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FULL PAPER

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

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Objective: In 2011, the International Commission on Radiological Protection (ICRP) recommended a substantial reduction in the equivalent dose limit for the lens of the eye, in line with a reduced threshold of absorbed dose for radiation-induced cataracts. This is of particular relevance in interventional radiology (IR) where it is well established that staff doses can be significant, however, there is a lack of data on IR eye doses in terms of $H_p(3)$. $H_p(3)$ is the personal dose equivalent at a depth of 3 mm in soft tissue and is used for measuring lens dose. We aimed to obtain a reliable estimate of eye dose to IR operators.

Methods: Lens doses were measured for four interventional radiologists over a 3-month period using dosimeters specifically designed to measure $H_p(3)$.

Results: Based on their typical workloads, two of the four interventional radiologists would exceed the new ICRP dose limit with annual estimated doses of 31 and 45 mSv to their left eye. These results are for an "unprotected" eye, and for IR staff who routinely wear lead glasses, the dose beneath the glasses is likely to be significantly lower. Staff eye dose normalized to patient kerma-area product and eye dose per procedure have been included in the analysis.

Conclusion: Eye doses to IR operators have been established using a dedicated $H_p(3)$ dosimeter. Estimated annual doses have the potential to exceed the new ICRP limit.

Advances in knowledge: We have estimated lens dose to interventional radiologists in terms of $H_p(3)$ for the first time in an Irish hospital setting.

Interventional radiology (IR) procedures can result in occupational radiation doses that are high enough to warrant concern.^{1–6} While there is good awareness and understanding of radiation risks to staff from IR procedures, a lack of reliable values for eye doses has persisted. Recent publications have attempted to address this and have established that dose to the eyes can be significant, particularly if the X-ray tube is positioned over the patient table and if no ceiling-mounted lead screen or lead glasses are used;^{7–16} however, more data on lens dose, particularly in terms of $H_p(3)$ (personal dose equivalent at 3 mm in soft tissue), is required.^{15,16}

Revised International Commission on Radiological Protection dose limit

In April 2011, the International Commission on Radiological Protection (ICRP) published a statement on tissue

reactions recommending an equivalent dose limit for the lens of the eye of 20 mSv per annum.¹⁷ This is a considerable reduction from the previous equivalent dose limit of 150 mSv per annum.¹⁸ Since this statement was released, awareness in the scientific literature has grown at a rapid pace and the need for improved eye lens dosimetry has been acknowledged.^{19,20} Although the rationale for reduction in the eye lens limit has been debated in the literature,^{19–23} the limit is now on a firm footing within Europe as it has been adopted into the new European Union (EU) basic safety standards directive.²⁴ The directive must be transposed into national legislation by EU member states within a period of 4 years. Efforts to establish reliable estimates of eye doses prior to legislative changes will assist with the transition to this significantly lower limit. The goal of this study was to obtain a reliable estimate of occupational eye doses to IR operators in terms of $H_p(3)$.

METHODS AND MATERIALS

Eye doses to staff performing fluoroscopically guided procedures in a dedicated IR laboratory in Ireland were measured over a 3-month period from July to October 2012.

Clinical settings and room shielding

The setting for this study was a large acute hospital with a dedicated IR laboratory (X-ray room) within the radiology department. The IR X-ray room is fitted with a modern flat panel detector fluoroscopy X-ray system, with C-arm configuration (Artis Zee; Siemens Healthcare, Erlangen, Germany). This hospital is also an academic teaching hospital, and IR fellows in training participate in IR cases performed here. The size of the X-ray room is around 55 m², which is in line with published guidelines (for IR suites, a range spanning 38–50 m² has been recommended).^{25,26} The room is sufficiently large to accommodate the X-ray system, ancillary equipment, patient table and several staff members (typically one or two interventional radiologists, nurses and support staff). There is a ceiling-mounted lead glass screen, which is usually (but not always) positioned in front of the radiologist. It is more likely to be used during longer complex procedures. One operator routinely uses disposable radiation protection drapes, which are placed on the patient. There is also table-side lead shielding. For the majority of cases, the radiographer remains at the system controls behind a fixed protective lead glass screen, which is sufficiently large to accommodate three or four people.

