PAPER

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PAPER

Eye lens dose for medical staff assisting patients during computed tomography: comparison of several types of radioprotective glasses

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Keywords: radioprotective glasses, eye lens, computed tomography, radiation protection, occupational exposure

Abstract

Medical staff sometimes assists patients in the examination room during computed tomography (CT) scans for several purposes. This study aimed to investigate the dose reduction effects of four radioprotective glasses with different lead equivalents and lens shapes. A medical staff phantom was positioned assuming body movement restraint of the patient during chest CT, and $H_p(3)$ at the eye surfaces of the medical staff phantom and inside the lens of the four types of radioprotective glasses were measured by changing the distance of the staff phantom from the gantry, eye height, and width of the nose pad. The $H_p(3)$ at the right eye surface with glasses of 0.50–0.75 mmPb and 0.07 mmPb was approximately 83.5% and 58.0%, respectively, lower than that without radioprotective glasses. The dose reduction rates at left eye surface increased with over-glass type glasses by 14%–28% by increasing the distance from the CT gantry to the staff phantom from 25 to 65 cm. The dose reduction rates at the left eye surface decreased with over-glass type glasses by 26%–31% by increasing the height of the eye lens for the medical staff phantom from 130 to 170 cm. The $H_p(3)$ on the left eye surface decreased by 46.9% with the widest nose pad width compared to the narrowest nose pad width for the glasses with adjustable nose pad width. The radioprotective glasses for staff assisting patients during CT examinations should have a high lead equivalent and no gap around the nose and under the front lens.

1. Introduction

The International Commission on Radiological Protection publication 118 indicated that the threshold dose for radiogenic cataracts is considered to be 0.5 Gy, and it recommended the new equivalent dose limit for occupational exposure of the lens of the eye from 150 mSv yr^{-1} to 20 mSv yr^{-1} averaged over five consecutive years, with no single year exceeding 50 mSv [1].

Several previous studies about the effects of radioprotective glasses have focused on interventional radiology (IR) physicians [2–11]; however, only a few studies focused on medical staff assisting patients during computed tomography (CT) examinations [12–14]. The staff should stay outside the examination room for good radiation protection practice, but it is not always possible for them due to several reasons such as restraining patient's body movement and assisting ventilation.

A higher tube voltage is generally used in CT, and the scattered x-rays energy for CT is higher than that for IR. Additionally, the IR physician generally looks at the monitor, whereas the medical staff assisting the patient undergoing CT in the examination room generally looks down at the patient that is the source of the scattered x-rays. Therefore, the situation in the staff's eye lens exposure is different between IR and CT.

Studies by Miyajima *et al* and Nagamoto *et al* revealed that the combination of radioprotective glasses, radiation protection curtains, and low dose-length product (DLP) imaging using volume scans are effective for reducing eye lens dose for medical staff during CT assistance [12, 13]. However, there are no radioprotective glasses specifically designed for IR physicians or medical staff who assists patients during CT examinations, and no studies have specifically investigated that radioprotective glasses are suitable for medical staff assisting patients during CT examinations. Therefore, this study aimed to identify the characteristics of the radioprotective glasses suitable for assisting patients during CT examinations by comparing four types of radioprotective glasses with different lead equivalents and lens shapes under different situations.

2. Methods

2.1. Radioprotective glasses

This study compared four radioprotective glasses with different lead equivalents and lens shapes (figure 1).

Glasses 1 – PANORAMA SHIELD HF-400S (Toray Medical, Tokyo, Japan) with 0.07 mmPb at the front and side lens. It can be worn over glasses.

Glasses 2 – PANORAMA SHIELD HF-480S (Toray Medical) with 0.07 mmPb at the front, side, and lower front lens. It has an adjustable nose pad that is made of rubber and does not contain shielding material. By widening the nose pad to fit the size of the nose, the distance between the glasses and the face can be closer by fitting more closely to the face, and the gap between the nose and the glasses can also be smaller. It can be worn over glasses.

Glasses 3 – HAGOROMO FG50-770 (Maeda, Tokyo, Japan) with 0.5 mmPb at the front lens and 0.6 mmPb at the side lens. It can be worn over glasses.

