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Abstract: PURPOSE Fluoroscopy guided interventional procedures guarantee high benefits for patients, but are associated with high levels of radiation exposure for the medical staff. Their increasing use and complexity results in even higher radiation exposures, with a risk to exceed the annual dose limit of 20 mSv for the eye lens. The aim of the study was to evaluate the potential dose reduction of eye lens exposure for lead glasses and for two types of visors (half and full), used by physicians performing interventional procedures. METHODS Eye lens dose measurements were carried out on an anthropomorphic phantom simulating a physician performing a fluoroscopy guided interventional procedure. Dose reduction factors were calculated using high sensitivity thermoluminescent dosimeters. Moreover, a spatial dose distribution was generated for the two visors. RESULTS The dose reduction coefficient was found to be 1.6 for the glasses, 1.2 for the half visor and 4.5 for the full visor. CONCLUSIONS Optimal radiation protection requires a combination of different radiation protection equipment. Full visors that cover all the face of the operator are recommended, as they absorb scattered radiation reaching the eyes from all directions. Full visors should be prioritized over radiation protection glasses for cases where other protective equipment such as ceiling shielding cannot be used.

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Technical note

Efficiency evaluation of leaded glasses and visors for eye lens dose reduction during fluoroscopy guided interventional procedures

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ABSTRACT

Purpose: Fluoroscopy guided interventional procedures guarantee high benefits for patients, but are associated with high levels of radiation exposure for the medical staff. Their increasing use and complexity results in even higher radiation exposures, with a risk to exceed the annual dose limit of 20 mSv for the eye lens. The aim of the study was to evaluate the potential dose reduction of eye lens exposure for lead glasses and for two types of visors (half and full), used by physicians performing interventional procedures.

Methods: Eye lens dose measurements were carried out on an anthropomorphic phantom simulating a physician performing a fluoroscopy guided interventional procedure. Dose reduction factors were calculated using high sensitivity thermoluminescent dosimeters. Moreover, a spatial dose distribution was generated for the two visors.

Results: The dose reduction coefficient was found to be 1.6 for the glasses, 1.2 for the half visor and 4.5 for the full visor.

Conclusions: Optimal radiation protection requires a combination of different radiation protection equipment. Full visors that cover all the face of the operator are recommended, as they absorb scattered radiation reaching the eyes from all directions. Full visors should be prioritized over radiation protection glasses for cases where other protective equipment such as ceiling shielding cannot be used.

Introduction

The primary pathology of the eye lens is its opacification, known in its advanced stages as “cataract”. Cataract is the leading cause of blindness worldwide, with more than 36 million blind [1]. Given the increasing human life span, the societal burden of cataract surgery is expected to worsen in future years. The eye lens is one of the most radiosensitive tissues in the human body. Initial stages of eye lens opacification do not usually result in visual disability, but the severity of these changes may progressively increase with dose and time until vision is impaired and cataract surgery is required. The latency of such changes is inversely related to dose [2]. A number of recent studies suggested a high risk for cataract development in populations exposed to low doses of ionizing radiation. For example, dose-related eye lens opacification has been reported at exposures significantly lower than 2 Gy among those undergoing CT scans or radiotherapy, atomic bomb survivors, survivors of the Chernobyl nuclear accident, radiological

radiographers, interventional radiologists and cardiologists, etc. [2]. These human epidemiological studies, as well as recent work with experimental radiation cataracts in animals, suggest that cataract may occur following exposure to significantly lower doses of ionizing radiation than assumed previously. Such observations have implications not only for patients undergoing radiotherapy or diagnostic procedures, but also for those that are occupationally exposed to ionizing radiation, such as interventional medical personnel or nuclear workers. Based on recent epidemiological data, the International Commission on Radiation Protection (ICRP) revised the threshold dose of ionizing radiation for tissue reactions with late manifestation, such as the cataract [2]. The reduced threshold for eye lens effects (cataract and other opacities) is set at 0.5 Gy for low-LET radiation for acute or protracted exposures [2]. Furthermore, to protect the personnel working with radiation, ICRP recommended the annual dose limit to be reduced from 150 mSv per year to 20 mSv per year. The European Union in its Basic Safety Standards adjusted the limit. Since 2018, the annual limit on the equivalent

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dose for the eye lens was set at 20 mSv in almost all countries including Switzerland [3].