The X-ray equipment in question had recently undergone routine quality assurance (QA) testing in accordance with local protocols, which are based on recommended guidelines and standards for radiology equipment.^{27–30}

Case mix of interventional radiology procedures

The remit of the IR service ranges in complexity from the secondary to tertiary level. The interventional radiologists at this hospital perform approximately 3000 interventional procedures per annum in this X-ray room, across an array of vascular, cancer-related, genitourinary, gastrointestinal and neurological conditions. Examinations include complex angiography/embolization, biliary and genitourinary procedures as well as more routine drainages and line placements typical of an IR service.

Personal protective equipment and personal monitoring

All IR staff included in this study wear personal protective equipment (PPE) in the form of wrap-around lead aprons (0.25–0.35 mm lead equivalence wrapped around to give 0.5–0.7 mm lead equivalence at the front) and a thyroid collar (0.5 mm equivalence). In addition, most of the radiologists wear lead glasses. Personal monitoring with whole-body passive dosimeters is already carried out in accordance with legal requirements in Ireland.³¹ Interventional radiologists and IR nurses are issued with two dosimeters, one to be worn on the trunk under the lead apron and one to be worn at the neck or shoulder level unprotected (outside the thyroid collar). Other staff (radiographers, healthcare assistants) are issued with one dosimeter to be worn on the trunk under the lead apron.

Eye lens dosimeter specifications

In addition to the personal monitoring described above, a new dedicated eye lens dosimeter (Eye-DTM; RadCard, Krakow, Poland) was issued to staff who were participating in this study. This dosimeter was developed as part of the EU Optimisation of Radiation Protection of Medical Staff project specifically to measure H_p(3), and it fulfils all requirements for its application in IR.³² It consists of a thermoluminescent dosimeter (TLD) pellet (MCP-N, lithium fluoride doped with magnesium, copper and phosphorus) and a plastic (polyimide) capsule, and can be attached to an adjustable fabric headband. The dosimeter is sensitive to low doses and has a satisfactory photon energy response and angular response.³²

H_p(3) calibration

The calibration and readout of the eye lens dosimeters was performed by the laboratory at RadCard. At the request of the authors, the H_p(3) calibration was performed using a cylindrical phantom that is more representative of the head than a slab phantom.^{33,34} Following the 3-month measurement period, all dosimeters (including unirradiated transport dosimeters) were returned to RadCard in Poland to be read out.

Eye dose protocol

The IR staff were consulted on the project methodology, and several IR cases were observed by the authors prior to distributing the badges. The typical position of the operator was noted. Most cases were performed with the left eye closest to the source of scatter. It was therefore hypothesized that a TLD worn on the outer edge of the left eye would record the greatest dose. In order to confirm this and compare with the dose to the right eye, two TLDs were issued to all four radiologists—one to be worn on the outer edge of the left eye and one to be worn on the outer edge of the right eye.

Dosimeters were initially assigned to staff by placing two TLDs on the adjustable headband that comes supplied with the eye dosimeter. After a short trial period, the radiologists gave feedback that wearing the TLDs on a headband was uncomfortable and would be too difficult to tolerate. The protocol was reviewed in consultation with the radiologists, and it was agreed that affixing the TLDs to the outside arm of a pair of glasses would overcome some of the issues. Of the four staff in the study, three always wore lead glasses. For these radiologists, their TLDs were semi-permanently attached to the outside arm of the glasses using a plastic cable tie. The fourth staff member wears ordinary prescription spectacles, and therefore he was provided with an elastic sleeve to allow the TLDs to be easily attached and removed before and after each IR case. Feedback on the issues of comfort with the headband was submitted to the manufacturer so that they could consider other options for affixing the eye dosimeter.