Glasses 4 – Protec Eyewear PT-COMET (Maeda) with 0.75 mmPb at the front lens and 0.50 mmPb at the side and lower front lens. It cannot be worn over glasses.

2.2. Study design

Small optically stimulated luminescence dosimeters (nanoDot; Landauer, Glenwood, IL, USA) were placed at the eye surfaces of the medical staff phantom and inside the lens of the four types of radioprotective glasses (figure 2), and chest CT was conducted for a patient phantom (Alderson; Radiology Support Devices, Long Beach, CA, USA) with a 16-slice CT system (SOMATOM Emotion, Siemens Healthineers, Erlangen, Germany). Measurements were repeated three times with separate sets of nanoDot dosimeters. They were read by the microStar reader (Landauer) three times before and after irradiation to reduce random errors [15]. Background dose subtraction was done by subtracting the average readings of the pre-irradiation from those of the post-irradiation. Finally, the readings with background dose subtracted were multiplied by the sensitivity correction factor and the $H_p(3)$ conversion factor. The sensitivity correction factor was obtained by a diagnostic x-ray system (UD150L-40E; Shimadzu, Kyoto, Japan) with total filtration of 2.5 mm Al adding an 8.0 mm aluminium filter so that the effective energy of x-rays were equivalent to those of CT. The nanoDot dosimeters and a 3 cm^3 ion chamber connected to an electrometer (EMF520R; EMF Japan) were placed side-by-side and were simultaneously irradiated by tube voltage of 110 kV and tube current-time product of 25 mAs. Here, this ion chamber was calibrated at 70 and 120 kV x-ray by Japan Quality Assurance Organization and the same calibration factors were given for both tube voltages. The ratio of the air kerma obtained by the ion chamber to that obtained by the nanoDot was used as the sensitivity correction factor for the nanoDot. The sensitivity correction factors calculated for the nanoDot dosimeters ranged from 0.95 to 1.23, with a median of 1.02.

The $H_p(3)$ conversion factor was 1.54, which is for beam quality of N-60 and incident angle of 0° [16]. Here, the effective energy of the CT was 50.9 keV, which was obtained from a half-value layer using C1100 copper plates and mass attenuation coefficients [17]. A 3 cm^3 ion chamber (DC300; IBA Dosimetry, Schwarzenbruck, Germany) connected to an electrometer (EMF520R; EMF Japan, Hyogo, Japan) was placed at the centre of the gantry, and the ion chamber was irradiated with the x-ray tube parked in the 12 o'clock position (without rotation) with the following conditions: tube voltage of 110 kV and tube current-time product of 150 mAs. The position of the medical staff phantom was decided to simulate the body movement restraint of the patient during chest CT. The distance from the CT gantry to the medical staff phantom was set to 35 cm, and the height of the eye lens for the medical staff phantom was set to 130 cm, assuming that the medical staff is short or stooped and the eye lens is close to the patient. Additionally, the angle between the medical staff phantom and CT gantry was set to 30°. It was used as the reference arrangement (figure 3).

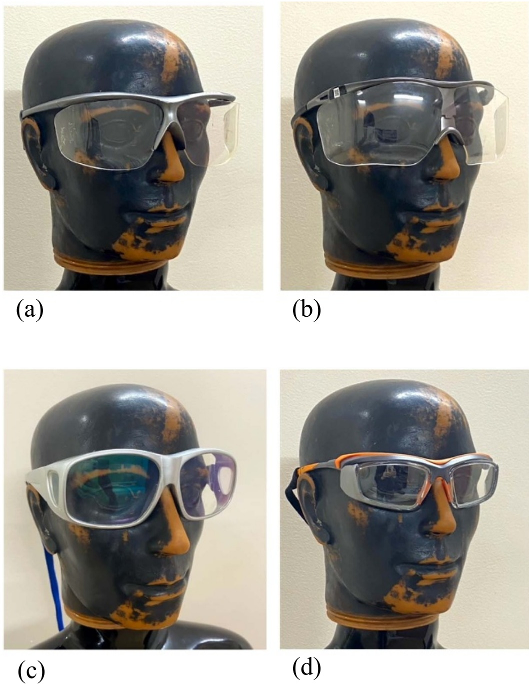

Figure 1. Radioprotective glasses on the head phantom. (a) Glasses 1, (b) Glasses 2, (c) Glasses 3, and (d) Glasses 4.