The number of fluoroscopy guided interventional procedures is increasing worldwide and so does the number of physicians exposed to radiation [4,5]. This comprises interventions in cardiology, radiology, vascular surgery, orthopedics, urology, etc. and is related to high radiation exposures for both the patient and the personnel. Innovations in interventional techniques allow treating more complex diseases. Some of these procedures are laborious and often have to be performed in an increasingly obese population. Although these issues have been addressed and fluoroscopy systems manufacturers have made major technological efforts, increased radiation exposure for the operators' eyes may still result. In addition to aprons and thyroid protections, equipment such as ceiling protections or cabins are available in interventional radiology and cardiology departments. However, during certain procedures, as for example transjugular intrahepatic portosystemic shunt creation, these shields cannot be used as they complicate the access to the patient or they are not even available as in the case of many operating theaters. This absence leaves the operators' eyes completely unprotected to ionizing radiation. Usually lead glasses are recommended to reduce the eye exposure. The lead glasses can also include eye view correction, but depending on the correction, their weight increases substantially or cannot be offered due to technical difficulties. In recent years, new devices that can be worn over the correction glasses such as visors that cover the face of the operators have been introduced to the market and may solve the above issues. However, these visors offer less lead equivalent protection than the glasses. The evaluation of eye lenses protective equipment during interventional procedures can be performed either experimentally, simulating a procedure with phantoms and dosimeters or in clinical practice, where the operators need to wear specific dosimeters over a long time. Many studies focus on the evaluation of the efficiency mainly of lead glasses and not visors and in case of clinical studies, shields like ceiling shielding could be used leading to uncertainties on the efficiency of the shield under evaluation. Aim of this study was to evaluate the efficiency of different eye lens protection equipment (wraparound glasses and two types of visors) and to propose practical solutions for eye lens protection.

Methods

A setup at a fluoroscopy unit was simulated with the detector at left-anterior-oblique projection (LAO) at 30° position (Image 1). The left oblique projections are the ones where the interventionists are the least favorable projections in terms of operator's irradiation. The 30° angle was the average angle from various oblique projections used in radiological procedures. After analyzing around 3000 projections from 500 procedures, the tube voltage was decided to be set at 80 kVp, which corresponds to the 90th percentile of the kVp used. Measurements were performed at a monoplane angiography unit (AXIOM-Artis, Siemens, Erlangen). The field of view was 30 × 30 cm² with no use of collimators or semitransparent filters and the simulation was performed with fluoroscopy mode with a dose rate of 30 images per second. The head and chest of an anthropomorphic phantom (Atom phantom, CIRS) was used to simulate the operator. The phantom head was oriented with its face perpendicular to the table to simulate an operator looking straight at the digital screens on the opposite side of the bed. Thus, the left eye was at the tube side. The abdomen/pelvis of the Atom phantom was placed on the table to simulate the patient during interventional operation and generate scattered radiation. The phantom simulated an individual of 1.75 m in height and 73.5 kg in weight. The distance between the patient and the operator's eyes was 90 cm.

Three different types of eye lens radiation protection were evaluated:

- i) a half visor with 0.12 mm Pb equiv. (PSFMPAN, XPROTEC Swiss GmbH),
- ii) a full visor with 0.12 mm Pb equiv. (PSFM-FULL, XPROTEC Swiss GmbH), and.

Table 1

Characteristics of eye lens protective equipment.

Protective mean	Pb equiv. protection (mm)	Weight (gr)	Dimensions (cm)
Lead glasses	0.75 frontal + 0.5 lateral	53	
Half visor	0.12	354	Length 14 cm, width at nose level 22 cm
Full visor	0.12	398	Max length 21 cm, width at nose level 20 cm

iii) lead glasses with 0.75 mm Pb equiv. frontal protection and 0.5 mm Pb equiv. lateral protection (RG-50SS, XPROTEC Swiss GmbH). Table 1 provides a description of the eye lens radiation protection equipment. The full visor is 21 cm high, measured at the center of the visor, providing a protection over all the face of the operator, while the half visor is slightly wider than the full one that gets narrower towards the chin.