Sample size of staff

The IR laboratory is staffed by three consultant radiologists and one first-year fellow starting the first 6 months of their fellowship in IR. Several other radiology specialist registrars in training carry out some procedures in the laboratory under supervision. However, for this study, the three consultants and the fellow

were chosen for eye dose monitoring to represent the staff with the busiest and most complex workload. All four radiologists were issued with their own unique eye dosimeters (two for each staff member), and the identification (ID) numbers of their dosimeters were recorded for tracking purposes. For this study, nursing staff were not monitored, as they are rarely in close contact with the patient during the period of X-ray exposure, and we established that the same applies to support staff and radiographers working in this particular laboratory.

All eye dosimeters were stored in the radiology department, either in the control room of the IR laboratory or in the radiologist's office. A copy of the project protocol, with staff names and assigned ID numbers was displayed in the IR control room. Three transport dosimeters were left (unirradiated) in the control room. Prior to the start of each IR case, the radiographer reminded relevant staff to wear their eye dosimeters. Compliance was increased by virtue of the fact that for three out of the four staff, the dosimeter was already attached (semi-permanently) to the lead glasses. A cumulative dose reading over the 3-month (13-week) measurement period was obtained.

Patient dosimetry

The focus of this study was occupational eye lens dosimetry. Nonetheless, as staff exposure is strongly correlated to patient exposure,³⁵ a record of kerma-area product (KAP) (Gray centimetres squared) and fluoroscopy screening time (minutes and seconds) was recorded for each examination.

RESULTS

Annual occupational $H_p(3)$ doses in interventional radiology

The estimated annual doses to four interventional radiologists monitored with the eye lens dosimeters are shown in [Table 1](#). [Tables 2](#) and [3](#) show the calculated eye dose per procedure and eye dose per unit patient dose (in terms of KAP). 354 interventional procedures in total were monitored. Four interventional radiologists were issued with dosimeters, and at the end of the 3-month monitoring period, it was confirmed that all four staff wore the eye lens dosimeter while performing IR cases at this institution. In some IR cases, two of the radiologists were present in the X-ray room and the role of primary operator

would rotate between the two as required for teaching and training purposes.

The equivalent dose to the eye of an interventional radiologist ([Table 1](#)) was estimated to be between 7.1 and 44.9 mSv per annum (left eye) (based on measurements over 13 weeks extrapolated to a 50-week working year). In comparison, the dose to the right eye was estimated to be between 4.1 and 29 mSv. For individual staff, the dose to the left eye is higher in all cases as expected based on their positioning.

Normalized dose data, $H_p(3)$ per procedure and per unit kerma-area product

Patient dose data were recorded for each case and used to normalize the staff dose results by both workload (number of procedures, [Table 2](#)) and KAP ([Table 3](#)). An estimation of $H_p(3)$ per procedure (μSv) and $H_p(3)$ per KAP ($\mu\text{Sv Gy}^{-1} \text{cm}^{-2}$) was carried out for all four radiologists. $H_p(3)$ per procedure is a useful parameter to estimate and use in risk assessments, however, it is preferable to normalize eye dose by KAP as this quantity will allow adjustment based on the amount of radiation used.³⁶ For the eye dose per KAP, each individual staff member's cumulative $H_p(3)$ result was divided by the total patient KAP that they were exposed to during the monitoring period. It is likely that this is an overestimation of the total patient KAP, as, for some procedures, two radiologists were present at the patient's side, and in these cases, it has been assumed that they were both subject to the same level of exposure.

Individual eye doses per procedure are shown in [Table 2](#). On average, the dose to the eye (left and right eyes) for an interventional procedure was calculated to be 55 μSv . The average eye dose per unit KAP (left and right eyes) was calculated to be 1.2 $\mu\text{Sv Gy}^{-1} \text{cm}^{-2}$. These results are broadly comparable with values quoted in the literature,^{15,16} however, if left and right eye results are analysed separately, the dose per procedure and dose per unit KAP to the left eye will be higher. In addition, the accuracy of the KAP meter was considered, as this should be taken into account when normalizing data to KAP measurements (see the Discussion section below). Based on these factors, a range of 1.0–2.0 $\mu\text{Sv Gy}^{-1} \text{cm}^{-2}$ would be representative of eye dose per unit KAP from our study.