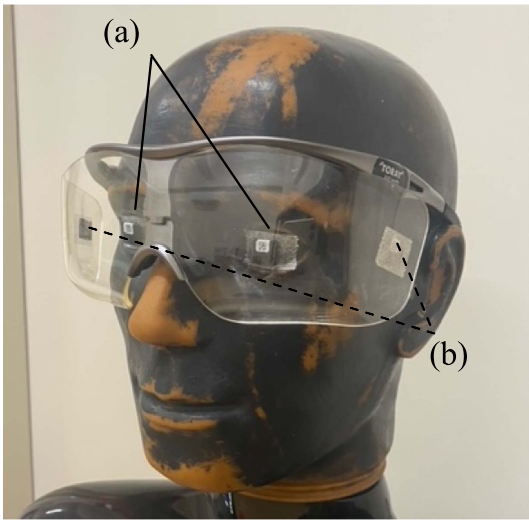

Figure 2. Positions of the nanoDot dosimeters. (a) Both eye surfaces of the medical staff phantom, and (b) inside of the lateral lens.

The following scan conditions assuming a standard chest CT were used: tube voltage of 110 kV, tube current–time product of 150 mAs, scan time of 15.4 s, tube rotation speed of 0.6 s/rotation, beam width of 16 × 1.2 mm, pitch factor of 0.8, volume CT dose index ($CTDI_{vol}$) of 10.77 mGy, and DLP of 433.68 mGy cm.

2.3. Method for evaluating eye lens dose in different situations

2.3.1. The distance from the CT gantry to the medical staff phantom

The distance from the CT gantry to the medical staff phantom was changed from 25 cm to 65 cm at a 10 cm interval. The angle between the medical staff phantom and CT gantry was 24°, 30°, 41°, 46°, and 52°, respectively, as a result of always looking at the patient's chest.

2.3.2. The height of the eye lens for the medical staff phantom

The height of the eye lens for the medical staff phantom was changed to 130, 150, and 170 cm using an adjustable height table.

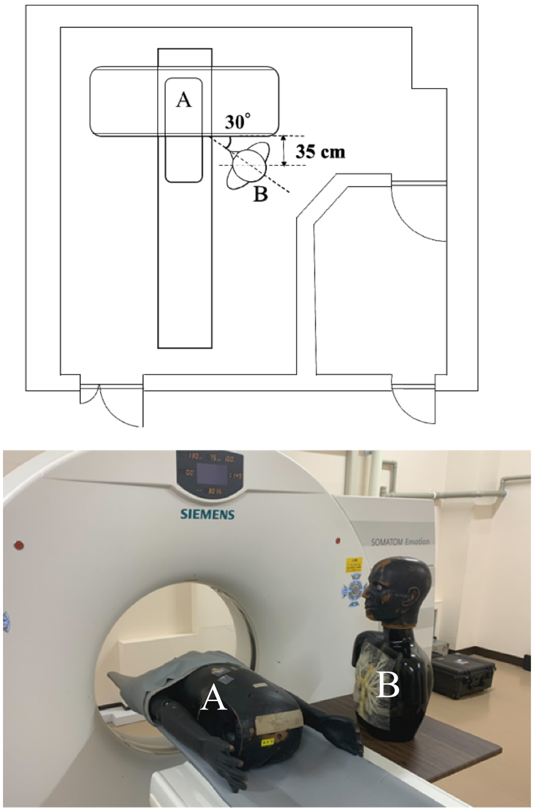

Figure 3. Layout of the reference arrangement. A is the patient phantom and B is the medical staff phantom.

