.5$	$R^2 = 0.82$
60°	$y = -8.9\ln(x) + 41.8$	$R^2 = 0.13$
75°	$y = 11.3\ln(x) + 99.2$	$R^2 = 0.76$
90°	$y = 2.0\ln(x) + 60.1$	$R^2 = 0.00$
b) Vertical direction		
−75°	$y = -0.42\ln(x) + 23.0$	$R^2 = 0.00$
−60°	$y = 22.1\ln(x) + 90.3$	$R^2 = 0.34$
−45°	$y = 17.8\ln(x) + 102.6$	$R^2 = 0.66$
−30°	$y = 13.8\ln(x) + 101.0$	$R^2 = 0.97$
0°	$y = 15.0\ln(x) + 100.0$	$R^2 = 0.97$
30°	$y = 4.4\ln(x) + 67.8$	$R^2 = 0.02$
45°	$y = -7.5\ln(x) + 3.3$	$R^2 = 0.14$
60°	$y = -8.0\ln(x) - 3.2$	$R^2 = 0.16$
75°	$y = -7.1\ln(x) - 4.0$	$R^2 = 0.12$

The relationship between lead equivalence and shielding rate varies markedly depending on the irradiation angle

3.2 A comparison of angular dependences of shielding rate by design type

A diagram of the shielding rates of the four types of RP eyewear at each horizontal irradiation angle is shown in Fig. 5a. For the front and side, panorama, and screen types, X-ray irradiation from the sides (−90°, 90°) was shielded by the side lead shield, as shown in Fig. 6a, b. The front type, which only has an RP glass at the front, did not shield X-rays directed from the sides, as shown in Fig. 6c.

Parts of the eyewear frame that lack shielding ability reduce the shielding coverage. In this study, this part of the frame was seen at 60° in the horizontal direction.

A diagram representing the shielding rates of the four types of RP eyewear at each vertical irradiation angle are shown in Fig. 5b. None of the eyewear types successfully shielded X-rays from the head end (90°–30°), as shown in Fig. 7b.

The lead seal attached to the bottom of the RP eyewear shielded X-rays from the foot end (down to −75°). In the front type, X-rays from the foot end were not shielded sufficiently, as shown in Fig. 7b.

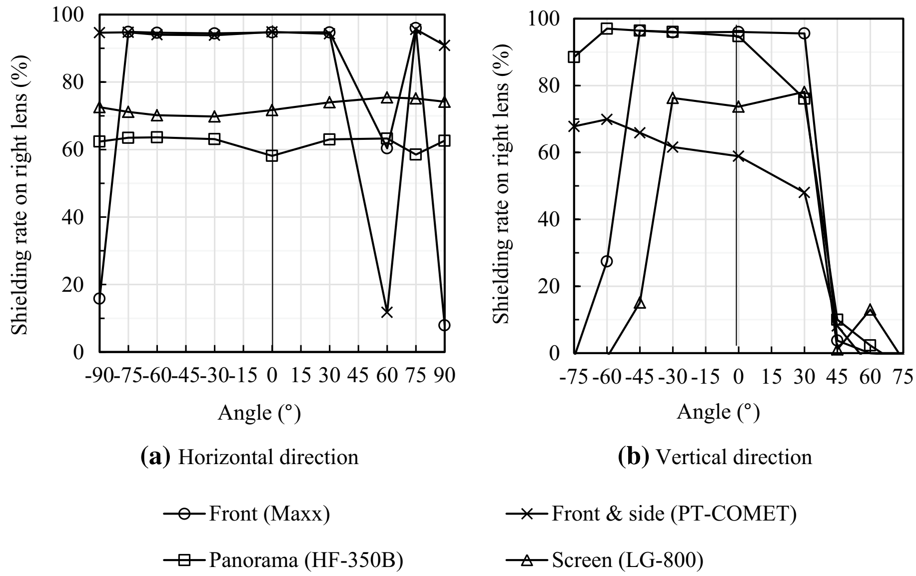

Fig. 5 Shielding rates of four types of RP eyewear at each irradiation angle. Angular dependency of the shielding rate varies depending on the design of the RP eyewear. Factors affecting angular dependency include the gap between the lens and the RP eyewear, the length of the front RP glass, whether a lead shield is placed on the bottom or on the sides, and the position of the frame