Table 1. Annual dose to lens of eye estimated for four interventional radiologists

Staff	Left/right eye	Annual ^a equivalent dose to eye lens, $H_p(3)$ (mSv)
Radiology fellow	Left	44.9
	Right	29.0
Consultant Radiologist 1	Left	30.9
	Right	14.5
Consultant Radiologist 2	Left	7.1
	Right	4.1
Consultant Radiologist 3	Left	16.0
	Right	10.7

^aAnnual doses based on extrapolation of 13-week study period to 50-week working year.

Table 2. Equivalent dose to lens of eye per procedure

Staff	Number of cases	Left/right eye	Equivalent dose to eye lens, $H_p(3)$ per interventional radiology procedure (μSv)
Radiology fellow	278	Left	42.0
		Right	27.1
Consultant Radiologist 1	56	Left	143.2
		Right	67.5
Consultant Radiologist 2	65	Left	28.5
		Right	16.5
Consultant Radiologist 3	61	Left	68.3
		Right	45.7

DISCUSSION

In this study, we have estimated lens dose to interventional radiologists in terms of $H_p(3)$ for the first time in an Irish hospital setting. Our findings will add to the growing literature regarding the potential for high ocular radiation doses to IR operators, particularly if no eye protection is used.

Interventional radiologists should be aware that key factors that will reduce eye doses in particular are (i) positioning the X-ray tube under the patient table, (ii) habitual use of ceiling-mounted screens during all procedures and (iii) consistent use of appropriately fitting lead-protective spectacles. These practices are well established in IR, yet the operators who participated in our study agreed that the attention given to eye dosimetry has encouraged them to revisit their own procedures and see how they can further protect themselves. In addition, one radiologist uses disposable protective patient drapes (along with consistent use of a ceiling-mounted screen) for complex cases, and his left eye dose per unit KAP was found to be the lowest of the four staff. Our study did not quantify the dose reduction attributable to the use of drapes, however, they have been shown to reduce operator eye dose; therefore, while their use adds some cost to the procedure, disposable protective drapes should be considered for complex procedures.^{3,37}

The results for the three consultant radiologists were compared with the eye dose measured for the fellow. The results show that

the fellow performs the greatest number of cases, which is typical of this stage of their training. As a result, this operator recorded the highest eye dose during the study. However, it is likely that this workload will change further into their career. The fellow performed the greatest number of cases, yet his eye dose per unit KAP (which will take variable levels of patient exposure into account) is lower than that of two of the consultant colleagues, indicating good radiation protection practice. It can be seen from the data that, in general, the consultant radiologist will perform more complex higher KAP procedures (with longer screening times), whereas the fellow typically performs more routine examinations to build skill and experience. Education and training should ensure that best radiation protection practice is maintained throughout all of these stages.

The eye doses quoted in this study are based on measurements taken over lead glasses, where they were worn. This was decided for pragmatic reasons largely because it is difficult to get the chosen eye dosimeter to fit securely and comfortably under lead glasses, particularly when the lead glasses are smaller sports style glasses that wrap around and fit close to the face. Furthermore, the exact placement for the dosimeter under lead glasses to measure protection factors in a clinical setting is an area of debate.

Manufacturer data on lead glasses may not report protection factors for all angles to the radiation source.³⁸ Recent literature

Table 3. Equivalent dose to eye lens per unit patient kerma-area product (KAP)