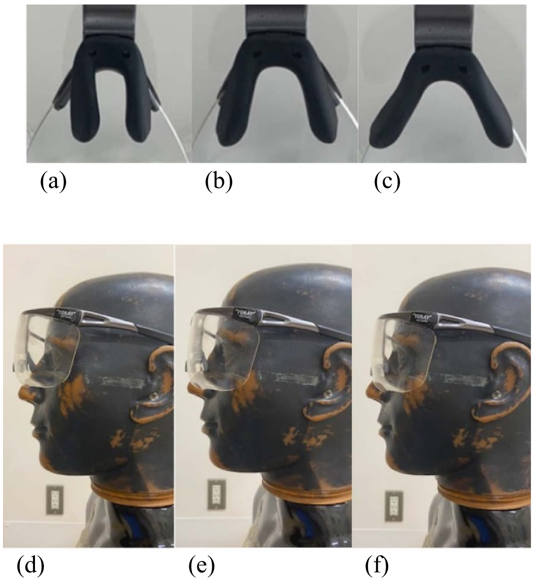

Figure 4. The width of the nose pad for Glasses 2. (a) Narrow, (b) intermediate, (c) wide, (d) lateral view with narrow, (e) lateral view with intermediate, and (f) lateral view with wide.

2.3.3. The width of the nose pad for Glasses 2

Glasses 2 can adjust the width of the nose pad by moving the nose pad sideways. This study evaluated three different nose pad widths: narrow, intermediate, and wide (figure 4).

2.4. Statistical analysis

Data were statistically analysed using Tukey's honestly significant difference test by IBM Statistical Package for the Social Sciences software version 27 (International Business Machines Cooperation, Armonk, NY, USA). *P*-values of $\leqslant 0.01$ were considered statistically significant.

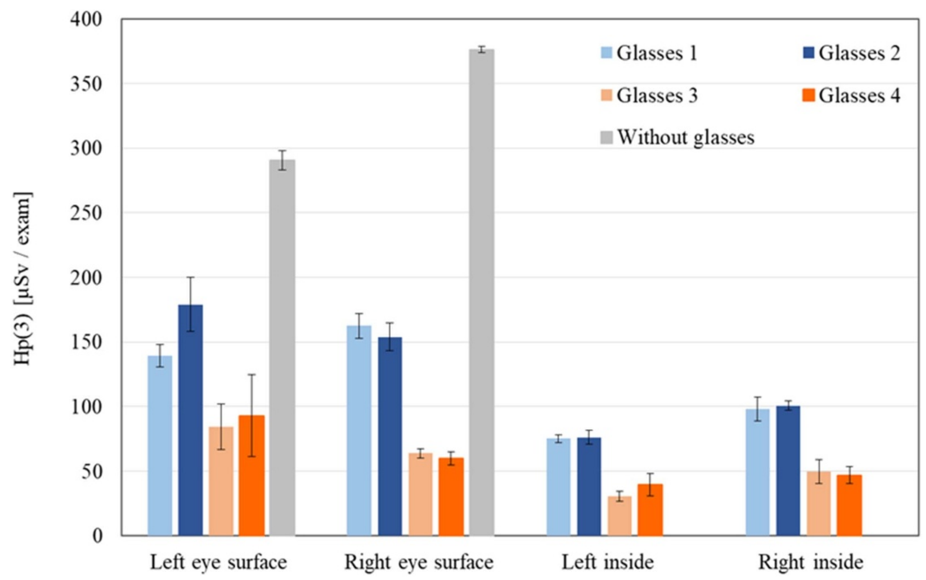

Figure 5. $H_p(3)$ on the staff phantom's eye surface and inside the four types of radioprotective glasses at the reference arrangement.

Table 1. $H_p(3)$ and dose reduction rates with different radioprotective glasses: (a) left eye surface, (b) right eye surface.