The protections were placed consecutively on the head of the phantom and measurements were performed with thermoluminescent dosimeters (TLD). The TLDs were placed on the outer surface of the radiation protection means in front of the eyes and on the eyes of the phantom to measure as good as possible the eye lens exposure. The dose reduction factor (DRF) was calculated as follows:

DRF = average $H_p(0.07)$ at the level of the eye without protective means / average $H_p(0.07)$ at the level of the eye with protective means.

Image 1: Setup at the fluoroscopy unit – simulation of typical interventional radiology procedures (LAO 30°).



Dose measurement

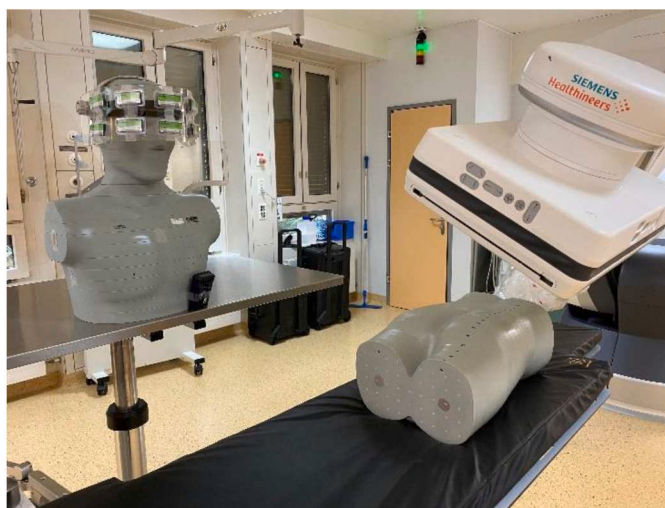
The dose was measured with lithium fluoride LiF: Mg, Cu, P TLD (Harshaw TLD-100H, RadPro MCP-N, the Harshaw Chemical Company, Solon, OH) of small square form approximately 3.2 mm long and 0.6 mm thick. Three dosimeters were packed in sealed-water tight plastic bags with 0.5 cm distance between each other and the mean dose was determined for each measurement point. Extra TLDs were used for

background correction. The MCP-N dosimeters were calibrated in $H_p(0.07)$ quantity, by a certified dosimetry laboratory (Institute of radiation physics, Center of university hospitals of Lausanne,). The measurements were corrected for the energy dependence for scattered radiation from 80 kVp X-rays. The uncertainty of the measurements was $\pm 15\%$ for doses larger than 0.05 mSv and $\pm 30\%$ for doses lower than 0.05 mSv. Although the measurements for eye lens dose should be performed at $d = 3$ mm depth, a dose measurement, based on the operational quantity $H_p(0.07)$ can be performed in practice and with good approximation [6]. This is justified by the fact that the conversion coefficients $h_{pK}(0.07; N, \alpha)_{slab}$ and $h_{pK}(3; N, \alpha)_{cyl}$ from air kerma K_a to dose equivalent $H_p(0.07)$ and $H_p(3)$, respectively, do not differ by more than 6% at photon energies equal to or higher than N-30 (N-series radiation qualities), corresponding to 25 keV mean energy and higher [7,8].

Additional standard badges with TLD dosimeters used for personal dosimetry were provided by Dosilab AG, Switzerland. Each badge included four dosimeters and their average dose was determined for each measurement point. Two additional badges were used for background subtraction. These TLDs were calibrated in $H_p(10)$ quantity and were corrected for the effectively measured photon energy, based on an algorithm deriving spectral information from the four element detector badge. Conversion to $H_p(3)$ was calculated via energy dependent conversion factors where needed [7,8]. The badges were placed on all the outer surface of both visors to measure the different exposure over the operators' face (Image 2).

During all measurements, an active dosimeter (DMC 3000, Mirion Technologies, Inc., Atlanta, USA) was used to monitor that at least 2 mSv of radiation dose was accumulated by the passive dosimeters at the level of the chest.

Image 2: Configuration of the phantoms, machine and radiation detectors on the full visor protection (left) and half visor protection (right). An active dosimeter was used to verify that at least 2 mSv of radiation dose at the level of the chest was accumulated by the passive dosimeters.