Staff	Left/right eye	Equivalent dose to eye lens, $H_p(3)$ per KAP ($\mu\text{Sv Gy}^{-1} \text{cm}^{-2}$)
Radiology fellow	Left	1.58
	Right	1.02
Consultant Radiologist 1	Left	1.79
	Right	0.84
Consultant Radiologist 2	Left	1.62
	Right	0.94
Consultant Radiologist 3	Left	1.31
	Right	0.87

on lead glasses highlights that protection from scatter from below and from the sides is highly variable and that protection factors vary considerably depending on the design of the glasses and for the left and right lenses.^{38–40} This is an area that requires further investigation.²⁰ As such, until protection factors can be accurately verified for lead glasses in clinical use, we have taken the approach that measurements over lead glasses are repeatable and reliable in terms of positioning, they are unobtrusive and certainly the lens dose below the glasses will be much lower. One radiologist in our study did not wear lead glasses and recorded an estimated annual dose to his left eye of 30.9 mSv. This is clearly well above the new ICRP limit. Lead glasses were advised as a matter of priority and have since been obtained for this radiologist.

The review of radiation protection practice showed that this dedicated interventional suite is well suited for its purpose; however, we identified opportunities for further optimization of eye doses. The X-ray room is of a suitable size, the equipment is only a few years old and is suitable for interventional procedures. The C-arm is predominantly used with the X-ray tube under the patient table (undercouch). PPE is worn consistently by all staff. A ceiling-mounted lead screen is available in the room; however, all operators confirmed that it is employed with variable frequency. It was also noted that there are ergonomic issues when using the ceiling-mounted screen for right-side (atypical or contralateral side) protection. To optimize upper body and eye protection, it is recommended that the ceiling-mounted screen is used on a consistent basis for all procedures, even those with expected short screening times. It is hoped that using it in this manner will encourage formation of habits and also be a good example of best practice for radiology staff involved in teaching and training.

Issues with personal monitoring compliance were noted during this study. Interventional radiologists at this centre are already issued with a second TLD to be worn at the neck or shoulder. This arrangement has been in place for many years. Despite this, the dose recorded on the majority of these second TLDs is extremely low, or zero, indicating that it is likely that staff are not complying with existing recommendations for dose monitoring. This is likely to persist, making it difficult to use current routine monitoring to obtain baseline data on eye doses in advance of the new ICRP limit being adopted into legislation and to assess compliance with the limit once it is introduced. It is important for compliance with any radiation dose monitoring method to make wearing conditions as comfortable as possible²⁰ and for clear instructions about positioning to be provided.

Some limitations noted in the authors' previous study¹¹ have been taken into account and efforts made to resolve them in this study. The period of monitoring in this work was extended from 6 weeks to 3 months (13 weeks) and the number of cases monitored was greater than that in the previous study. In addition, the calibration phantom used by RadCard for this study was a cylindrical head-shaped phantom. The number of staff

monitored in this study was relatively small but did encompass all of the relevant senior IR staff at the hospital. This study measured staff doses at one institution only. Some staff in our study have an additional IR workload that they perform at other institutions. The eye doses measured here do not take radiation doses from any other employment into account, which means that actual annual eye lens doses from all employers may further exceed the new ICRP limit. It is recommended that there is greater communication and sharing of personal dosimetry data amongst employers in order to protect the employee from cumulative doses exceeding annual limits.

Calibration of KAP meters for the geometries used in IR is known to be challenging⁴¹ and prone to error. The accuracy of the KAP meter on the system used in this study was assessed in accordance with recommended protocols as part of routine QA testing.^{28,29} Various configurations (table in and out of the beam) were assessed to take account of different clinical geometries. Results indicate KAP accuracy was close to the limit of 35%^{27,30} with the table out of the beam and exceeded the limit of 35% when the table was in the beam. In each case, the KAP was overestimating exposure. Correction factors of between 0.82 (table out of beam) and 0.67 (table in beam) were calculated based on QA results. Applying these to our data would bring the estimate of eye dose per unit KAP from $1.2 \mu\text{Sv Gy}^{-1} \text{cm}^{-2}$ to between 1.50 and $1.90 \mu\text{Sv Gy}^{-1} \text{cm}^{-2}$. Unfortunately, a simple correction factor cannot be applied to KAP data, as interventional cases typically involve a range of geometries, and the table is in the beam at some angles and out of the beam at others. However, based on our QA results, the actual KAP is likely to be lower than the displayed KAP, and as a consequence, eye dose per unit KAP is likely to be underestimated. Given the problems with KAP accuracy and varying geometry typical of interventional procedures, quoting a range rather than a single value for conversion factor may be appropriate: thus for our study quoting a range of $1.0\text{--}2.0 \mu\text{Sv Gy}^{-1} \text{cm}^{-2}$ rather than $1.2 \mu\text{Sv Gy}^{-1} \text{cm}^{-2}$ may provide a truer, if less precise, representation of possible eye dose.

