Occupational exposure of the eye lens in the interventional procedures: how to assess and manage the radiation dose

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Abstract

The occupational exposure in interventional procedures is one of the areas in which increased eye lens exposure may occur. Accurate dosimetry is an important element to investigate the correlation of observed radiation effects with radiation dose, to verify the compliance with regulatory dose limits and it certainly contributes to optimized radiation protection. The objective of this work is to review the eye lens dose levels in clinical practice which may occur from the use of ionizing radiation. The use of a dedicated eye lens dosemeter is the recommended methodology, however, in practice, it cannot always be easily implemented. Alternatively, the eye lens dose could be assessed from measurements of other dosimetric quantities or other indirect parameters, such as the patient dose. The development of practical implementation of the monitoring of the eye lens doses and the use of adequate protective equipment still remains a challenge. The use of lead glasses with good fit to the face, appropriate lateral coverage and/or ceiling suspended screens is recommended in workplaces with potential high eye lens doses.

Keywords: eye lens, radiation dose, interventional procedures, occupational exposure, fluoroscopy

1. Introduction

Radiation-induced cataract was first reported in an experimental study in the early days of use of X-rays in medicine, only a year following the discovery of the X-rays [1]. Until recently, ocular exposure guidelines were based on the assumption that radiation cataract is a deterministic effect with a threshold dose of 2 Gy [2].

Following the results of a number of studies on radiation cataractogenesis, the International Commission on Radiological Protection (ICRP) reevaluated the dose limit for the eye lens, based on the new findings that, at relatively high exposures (>1 Gy), lens opacities may occur within a few years; however, at lower doses and dose rates, similar to those that might be encountered in occupational practice in medicine, visually disabling cataracts may occur over many years [3]. It has been shown that the duration of the latency period is inversely dependent on dose and the new threshold ranges from zero to 0.8 Gy [4]. Consequently, ICRP has set the threshold dose for radiation-induced eye cataracts to be around 0.5 Gy for both acute and fractionated exposures [2] and recommended a reduction of the dose limit for the eye lens for workers from 150 mSv to 20 mSv per year [2]. This new 7.5-fold reduction has become the subject of intensive scientific debate, including authors who justified [5,6] and challenged [7] this issue. In the light of recent epidemiological evidence, some authors suggested that cataract should be classified as a stochastic effect [8]. As new evidence on eye lens injuries associated with exposure to ionizing radiation have become available, eye lens dosimetry has also become a very active research area [9-12].

The objective of this work is to review the eye lens dose levels in clinical practice which may occur from the use of ionizing radiation in fluoroscopy guided interventional procedures. The current and potential eye lens dose monitoring arrangements and dose assessment methods including the impact of potential dose reduction factors are also discussed.

2. Eye lens injuries due to occupational exposure in interventional procedures

Among categories of occupational exposure to ionizing radiation, occupational exposure in medicine is one of the areas in which increased eye lens exposure is likely to occur. There are numerous evidences on the high eye dose levels in fluoroscopy guided procedures in radiology, cardiology [13,14] and other areas as orthopedics surgery, urology, anesthesiology, vascular surgery, CT fluoroscopy and gastroenterology [15-23].

A pilot study performed on interventional radiologists reported that the prevalence and severity of post subcapsular cataract (PSC) was associated with age and years of practice [24], whereas assessed annual eye lens dose ranged from 0.45 to 0.90 Sv. Approximately half of those examined had early lens changes including posterior dots and vacuoles associated with radiation exposure [2]. Recently, other pilot studies in collaboration with the International Atomic Energy Agency (IAEA) and professional cardiology societies have investigated the relationship between such occupational exposure and subsequent eye lens changes [3, 9-11]. The three studies included a detailed questionnaire regarding exposure history as well as a comprehensive dilated slit-lamp examination of interventional cardiologists, nurses and technicians working in cardiac catheterization laboratories. PSC opacities were found in 38% of examined cardiologists and 21% of paramedical personnel, compared with 12% of controls. Cumulative occupational mean eye lens doses were estimated at 6.0 Sv for cardiologists and 1.5 Sv for associated staff when eye lens protection was not used [10-11]. A strong dose–response relationship between occupational X-ray exposure and detectable posterior eye lens changes in interventional cardiologists was reported. Another large study included prospective analysis accompanied by a 20-year follow-up of more than 35000 radiological technologists assessed the risk for eye lens opacification and cataract [25]. The study provided evidence that exposure to relatively low doses of ionizing radiation (lifetime dose up to 60 mGy) may be harmful to the eye lens and increases the long-term risk of cataract formation. The findings suggested that likelihood of cataract formation increases with increasing exposure to ionizing radiation with no apparent threshold level.