	$H_p(3)$ (μSv)		
(a) Radioprotective glasses	Without	With	Dose reduction rate (%)
Glasses 1	290.3	139.4	52
Glasses 2		179.1	38
Glasses 3		84.5	71
Glasses 4		92.9	68

	$H_p(3)$ (μSv)		
(b) Radioprotective glasses	Without	With	Dose reduction rate (%)
Glasses 1	376.2	162.4	57
Glasses 2		153.9	59
Glasses 3		63.9	83
Glasses 4		60.1	84

3. Results

3.1. $H_p(3)$ at the reference arrangement

Figure 5 shows the $H_p(3)$ on the medical staff's eye surfaces and inside the radioprotective glasses at the reference arrangement. On the left eye surface, the $H_p(3)$ was the highest without glasses (290.3 ± 7.4 mSv) and the lowest with Glasses 3 (84.5 ± 17.5 mSv). Also, on the right eye surface, the $H_p(3)$ was the highest without glasses (376.2 ± 2.4 mSv) and the lowest with Glasses 4 (60.1 ± 5.16 mSv). The $H_p(3)$ obtained from the eye surfaces were equal to or higher than those obtained from the lateral insides of the radioprotective glasses in all types of radioprotective glasses.

Additionally, dose reduction rates for the four types of radioprotective glasses were shown in table 1. The dose reduction rate was the highest with Glasses 3 (71%), followed by Glasses 4 (68%), 1 (52%), and 2 (38%) on the left eye surface, whereas the highest was Glasses 4 (84%), followed by Glasses 3 (83%), 2 (59%), and 1 (57%) on the right eye surface.

3.2. $H_p(3)$ with the changing distance from the CT gantry to the medical staff phantom

Figure 6 shows the relationship between the $H_p(3)$ on the staff phantom's eye surfaces and the distance from the CT gantry to the staff phantom. Table 2 shows the dose reduction rates compared to $H_p(3)$ without glasses at each distance from the CT gantry to the medical staff phantom. For Glasses 1, 2, and 3, the dose reduction rates increased by 14, 28, and 15%, respectively, when the distance was increased from 25 to 65 cm on left eye surface. However, the dose reduction rate did not increase significantly for Glasses 4 on left eye

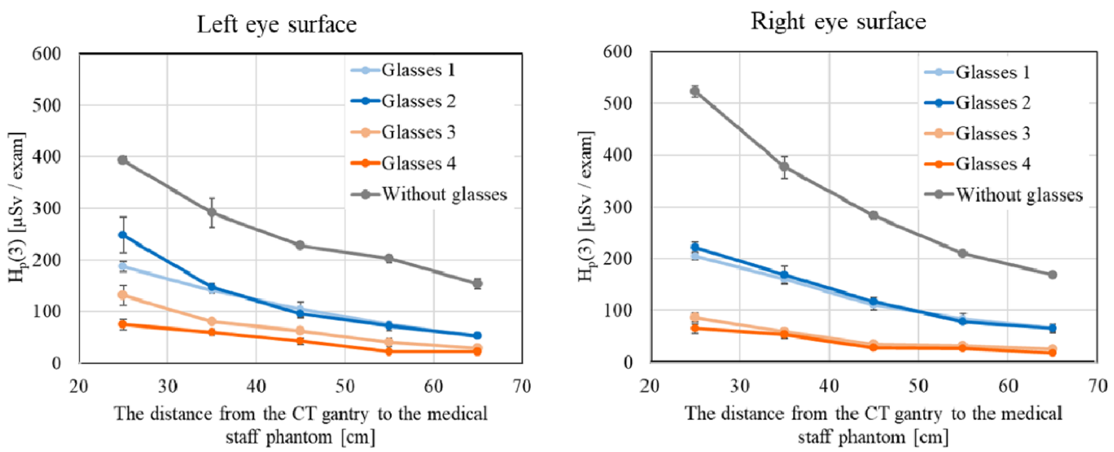

Figure 6. $H_p(3)$ with the different distance from the CT gantry to the medical staff phantom.

Table 2. Dose reduction rates (%) with different distance from the CT gantry to the medical staff phantom.