CONCLUSION

Occupational eye doses from IR procedures have the potential to significantly exceed the new ICRP equivalent dose limit of 20 mSv per annum, particularly if no lead glasses are worn. An interventional radiologist may also exceed the threshold for Category A workers of 15 mSv to the lens of the eye, and this new threshold will apply once the new European directive is transposed into national legislation for EU member states.²⁴ Lead glasses should be considered an absolute requirement for operators carrying out interventional procedures. It is recommended that approximately 3 months is a suitable period for sample eye dose monitoring and a reasonable target to use for comparable caseloads. Eye doses to staff performing any fluoroscopically guided procedures should be measured and kept under review, particularly in light of the reduced ICRP and EU eye dose limit.

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REFERENCES

1. International Commission on Radiological Protection (ICRP). Avoidance of radiation injuries from medical interventional procedures. ICRP Publication 85. *Ann ICRP* 2000; **30**: 7–67.
2. ICRP. Radiological protection in fluoroscopically guided procedures performed outside the imaging department. ICRP Publication 117. *Ann ICRP* 2010; **40**: 1–102.
3. Faulkner K, Teunen D, eds. *Radiation protection in interventional radiology*. London, UK: British Institute of Radiology; 1995.
4. Miller DL, Vañó E, Bartal G, Balter S, Dixon R, Padovani R, et al. Cardiovascular and Interventional Radiology Society of Europe; Society of Interventional Radiology. Occupational radiation protection in interventional radiology: a joint guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology. *Cardiovasc Intervent Radiol* 2010; **33**: 230–9. doi: [10.1007/s00270-009-9756-7](https://doi.org/10.1007/s00270-009-9756-7)
5. Vañó E, González L, Guibelalde E, Fernández JM, Ten JJ. Radiation exposure to medical staff in interventional and cardiac radiology. *Br J Radiol* 1998; **71**: 954–60.
6. Bartal G, Vano E, Paulo G, Miller DL. Management of patient and staff radiation dose in interventional radiology: current concepts. *Cardiovasc Intervent Radiol* 2014; **37**: 289–98. doi: [10.1007/s00270-013-0685-0](https://doi.org/10.1007/s00270-013-0685-0)
7. Rehani MM, Vano E, Ciraj-Bjelac O, Kleiman NJ. Radiation and cataract. *Radiat Prot Dosimetry* 2011; **147**: 300–4. doi: [10.1093/rpd/ncr299](https://doi.org/10.1093/rpd/ncr299)
8. Dauer LT, Thornton RH, Solomon SB, St Germain J. Unprotected operator eye lens doses in oncologic interventional radiology are clinically significant: estimation from patient kerma-area-product data. *J Vasc Interv Radiol* 2010; **21**: 1859–61. doi: [10.1016/j.jvir.2010.08.006](https://doi.org/10.1016/j.jvir.2010.08.006)
9. Ciraj-Bjelac O, Rehani MM, Sim KH, Liew HB, Vano E, Kleiman NJ. Risk for radiation-induced cataract for staff in interventional cardiology: is there reason for concern? *Catheter Cardiovasc Interv* 2010; **76**: 826–34. doi: [10.1002/ccd.22670](https://doi.org/10.1002/ccd.22670)
10. Domienik J, Brodecki M, Carinou E, Donadille L, Jankowski J, Koukorava C, et al. Extremity and eye lens doses in interventional radiology and cardiology procedures: first results of the ORAMED project. *Radiat Prot Dosimetry* 2011; **144**: 442–7. doi: [10.1093/rpd/ncq508](https://doi.org/10.1093/rpd/ncq508)
11. O'Connor U, Gallagher A, Malone L, O'Reilly G. Occupational radiation dose to eyes from endoscopic retrograde cholangiopancreatography procedures in light of the revised eye lens dose limit from the International Commission on Radiological Protection. *Br J Radiol* 2013; **86**: 20120289. doi: [10.1259/bjr.20120289](https://doi.org/10.1259/bjr.20120289)
12. Jacob S, Donadille L, Maccia C, Bar O, Boveda S, Laurier D, et al. Eye lens radiation exposure to interventional cardiologists: a retrospective assessment of cumulative doses. *Radiat Prot Dosimetry* 2013; **153**: 282–93. doi: [10.1093/rpd/ncs116](https://doi.org/10.1093/rpd/ncs116)