The above mentioned studies highlighted the need to assess eye lens dose in clinical practice. However, one of their main limitations is the large uncertainty in occupational doses assessment.

3. Approaches in eye lens dose assessment in clinical practice

Contrary to the whole body dosimetry, eye lens dosimetry is not currently well established and numerous studies were carried out to investigate various aspects of eye dosimetry, such as the development of new dedicated eye dosemeters and calibration procedures [10,12, 26-30]. Furthermore, clinical studies have been conducted to discuss the methodology of the assessment of the eye lens dose levels, to investigate the monitoring arrangements using different types of dosemeters, to study correlations of eye lens dose with patient dose indices and to perform retrospective eye lens dose assessment [17,18,20,22,26].

3.1 Eye lens dose assessment

According to ICRU, the operational quantity, personal dose equivalent at depth 3mm, Hp(3), is the most appropriate quantity to monitor the eye lens dose as the lens is covered by about 3 mm of soft tissue [31]. Recently, several important initiatives were undertaken to develop eye lens dosemeters calibrated in terms of Hp(3). Generally they employ a thermoluminescent chip as passive dosemeter and some material covering it to mimic the necessary thickness to assure the coherence with the respective quantity definition [30, 32-34]. All these new devices should conform to suitable calibration procedures and type tests [29]. When a specific dosemeter is not available, Hp(3) can be estimated through dosemeters calibrated in terms of Hp(10) and Hp(0.07) through proper correction factors, [6, 28,35].

It is important to underline that such evaluation can be quite inaccurate; as an example, if a collar dosemeter is used to evaluate the eye lens dose, the correction factor can vary from 0.4 [36] to 1.4 [37], due to the difference in radiation field characterizing the measuring point where the dosemeter is placed, with respect to the operator’s head.

However, if the single whole body dosemeter is worn under the lead apron, it is impossible to determine the eye lens dose [9,10].

It has been demonstrated that active personal dosemeters can be an effective tool for reduction of occupational doses [38-40], however, they must meet certain requirements to be suitable for the assessment of the occupational exposure in medical applications [39,41].

3.2 Alternative approaches for eye lens dose assessment

An approach based on kerma-area product (P_{KA}) has been used to perform, for example, a retrospective dosimetry for the medical staff. The accuracy of the assessed dose is affected by the quality of the provided information and by the assumptions made [18,42].

The difficulties in establishing a good correlation between the P_{KA} and medical staff eye lens dose are due to a number of influencing factors such as tube orientation, beam collimation, access route, working practices and use of protective devices (eye lens lead glasses, lead shielding, etc). Therefore, at present, there is no clear consensus in the literature about the use of correlation factors to convert patient dose to eye lens dose to the staff. However, tabulated data of normalized eye lens dose per unit P_{KA} , can be found in [18].

Another alternative is to assess eye lens dose from the dose evaluated in a “typical” procedure and multiply it by the number of procedures performed by the worker. Because of the variability of the doses evaluated during different practices [42] such methodology should be used carefully. The estimated doses can be corrected, when appropriate, by a dose reduction factor if protective tools are used [9,10].

4. Current status of eye lens dose levels

Available clinical studies have provided a valuable input to recent knowledge about methods for eye lens dose assessment and assessed dose levels. However, there is a huge variety in both dosimetry approaches and reported results, which makes comparison and overall use of the available dosimetric data very difficult. Eye lens doses were assessed in various clinical set-ups, using both measurements on phantoms, as scattering medium and operator, and measurements on operators during various interventional procedures. Information about routine use of eye lens dosimetry is fairly lacking. The dose data is available mainly for the first operator and occasionally for other staff members such as nurses and radiographers. As expected, the reported range of doses is huge, from few µSv to few mSv, as presented in Table 1 and Table 2. These dose levels are associated with different arrangements of personal and collective protective tools, such as lead glasses, ceiling suspended screens, disposable pads and their combinations.