Results

Dose reduction factors

The correction factors for the visors and lead glasses were

determined in Table 2 using the measurements for the left eye with and without protection. The last column concerns the DRF determined with the use of sensitive dosimeters, placed on the eyes of the phantom and on the external surface of the protections. The most efficient equipment was found to be the full visor, with a DRF of 4.5, followed by the lead glasses with a DRF of 1.6.

Spatial dose distribution

Table 3 provides the results of the TLD badges placed in different positions on the face shields. For the half visor, positions 2 and 7 represent the right eye and positions 4 and 9 represent the left eye, while for the full visor positions 2 and 4 correspond to the right and left eye, respectively. As expected, we observed a large difference between the exposure over the right and left eye. The exposure is about 3 times higher for the left than for the right eye. However, it is interesting to note that the exposure values measured on the full visor show very little variation over the left half of the shield (positions 4, 7, 8, 10 for the full visor). Heatmaps for the two visors are presented in Figs. 1 and 2 representing the radiation field to which the person's face is exposed to. The results were normalized to the highest value of each visor, which was over the left eye of the operator, at the side of the X-ray tube. The interpolation was performed only between the measurement points and does not extend outside of these points.

Discussion

As the annual limit for the eye lens was reduced from 150 mSv to 20 mSv and at the same time the interventional procedures become more numerous and complicated, an efficient radiation protection equipment for the eyes is crucial. In our attempt to estimate which equipment is the most efficient, we estimated the DRF for three different radiation protections for the eyes by using an anthropomorphic phantom simulating clinical conditions in a radiology department. Moreover, we estimated the exposure difference between face and eyes. Indeed, wearing radiation protection glasses is an effective way to protect the eye lens. However, we found out that full visors may provide better protection to

the eyes.

The effectiveness of radiation glasses was studied in multiple studies either by means of phantom studies or measurements in clinical settings [9–15]. Great variation of DRF is observed as the efficiency of the glasses depends on factors, such as the geometry of the irradiation (projection, field size, distance of the operator from the X-ray tube, distance from the patient, angle of the head in relationship with the X-ray field, etc.) and

Table 2

TLD measurements (mSv) over the eye protection equipment (without protection) and on the eye lens of the phantom (with protection).

Protective equipment		Left eye	Right eye	DRF
Lead glasses	w/o	1.09	0.89	1.6
	with	0.70	0.53	
Half visor	w/o	0.51	–	1.2
	with	0.44	–	
Full visor	w/o	1.00	0.74	4.5
	with	0.22	0.13	

Table 3

DAP-normalized radiation dose (mSv/mGy•cm²) for the visors as measured with the TLD badges.

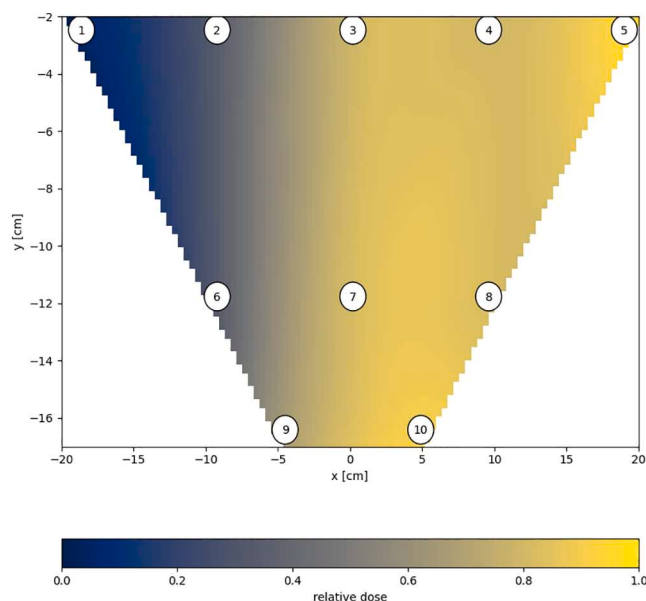
	Half visor	Full visor
Position 1	0.30	0.25
Position 2	0.07	2.42
Position 3	2.12	6.19
Position 4	3.72	6.25
Position 5	4.23	7.79
Position 6	0.57	2.31
Position 7	0.18	6.39
Position 8	2.61	6.39
Position 9	3.49	5.09
Position 10	4.08	7.24