13. Kim KP, Miller DL, Berrington de Gonzalez A, Balter S, Kleinerman RA, Ostroumova E, et al. Occupational radiation doses to operators performing fluoroscopically-guided procedures. *Health Phys* 2012; **103**: 80–99. doi: [10.1097/HP.0b013e31824dae76](https://doi.org/10.1097/HP.0b013e31824dae76)
14. Vano E, Kleiman NJ, Duran A, Romano-Miller M, Rehani MM. Radiation-associated lens opacities in catheterization personnel: results of a survey and direct assessments. *J Vasc Interv Radiol* 2013; **24**: 197–204. doi: [10.1016/j.jvir.2012.10.016](https://doi.org/10.1016/j.jvir.2012.10.016)
15. Martin CJ, Magee JS. Assessment of eye and body dose for interventional radiologists, cardiologists, and other interventional staff. *J Radiol Prot* 2013; **33**: 445–60. doi: [10.1088/0952-4746/33/2/445](https://doi.org/10.1088/0952-4746/33/2/445)
16. Vanhavere F, Carinou E, Gualdrini G, Clairand I, Sans Merce M, Ginjaume M, et al. ORAMED: optimisation of radiation protection for medical staff. 7th EURADOS report; 20–22 January 2011; Barcelona, Spain. Braunschweig, Germany: European Radiation Dosimetry, 2011.
17. ICRP. *Statement on tissue reactions*. Ottawa, Canada: ICRP; 2011.
18. ICRP. The 2007 recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Ann ICRP* 2007; **37**: 1–332.
19. Haskal ZJ. Get protected: the eyes have it. *J Vasc Interv Radiol* 2013; **24**: 205–6. doi: [10.1016/j.jvir.2012.11.003](https://doi.org/10.1016/j.jvir.2012.11.003)
20. Broughton J, Cantone MC, Ginjaume M, Shah B. Report of task group on the implications of the implementation of the ICRP recommendations for a revised dose limit to the lens of the eye. *J Radiol Prot* 2013; **33**: 855–68.
21. Martin CJ. What are the implications of the proposed revision of the eye dose limit for interventional operators? *Br J Radiol* 2011; **84**: 961–2. doi: [10.1259/bjr/17012242](https://doi.org/10.1259/bjr/17012242)
22. Martin CJ. A 20mSv dose limit for the eye: sense or no sense? *J Radiol Prot* 2011; **31**: 385–7. doi: [10.1088/0952-4746/31/4/E03](https://doi.org/10.1088/0952-4746/31/4/E03)
23. Englefield C. Is the new ICRP eye dose limit justified? *J Radiol Prot* 2011; **31**: 499–500. doi: [10.1088/0952-4746/31/4/L01](https://doi.org/10.1088/0952-4746/31/4/L01)
24. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. *Off J Eur Union* 2014; **57**: 13.
25. NHS Estates. *Facilities for diagnostic imaging and interventional radiology*. HBN 6. London, UK: Stationery Office; 2001.
26. Sutton DG, Martin CJ, Williams JR, Peet DJ. *Radiation shielding for diagnostic radiology. Report of a BIR working party*. 2nd edn. London, UK: British Institute of Radiology; 2012.
27. European Commission (EC). *Radiation protection 162, criteria for acceptability of medical radiological equipment used in diagnostic radiology, nuclear medicine and radiotherapy*. Luxembourg: Office for Official Publications of the European Communities; 2012.
28. Institute of Physics and Engineering in Medicine (IPEM). *Recommended standards for the routine performance testing of diagnostic X-ray imaging systems, report No. 91*. York, UK: IPEM; 2005.
29. Dosimetry Working Party of the Institute of Physical Sciences in Medicine, National Radiological Protection Board and College of Radiographers. *National protocol for patient dose measurements in diagnostic radiology*. Chilton, UK: National Radiological Protection Board; 1997.
30. International Electrotechnical Commission. *IEC 60601-2-43 Ed 2.0: medical electrical equipment. Part 2-43: particular requirements for the basic safety and essential performance of X-ray equipment for interventional procedures*. Geneva, Switzerland: IEC; 2010.
31. *Radiological Protection Act. Order SI. 125 (2000)*. Dublin, Ireland: The Stationery Office; 1990.
32. Bilski P, Bordy J-M, Daures J, Denozieri M, Fantuzzi E, Ferrari P, et al. The new EYE-D™ dosimeter for measurements of H_p(3) for medical staff. *Radiat Meas* 2011; **46**: 1239–42.
33. Gualdrini G, Mariotti F, Wach S, Bilski P, Denozieri M, Daures J, et al. Eye lens dosimetry: task 2 within the ORAMED