Unprotected eye lens dose values vary up to 250- fold for different fluoroscopic views [43] and reported eye lens dose values per procedure range from less than 0.1 to 1100 µSv [44]. Multiple acquisition modes are used in clinical conditions [45, 46] in which dose rate at the level of operator’s eye ranges from 1-22 mSv/h (fluoroscopy) to 12-235 mSv/h (DSA- digital subtraction angiography). Eye lens doses for seven interventional radiology systems were measured using phantoms simulating patients 16–28 cm in thickness undergoing low-, medium and high-mode fluoroscopy, cine cardiac imaging and DSA [47]. Mean dose rates to the eye lens during fluoroscopy were between 6.0 and 35 mSv per min for the low- and high-dose scenarios, respectively. Similar estimations were performed for hepatic chemoembolisation, iliac angioplasty, pelvic embolisation, and transjugular intrahepatic portosystemic shunt creation. Assessed eye lens doses for these procedures ranged from 0.25 to 3.72 mSv per procedure when protection was not used and from 11 to 330 µSv with use of protective tools [47].

5. Radiation protection of the eye lens

The factors influencing the eye lens dose can be grouped into few main categories: beam orientation, access route, fluoroscopy settings and operating mode, use of protective tools (shielding screens, glasses) and finally factors related to the operator such as workload, skill and training [42]. Multiple studies, based on Monte Carlo techniques or measurements performed either on phantoms or on operators have stressed the importance of protective equipment, such as ceiling suspended shields and lead glasses [26,47,61-63]. In general, a typical dose reduction factor for a single shielding tool is 5-25 and for combination of tools is 25 or more, even up to a factor of 1000 [63,64].

The use of lead glasses provides effective protection for the eye lens, but there are issues of comfort and practicality. The glasses are usually heavy and may slip down from the bridge of the nose, which creates a particular problem when performing sterile procedures [16]. Moreover, their efficiency as protective tool strongly depends on their orientation with respect to the scattered radiation and their design while their transmission for oblique projections can be up to 90% [37]. The dose reduction factor ranges from 1.4 to 10 [43,62]. The air gap between the glasses and the eyes was found to be the primary source of scattered radiation reaching the eyes [37,62,64]. Therefore, larger glasses with better lateral coverage provide better dose reduction.

Highest exposure to the operator is associated with left anterior oblique (LAO) and cranial projection [21,42]. In particular, LAO projection, which is common in clinical practice, delivers 3-7 times higher dose to the eyes compared to right anterior oblique (RAO) projection. In addition, over-couch X-ray tube geometry delivers, on average, 12 (range 2-27) times higher dose to the operator's eye compared to the undercouch geometry.

6. Eye lens monitoring arrangements

With introduction of the new dose limit for the eye lens, the number of situations requiring specific eye lens monitoring is likely to increase [6]. Prior to undertaking routine individual monitoring for the eye lens, the dose levels should be estimated in order to determine which method, if any, should be used as well as the length of monitoring period [6]. Routine monitoring of the eye lens dose should be undertaken if the provisional estimation indicates that the annual equivalent dose to the eye lens is likely to exceed a certain dose level, such as 5-6 mSv (i.e. 3/10 of the dose limit)[6,7].. To undertake a pilot individual monitoring assessment is one of the best approaches to identify workers that require eye lens monitoring and to decide on the best dosimetry system; for instance, eye lens monitoring may be necessary in interventional radiology and cardiology departments. Staff involved in fluoroscopy used outside the imaging departments may also be considered as workers to be monitored for eye lens dose monitoring, in particular in the case of high workloads.

The position of a dedicated eye lens dosemeter should be as close as possible to the eye, preferably in contact with the skin and the detector should face the radiation source. In particular, in interventional procedures, the dosemeter should be on the side closest to the X-ray tube /patient and when protective lead glasses or face masks are used, the dosemeter should be worn behind these tools, which is not very convenient in most cases. Alternatively, dosemeter could be worn above the protection and appropriate correction must be applied.

When the use of a dedicated eye lens dosemeter is impractical, the eye lens dose can be alternatively evaluated using a dosemeter at trunk or thyroid level above the protection tools [14]. A correction factor of 0.75 to estimate the eye lens dose from this unprotected dosemeter is recommended by several authors [26]. This method for the estimation of the eye lens doses is associated with large uncertainty and great caution is needed if the measured dose levels are close to the dose limits.