the form of the protection itself (size of glasses, distance between operator's face and glasses, lateral protection, etc.). It is important to note here that the variation in DRF cannot be explained by the lead equivalence as most of the lead glasses provided a frontal lead equivalent protection of 0.75 mm and lateral 0.50 mm, as the ones tested in our study. In this study, a DRF of 1.6 was estimated for glasses with lateral shielding and good contact with the face (nose and cheeks) of the operator. Our factor is quite lower, however, in agreement with the ones found in literature (Table 4) [9–13]. Most of the lead glasses provided a frontal lead equivalent protection of 0.75 mm and lateral 0.50 mm, as the ones tested in our study. Van Rooijen et al. determined an average DRF of 2.1 for the eye at the side of the tube in an experiment similar to ours, addressing also the importance of the irradiation geometry [9]. Domienik et al. estimated that the DRF ranged between 1.1 and 3.4 after comparing the eye exposure of interventional cardiologists wearing

different models of lead glasses [10]. In a second publication, Domienik et Brodecki estimated DRF values between 5 and 10 for exposures with the X-ray tube above the table, however, they addressed the fact that the methodology of measuring the eye exposure played a huge role in the calculation of the DRF [11]. Magee et al estimated DRF values for situations similar to those used in clinical practice between 1.4 and 5.2 affirming that specially designed lead glasses with side shields or of a wraparound style with angled lenses performed better than lead glasses of standard spectacles design [12]. Strocchi et al. estimated the DRF for different lead glass models between 3.7 and 5.4 [13]. As a rule, a DRF of 2 is conservatively applied for cases where glasses are employed. As seen in the literature, higher DRF may be achieved, but taking into account variations in exposure geometries, the ICRP stated that the applied DRF should not be higher than 4 [16].

Visors provided a lead equivalent protection of 0.1 mm. Our results showed that the full visor protection was the most efficient, reducing the dose by 4.5 times; although its nominal lead equivalency is typically five times less than in traditional lead-glasses, this visor covers the face of the operator from the forehead to the chin and reduces the scattered radiation. Our results are in line with other publications. Magee et al estimated a DRF of 4 for full visors [12], while Galster et al. estimated that the reduction would be up to 90% [14]. For the half visor, Guersen et al. estimated that the reduction for the left eye would be 82% and for the right eye 43% [15], while Galster et al. found that in general the half visor was less efficient than the full one [14]. As the radiation from the lower face is not absorbed by the half visor, it contributes to the higher eye lens exposure observed with this type of visor and therefore reduces its efficacy to protect the eyes (DRF of half visor was estimated 1.2 vs. 4.5 for the full visor). Thus, we recommend the use of full instead of half visor. From the practical point of view, there are also some advantages to select a full visor over lead-glasses. The weight of the visor is homogeneously distributed over the head of the operator and not mainly on the nose like with the glasses. As there is more space between the face of the operator and the visor, the operators can wear their own correction glasses under the visor. This is an important advantage since corrections usually change over the years and for each individual situation the balance between lead shielding and correction can result in protection glasses that are less comfortable than the personal ones. Fit-over protections to be worn over the correction glasses are also available in the market; however, their use is limited as they can also be uncomfortable because of their weight and reflections. As additional advantages, the visors provide an extra hygienic protection against biological fluids, and with the circulating air the fogging effect is highly reduced.

One limitation of this study was that the simulation was performed only for one projection of the X-ray machine (LAO 30°) and the operator (looking straight ahead with no head tilt). However, this projection is an average one in our department and in general, it exposes the operators to more radiation than the projections where the tube is under the table or on the opposite side and thus, allowed us to have a conservative estimation of the radiation protection means efficacy. Although higher voltage can be used for obese patients, only 10% of the projections were performed with voltage higher than 80 kVp. Other users may adopt this methodology and simulate different angles and voltage that are closer to their clinical conditions. A second limitation is related to the fact that the measurements with and without eye lens protections were performed simultaneously to reduce uncertainties in radiation dose. However, as the maximum distance between the eyes and the visor was 5 cm, the distance between the protection and the eye was neglected. Another limitation was that the DRF was evaluated individually for each radiation protection means and not in combination with other protections, such as ceiling, undercouch or protection used for the patient. This estimation allowed us to improve the radiation protection advice in cases where other protection may not be available or cannot be employed. Moreover, the use of radiation protection means for the patient has recently been re-evaluated and its use may even increase the dose to the patient and personnel, especially in complex procedures such