- project. *Radiat Prot Dosimetry* 2011; **144**: 473–7. doi: [10.1093/rpd/ncr011](https://doi.org/10.1093/rpd/ncr011)
34. Bordy JM, Gualdrini G, Daures J, Mariotti F. Principles for the design and calibration of radiation protection dosimeters for operational and protection quantities for eye lens dosimetry. *Radiat Prot Dosimetry* 2011; **144**: 257–61. doi: [10.1093/rpd/ncr010](https://doi.org/10.1093/rpd/ncr010)
35. Williams JR. The interdependence of staff and patient doses in interventional radiology. *Br J Radiol* 1997; **70**: 498–503.
36. Martin CJ. Personal dosimetry for interventional operators: when and how should monitoring be done? *Br J Radiol* 2011; **84**: 639–48. doi: [10.1259/bjr/24828606](https://doi.org/10.1259/bjr/24828606)
37. Thornton RH, Dauer LT, Altamirano JP, Alvarado KJ, St Germain J, Solomon SB. Comparing strategies for operator eye protection in the interventional radiology suite. *J Vasc Interv Radiol* 2010; **21**: 1703–7. doi: [10.1016/j.jvir.2010.07.019](https://doi.org/10.1016/j.jvir.2010.07.019)
38. Sturchio GM, Newcomb RD, Molella R, Varkey P, Hagen PT, Schueler BA. Protective eyewear selection for interventional fluoroscopy. *Health Phys* 2013; **104**: S11–16. doi: [10.1097/HP.0b013e318271b6a6](https://doi.org/10.1097/HP.0b013e318271b6a6)
39. McVey S, Sandison A, Sutton DG. An assessment of lead eyewear in interventional radiology. *J Radiol Prot* 2013; **33**: 647–59. doi: [10.1088/0952-4746/33/3/647](https://doi.org/10.1088/0952-4746/33/3/647)
40. Geber T, Gunnarsson M, Mattsson S. Eye lens dosimetry for interventional procedures—relation between the absorbed dose to the lens and dose at measurement positions. *Radiat Meas* 2011; **46**: 1248–51.
41. Järvinen H, Toroi P, Parviainen T, Turak O, Ginjaume M. Accuracy and convenience of the calibrations of field KAP meters in diagnostic radiology. Poster presentation EMAN workshop July 2012. [Accessed 22 January 2015.] Available from: http://www.eman-network.eu/IMG/pdf/Jarvinen_247986_STUK_jarvinen_A0_v2-1.pdf