In the absence of any dose measurement, the eye lens dose could be estimated from patient dose, using the conversion from P_{KA} to eye lens dose of 1µSv/Gycm^2, when protective tools are used, and 10 µSv/Gycm^2 for situations without protection. Indeed, the P_{KA} provides an ideal patient dose quantity, since it gives a measure of the total radiation emitted, which is linked to the amount of scatter to which operators are exposed. However, in this case the uncertainty and variability is even larger (Tables 1 and 2).

7. Conclusions and recommendations

The paper presented a comprehensive review of the eye lens dose levels in clinical practice related to the use of ionizing radiation in interventional workplaces, possible eye lens dose monitoring arrangements and dose assessment methods including the impact of potential dose reduction factors.

Whenever direct monitoring of eye lens dose in terms of $H_p(3)$ is not available, the eye lens dose could be estimated using other available methods, as whole body dosemeters or patient dose indices; however, an extra uncertainty factor should be considered.

The available dosimetry data shows large variations in eye lens doses that can be related to the examination technique and/or the use of protective tools. Changes in working practices are required to keep eye lens dose within the new limit. A way to optimise the eye lens exposure is to consider an adequate geometry and to make use of the adequate protective equipment. For example, LAO projection should be avoided, if possible from medical point of view. Lead glasses with a good fit to the face, good lateral coverage and/or ceiling suspended screens should be used. The protective tools are advised for staff performing interventional procedures in radiology and cardiology, as well as for personnel using fluoroscopy outside imaging departments.

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Table 1. Typical measured eye lens dose levels and eye lens dose normalized to respective kerma-area product (P_{KA}) in various interventional radiology procedures and other procedures performed outside radiology departments.

Type of procedure	Eye lens dose per procedure (µSv)	Eyelens dose/ P_{KA} (µSv/(Gycm^2))	Measurement Details	Reference
Various Interventional radiology, procedures, with protective tools	47 (0-557)	1.19	, 25 procedures, few cases per procedures	[20]
Hepatic chemoembolization	270-1070/16 -64 (unprotected/protected)	-	With phantom, different acquisition modes	[47]
Iliac angioplasty	250-1110/15-66 (unprotected/protected)	-		[47]
Neuroembolization (head)	1380-5600/83-336 (unprotected/protected)	-		[47]
TIPS creation	410-1860/25-112 (unprotected/protected)	-		[47]
Anesthethesiology, various procedures	44	0.278-1.305	+ simulations, 31 case	[48]
Gastroeneterology, ERCP	90/10 (unprotected, overcouch/undercouch)	0.98-1.4/14-21 (unprotected, undercouch/overcouch)	, 62 cases	[49]
Vascular surgery, EVAR	10 (unprotected)	-	, 149 cases	[50]
Urology, various procedures	26(unprotected)	-	s, 20 cases	[51]
Urology, percutaneous renal calculus removal	100 (unprotected)	-	, 102 cases	[52]
Orthopedic surgery, various procedures	50 (unprotected)	-	, 204 cases	[53]
CT fluoroscopy, various procedures	7-48	-	, 220 cases	[23]
CT guided interventions	3.5 (0.2–39.9)	-	, 89 cases	[22]
Various procedures	-	0.47-0.84	, 1300 cases	[54]

Table 2. Typical measured eye lens dose levels and eye lens dose normalized to respective kerma-area product (P_{KA}) in interventional cardiology procedures

Type of procedure	Eye lens dose per procedure (μSv)	Eye lens dose/ P_{KA} (μSv/(Gycm^2))	Measurements Details	Reference
Interventional cardiology, first operator, various procedures, dose with protective tools	121±84 (4.5-370)	0.94±0.61	, 35 cases	[18]
	52±77 (4-644)	1.0	, 646 cases	[55]
	3.3-1040	-	Literature survey, phantom and clinical, 3-1532 cases per survey	[44]
	170 (53-460)	3.3-6.0	, 83 cases	[56]
	13 (0-61)	1.37	, 7 cases	[20]
	72 (32-107)	0.86 (0.46-1.25)	, 166 cases	[19]
	66 (5-439)	1.0	Literature survey, 26 studies included	[16]
	-	1.0	, 1300 cases	[42]
	15-53	-	, 164 cases	[57]
	23 (10-230)	0.4 (0.2-2.6)	, 144 cases	[58]
	35±32 (pre year)	4.2	using collar dosemeter	[59]
Interventional cardiology, first operator, various procedures, dose without protective tools	-	10-11	, EPD, 1969 cases	[60]
	300-2500	3.2-3.4	Multicentric phantom study, different complexities	[46]