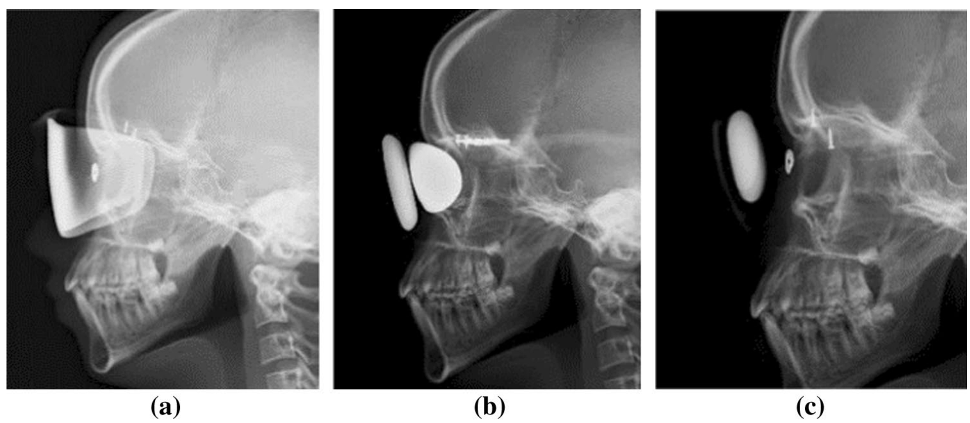

Fig. 6 Radiographs showing the positional relationship between the crystalline lens and RP eyewear when irradiated horizontally. **a** Panorama type. **b** Front and side types. **c** Front type. In the front and side, panorama, and screen types, X-ray irradiation from the sides (−90°, 90°) is shielded by the lead shields placed on the side. In the front type, which only has the front RP glass, the X-ray irradiation from the side and from the foot end was not sufficiently shielded

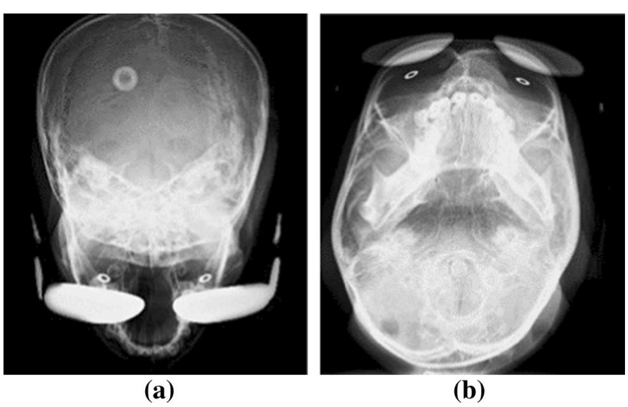

Fig. 7 Radiographs showing the positional relationship between the crystalline lens and the RP eyewear when irradiated **a** from the head end and **b** the foot end. None of the eyewear types were able to shield X-ray irradiation from the head end (up to 30°)

3.3 Relationship between the length of the RP glass and the shielding effect

A correlation diagram of the front RP glass length and the SSE is shown in Fig. 8. The coefficient of determination of 0.66 suggests a correlation between the length of the front RP glass and the SSE.

4 Discussion

4.1 Lead equivalence of the front RP glass

According to the simulation results reported by Hu et al., when the lead equivalence exceeds 0.35 mm Pb, it becomes difficult to improve the shielding rate [18]. In this study, it was difficult to improve the shielding rate above the lead equivalence of approximately 0.5 mm Pb. The attenuation of radiation is exponential, and the shielding rate is (1—attenuation rate). Therefore, this result is likely to be theoretical.