		Dose reduction rates (%)	
Radioprotective glasses	Distance (cm)	Left eye surface	Right eye surface
Glasses 1	25	53	61
	35	52	57
	45	54	61
	55	63	60
	65	67	60
Glasses 2	25	37	57
	35	50	55
	45	58	59
	55	65	63
	65	65	62
Glasses 3	25	67	83
	35	73	84
	45	72	88
	55	80	85
	65	82	85
Glasses 4	25	81	88
	35	79	86
	45	82	90
	55	89	87
	65	86	90

surface. On the other hand, the dose reduction rates did not increase significantly for all glasses on the right eye surface.

3.3. $H_p(3)$ with the changing height of the eye lens for the medical staff phantom

Figure 7 shows the relationship between the $H_p(3)$ on the staff phantom's eye surfaces and the height of the eye lens for the staff phantom. Table 3 shows the dose reduction rates compared to $H_p(3)$ without glasses at each height of the eye lens for the medical staff phantom. For Glasses 1, 2, and 3, the dose reduction rates decreased by 26, 31, and 26%, respectively, when the height was increased from 130 to 170 cm on the left eye surface. However, the dose reduction rate did not decrease significantly for Glasses 4 on the left eye surface. On the other hand, the dose reduction rates did not decrease significantly for all glasses on the right eye surface.

3.4. $H_p(3)$ with the changing width of the nose pad for Glasses 2

Figure 8 shows the relationship between the $H_p(3)$ on staff phantom's eye surfaces and the width of the nose pad for Glasses 2. The $H_p(3)$ on the left eye surface with the wide nose pad width was significantly lower than those with the narrow and intermediate nose pad widths, and the dose reduction rate was 47% by changing

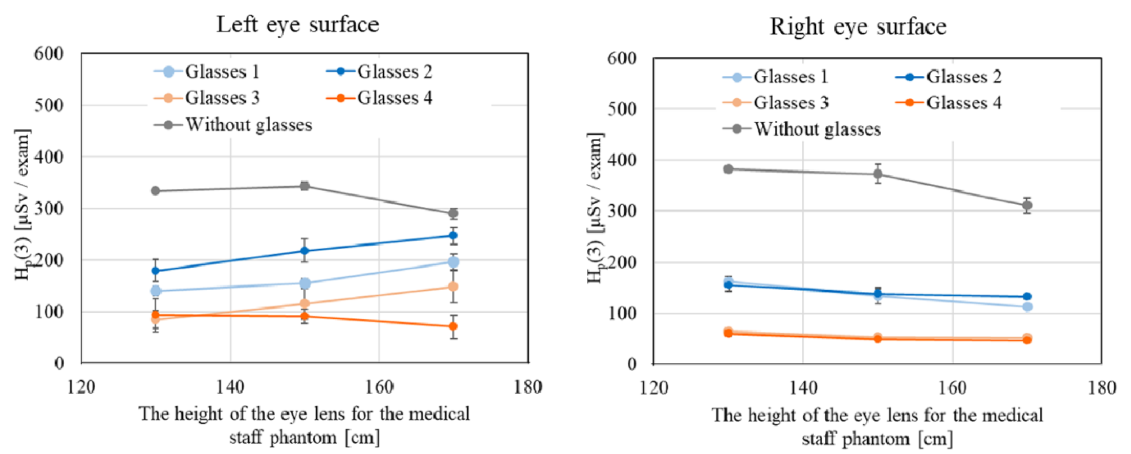

Figure 7. $H_p(3)$ with the different height of the eye lens for the medical staff phantom.

Table 3. Dose reduction rates (%) with different height of the eye lens for the medical staff phantom.

		Dose reduction rates (%)	
Radioprotective glasses	Height (cm)	Left eye surface	Right eye surface
Glasses 1	130	58	58
	150	55	64
	170	32	64
Glasses 2	130	46	60
	150	36	63
	170	15	57
Glasses 3	130	75	83
	150	67	86
	170	49	83
Glasses 4	130	72	84
	150	73	87
	170	76	85