**Fig. 1.** Spatial dose distribution for full visor.

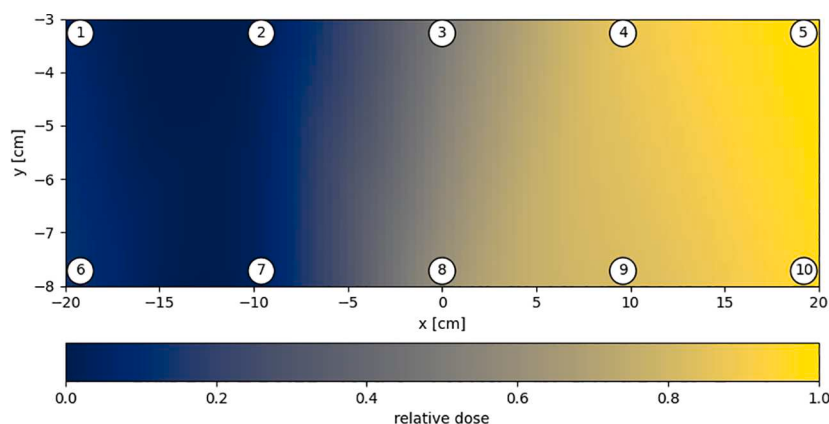


Fig. 2. Spatial dose distribution for the half visor.

Table 4

DRF values found in literature for protection means.

Radiation protection mean with frontal (F) and lateral (L) lead equivalence in mm	Geometry	Methodology	DRF	Reference
Wraparound glasses with 0.75F + 0.5L	Simulation LAO 30°	TLD measurements	1.6	This study
Different glass models 0.75F + 0.5L	Various simulations	TLD measurements	2.1	[9]
Different glass models 0.75F + 0.50/0.00(L)	Clinical conditions	TLD and routine eye dosimeters measurements	1.1–3.4	[10]
Two glass models 0.75 (F)	Simulation anterior-posterior projection	TLD and routine eye dosimeters measurements	5–10	[11]
Different glass models 0.75 (F) + 0.50(L)	Various simulations	TLD measurements	1.4–5.2	[12]
Different glass models 0.75F + 0.75/0.50/0.00(L)	Simulation of procedures	TLD measurements	3.7–5.4	[13]
Half visor 0.1	Simulation LAO 30°	TLD measurements	1.2	This study
Full visor 0.1	Simulation LAO 30°	TLD measurements	4.5	This study
Full visor 0.1	Various simulations	TLD measurements	4	[12]
Half and full 0.1	Various simulations	TLD measurements	0–5	[14]
Half visor 0.1	Simulation anterior-posterior projection	TLD measurements	2–4	[15]

as the interventional ones [17–20].

Only the adoption of good practice will reduce eye lens radiation dose. Training of personnel in radiation protection is essential in risk management and should include not only theoretical education but also clinical training. In this way, dose reduction techniques can be integrated in working procedures and become routine practice. For this, it is very important that all operators are acquainted with the X-ray unit in order to collimate the X-ray field, move the tube around the patient, and change the dose rate and image rate without losing time during the procedure. Setting a time-out for radiation protection before any procedure, the operators can check that they i) wear their standard and eye dosimeter, ii) wear apron and eye protection, iii) employ correctly any additional shielding available (ceiling shielding, lead curtains, disposable lead drapes), and iv) choose the correct protocol for each procedure starting with the lowest image rates. Finally, it is recommended that personnel regularly review their occupational radiation dose values.

Conclusions

In this study, we assessed the effectiveness of different eye lens protection devices. The DRF for wraparound glasses was estimated to be 1.6, the full visor DRF was estimated to be 4.5 while the DRF for the half visor was 1.2. Based on this information, we provide the following recommendations to protect the lens of the eye. Everyday use of full visors or wraparound leaded glasses fitting on the operators face is recommended. When no additional radiation shields can be used or are not available, personnel should use full visors. The use of half visor is not

recommended.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dr Miha Furlan is employer of the Dosilab AG, Switzerland, that provides dosimetry services.

The remaining authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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