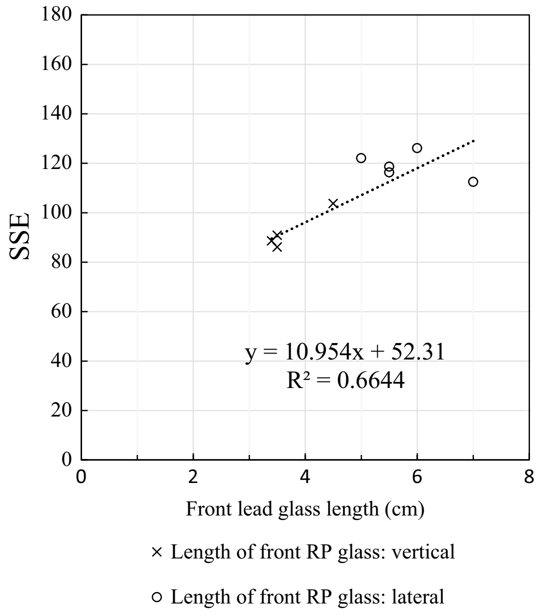

Fig. 8 Relationship between front RP glass length and the area under the curve (SSE). A correlation exists between the length of the front RP glass and the SSE. Thus, the length of the front RP glass is an important factor for improving the overall shielding ability of the RP eyewear. In this analysis, only the front-type RP eyewear with a lead equivalence of 0.75 mm Pb was used to confirm the relationship between the shielding effect and the length of the front RP glass only

These findings indicate that an excessive increase in the lead equivalence does not necessarily yield an improved shielding effect, and it merely increases the weight of the RP eyewear.

4.2 Design of RP eyewear

In this study, it was found that the angular dependence of the shielding rate varies depending on the design of the RP eyewear. Factors affecting angular dependence include the gap between the lens and the RP eyewear, the length of the front RP glass, whether the lead shield is placed on the bottom or on the left and right sides, and the position of the frame. The most influential angular dependence factors are the gap between the RP eyewear and the lens and the length of the front RP glass. If the length of the front RP glass is large, the overall shielding ability of the RP eyewear is improved. The larger shielding coverage observed in the horizontal direction compared to the vertical direction may be attributed to the dimensions of the front RP glass, which is longer horizontally than it is vertically. However, the screen type, which has a longer RP glass length in the vertical direction, did not shield the X-rays from the foot end sufficiently due to the markedly larger gap of 5 cm between the RP eyewear and the lens compared to the other types of eyewear. The other types of eyewear have a gap difference of 0.5 cm, which appears to have minimal influence on shielding coverage. In a clinical context, having a sufficient shielding rate at all angles is ideal to ensure the protection of crystalline lenses, because the positional relationship between the source of radiation and the lens of the surgeon changes frequently. However, if the RP glasses were large enough to provide adequate shielding at all angles, they would be too heavy and impractical for extended wear.

4.3 Limitations

Some limitations exist in this study. In this study, the irradiation angle was changed 15° at a time. The angular dependence of the shielding effect would have been different if the changes were made in smaller increments.

In addition, only the shielding ability of the RP eyewear was evaluated, and the influence of radiation absorption and scattering by a real human head composed of various organs was not considered. Therefore, the clinical lens dose and measured value are likely to be different.

Finally, the angular dependence of the shielding effect varies depending on individual differences in the size and shape of the head of the user. These individual factors affect the gaps between the crystalline lens and the RP eyewear. This study did not consider these variables.

5 Conclusion

In this study, factors that decrease or improve the shielding ability of RP eyewear were identified by measuring the angular dependence of the shielding rate of 21 models of RP eyewear, each with different lead equivalences and designs. Factors affecting angular dependence include the gap between the lens and the RP eyewear, the length of the front RP glass, whether the lead shield is placed on the bottom or on the sides, and the position of the frame. These factors cause marked angular-dependent variation in the shielding ability of RP eyewear. Thus, it is crucial to consider the state of lens exposure and the radiation field when selecting RP eyewear.

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Compliance with ethical standards

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

Ethical approval This article does not contain any studies performed with human or animal participants.