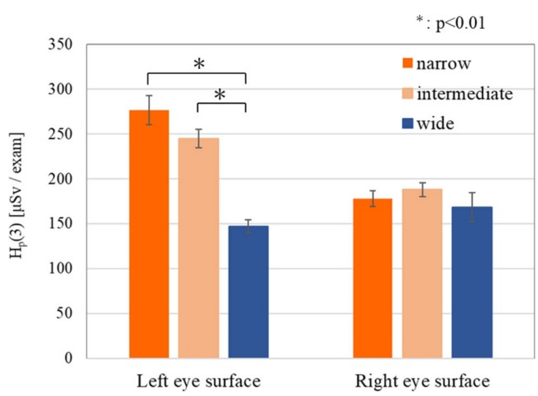

Figure 8. $H_p(3)$ with the different nose pad width (Glasses 2).

the nose pad width from narrow to wide. The $H_p(3)$ on the right eye surface did not vary significantly with the nose pad width.

4. Discussion

This study measured the $H_p(3)$ on the staff phantom's eye surfaces and inside the four types of radioprotective glasses with different lead equivalents and lens shapes. Additionally, the $H_p(3)$ on the staff phantom's eye surfaces was compared by changing the distance from the CT gantry to the medical staff phantom, the height of the eye lens, and the width of the nose pad.

The current study results suggest that radioprotective glasses for medical staff who frequently assist patients during CT examinations should have two characteristics. First, they should have a lens with a higher lead equivalent. The dose reduction rates with Glasses 1 and 2 (0.07 mmPb) were approximately 58% on the right eye surface, which is comparable to previous studies [13, 14]. Conversely, the reduction rates with Glasses 3 and 4 (0.50–0.75 mmPb) were approximately 84% on the right eye surface. The radioprotective glasses with a higher lead equivalent are heavy and not suitable for long time use. However, CT examinations take less time than IR procedures. Therefore, the medical staff does not need to wear radioprotective glasses for a long period of time. The results of the current study indicate that annual $H_p(3)$ exceeds 20 mSv with about two and four assists per week using Glasses 1 or 2 (0.07 mmPb) and Glasses 3 or 4 (0.50–0.75 mmPb), respectively, under our reference arrangement. In other words, when the medical staff wears Glasses 1 or 2, they can assist only about half the number of times when the staff wears Glasses 3 or 4. Second, the gaps around the nose pad and the lower front lens should be small. The $H_p(3)$ on the left eye surface was affected by the width of the nose pad. Narrow nose pad width increases the distance between the face and radioprotective glasses for Glasses 2, especially the gap around the nose, allows scattered x-rays to reach the eye lens directly. However, by widening the nose pad to fit the size of the nose, the gap around the nose is smaller, and the eye lens dose can be reduced because the glasses fit closely to the face. The $H_p(3)$ on the left eye surface was also affected by the height of the eye lens for the staff phantom. Table 3 shows that the dose reduction rates decreased for Glasses 1, 2, and 3 when the height of the eye lens was higher at the left side because the gap at the lower front was wider and more scattered x-rays reached the eye lens from the gap. However, this decreasing trend was not observed in Glasses 4. Glasses 4 cannot be worn over glasses, but it has a smaller gap on the lower front compared to other glasses. Additionally, Glasses 4 have a high lead equivalent (0.50 mmPb) at the lower front lens. Hence, Glasses 4 were not affected by the height of the eye lens.

Medical staff should wear radioprotective glasses and stay as far away from the patients as possible. The $H_p(3)$ decreased by changing the distance from 25 cm to 65 cm as a result of $H_p(3)$ on the eye surfaces with the different distances from the CT gantry to the medical staff phantom. Furthermore, table 2 shows that the dose reduction rates increased with increasing the distance for Glasses 1, 2, and 3 at the left side. This is because that the staff phantom was oriented toward the gantry by rotating the staff phantom to face toward the patient phantom as the distance was increased. At the distance of 25 cm, the staff phantom was right next to the CT gantry, and when the head of the staff phantom faced the patient phantom, there was a gap between the phantom and the glasses that allowed scattered x-rays reaching the eyes to enter. On the other hand, at the distance of 65 cm, when the head of the staff phantom faced the patient phantom, it also faced the CT gantry and there was almost no small gap between the phantom and the glasses that allowed the scattered x-rays reaching the eyes to enter. This tendency was not observed in Glasses 4 because it was not an over-glass type and the gap between the phantom and the glasses was small. In the clinical situations, the further the standing position of the medical staff from the gantry, the more difficult it is for them to restrain the patient. It is important for the medical staff to stay as far from the CT gantry as possible and to pay attention to the direction of the face in order not to enter the scattered x-rays through the gap between the face and the glasses.