References

1. Valentin J. Avoidance of radiation injuries from medical interventional procedures. Ann ICRP. 2000;30(2):7–67.
2. International Commission on Radiological Protection. ICRP Publication 118 statement on tissue reactions/early and late effects of radiation in normal tissues and organs—threshold doses for tissue reactions in a radiation protection context. ICRP Publ. 2012;3:313–27.
3. Principi S, Delgado C, Ginjaume M, Beltran M, Rovira JJ, Duch MA. Eye lens dose in interventional cardiology. Radiat Prot Dosimetry. 2015;165(1–4):289–93.
4. Anchali K, Suphot S, Kousuke M. The current status of eye lens dose measurement in interventional cardiology personnel in Thailand. Radiol Phys Technol. 2017;10(2):142–7.
5. Nachiappan AC, Horn GL, Spann SC, Mayo RC, Wynne DM, Archer BR, Whigham CJ, Hancock JA. Operator radiation dose reduction during fluoroscopic interventional procedures. J Am Coll Radiol. 2015;12(5):527–30.
6. O'Connor U, Walsh C, Gallagher A, Dowling A, Guiney M, Ryan JM, McEniff N, O'Reilly G. Occupational radiation dose to eyes from interventional radiology procedures in light of the new eye lens dose limit from the International Commission on Radiological Protection. Br J Radiol. 2015;88(1049):20140627.
7. Bahruddin NA, Hashim S, Karim MKA, Sabarudin A, Ang WC, Salehhon N, Bakar KA. Radiation dose to physicians' eye lens during interventional radiology. J Phys. 2016;694(1):012035 **(Conference Series)**.
8. Carinou E, Ferrari P, Bjelac OC, Gingaume M, Merce MS, O'Connor U. Eye lens monitoring for interventional radiology personnel: dosemeters, calibration and practical aspects of H p (3) monitoring. A 2015 review. J Radiol Prot. 2015;35(3):R17–34.
9. Principi S, Ginjaume M, Duch MA, Sánchez RM, Fernández JM, Vano E. Influence of dosemeter position for the assessment of eye lens dose during interventional cardiology. Radiat Prot Dosimetry. 2015;164(1–2):79–83.
10. McVey S, Sandison A, Sutton DG. An assessment of RP eyewear in interventional radiology. J Radiol Prot. 2013;33(3):647–59.
11. Farah J, Struelens L, Dabin J, Koukorava C, Donadille L, Jacob S, Schnelzer M, Auvinen A, Vanhavere F, Clairand I. A correlation study of eye lens dose and personal dose equivalence for interventional cardiologists. Radiat Prot Dosimetry. 2013;157(4):561–9.
12. Bart D, van Rooijen BD, de Haan MW, Das M, Arnoldussen CW, de Graaf R, van Zwam WH, Backes WH, Jeukens CR. Efficacy of radiation safety glasses in interventional radiology. Cardiovasc Intervent Radiol. 2014;37:1149–55.
13. Domienik J, Bissinger A, Grabowicz W, Jankowski Ł, Kręcki R, Makowski M, Masiarek K, Plewka M, Lubiński A, Peruga JZ. The impact of various protective tools on the dose reduction in the eye lens in an Interventional Cardiology-Clinical Study. J Radiol Prot. 2016;36(2):309–18.
14. Hu P, Kong Y, Chen B, Liu Q, Zhuo W, Liu H. Shielding effect of lead glasses on radiologists' eye lens exposure in interventional procedures. Radiat Prot Dosimetry. 2017;20:136–40.
15. Magee JS, Martin CJ, Sandblom V, Carter MJ, Almén A, Cederblad Å, Jonasson P, Lundh C. Derivation and application of dose reduction factors for protective eyewear worn in interventional radiology and cardiology. J Radiol Prot. 2014;34(4):811–23.
16. Sturchio GM, Newcomb RD, Molella R, Varkey P, Hagen PT, Schueler BA. Protective eyewear selection for interventional fluoroscopy. Health Phys. 2013;104(2 Suppl 1):S11–S16.
17. Clairand I, Bordy JM, Daures J, Debroas J, Denozière M, Donadille L, Ginjaume M, Itié C, Koukorava C, Krim S, Lebacq AL, Martin P, Struelens L, Sans-Mercé M, Tosic M, Vanhavere F. Active personal dosemeters in interventional radiology: tests in laboratory conditions and in hospitals. Radiat Prot Dosimetry. 2011;144(1–4):453–8.
18. Hu P, Kong Y, Chen B, Liu Q, Zhuo W, Liu H. Shielding effect of lead glasses on radiologists' eye lens exposure in interventional procedures. Radiat Prot Dosimetry. 2017;174(1):136–40.