Tables 2 and 3 and figure 8 show that $H_p(3)$ obtained from the right eye surface was not affected by the distance between the CT gantry to the medical staff phantom, the height of the eye lens for the medical staff phantom and the nose pad width. A study by Mao *et al* revealed that the eye lens side further from the patient was exposed to more scattered x-rays from the gap around the nose [2]. In most IR or interventional cardiology situations, since the x-ray tube is on the left side of the physicians, their right eyes, which are farther from the x-ray tube, are exposed to more scattered x-rays from the gap around the nose. On the other hand, in our experimental geometry, since the right eye was the closest to the x-ray tube, the left eye was more susceptible to the scattered x-rays from the gap around the nose.

The $H_p(3)$ on both left and right sides was equal to or lower in all types of radioprotective glasses on both eye surfaces. The $H_p(3)$ inside the radioprotective glasses was not affected by the scattered x-rays entered from the gap between the face and the radioprotective glasses because the nanoDots were attached inside the lead lens on the lateral sides, while the $H_p(3)$ on eye surfaces were strongly affected by the scattered x-rays entered directly through the gap. The International Atomic Energy Agency recommended $H_p(3)$ measurement as the most accurate method for monitoring eye lens doses, with a dosimeter worn as close as possible to the eye [18]. Eye lens dosimeters that are used to measure the eye lens dose should be placed inside the lateral lens of the radioprotective glasses [5, 19–21]. Therefore, considerably, they may underestimate the eye lens doses.

Finally, when assuming that the medical staff assists the patient three times per week during standard chest CT under our reference arrangement, the estimated annual $H_p(3)$ is 58.9, 25.4, 28.0, 13.2, and 14.5 mSv without radioprotective glasses and with Glasses 1, 2, 3, and 4, respectively. The annual $H_p(3)$ would exceed 50 mSv if they do not wear any glasses, and it would exceed 20 mSv if they wear Glasses 1 or 2 (0.07 mmPb).

This study has several limitations. First, this was a phantom study, and the movement of the medical staff during the CT examinations was not considered. The medical staff's body orientation, standing position, and head angle may change at any time during the CT examinations, and the $H_p(3)$ and dose reduction rates in this study did not consider these effects. Second, the standing position was fixed on the lateral side of the patient. However, the medical staff may stand near the patient's head depending on the purpose of the assistance, and assessing the impact of different standing positions is also necessary. Third, the effects of beam hardening of the scattered x-rays through the glasses and the energy dependence of Al_2O_3:C on the dose reduction rates were not considered. The sensitivity of nanoDots was corrected for x-rays with the same effective energy as the CT primary x-rays used, but different from the energy of the scattered x-rays. Finally, the $H_p(3)$ conversion factor is generally applied by multiplying the air kerma free-in-air [16]. Because the nanoDot readings in the present study were affected by the backscatter x-rays from the glasses and the phantom, which might have resulted in overestimations of the $H_p(3)$.

5. Conclusion

This study identified the characteristics of the radioprotective glasses suitable for the medical staff who frequently assist patients during CT examinations. They should have a lens with a higher lead equivalent considering the short duration of use and protective effect even though they are heavy. In addition, the gaps around the nose pad and the front lens of the radioprotective glasses should be small to fit the lenses closely to the face. When the staff stands near the CT gantry, scattered x-rays are more likely to enter the eye lens directly through the gap between the face and the glasses. Furthermore, when the medical staff's eye lens is higher, it results in a higher eye lens dose because the eye lens may be exposed through the gap under the front lens.

Data availability statement

The data cannot be made publicly available upon publication because no suitable repository exists for hosting data in this field of study. The data that support the findings of this study are available upon reasonable request from the authors.

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