UTILIZING MONTE CARLO SIMULATIONS IN ESTIMATION OF OCCUPATIONAL EYE LENS DOSE BASED ON WHOLE BODY DOSIMETER IN INTERVENTIONAL CARDIOLOGY AND RADIOLOGY

by

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Medical staff performing interventional procedures in cardiology and radiology is considered to be a professional group exposed to high doses of ionizing radiation. With new epidemiological evidences and recently reduced eye lens dose limit, dose assessment to the lens of the eye, in the interventional cardiology, has become one of the most challenging research topics. This paper presents results of the eye lens dose assessment in interventional cardiology obtained by means of the computational dosimetry. Since placing and wearing the dedicated eye lens dosimeter is encumbering for the staff, Monte Carlo simulation provides an accurate and efficient method for obtaining an indication of doses to the eye lenses. Eye lens doses were estimated for three typical beam projections (PA, LAO, and RAO) and tube voltages ranging from 80 kV to 110 kV, with different protective equipment setups, for the first operator position. Simulations were carried out using MCNPX code. Results revealed that a whole body dosimeter worn at the thyroid center position gives the best estimate of the eye lens dose with a spread from 11 % to 18 % for the left eye. Corresponding average conversion coefficient from whole body to the eye lens dose is estimated to be 0.18.

Key words: eye lens dose, interventional cardiology, X-ray, scattered radiation, Monte Carlo method

INTRODUCTION

The use of X-rays for interventional procedures in cardiology and radiology has increased in recent years. The number of performed procedures is increasing along with their complexity and exposure time during these procedures. The radiation dose to the staff is significantly higher than exposure of staff performing common diagnostic procedures [1-3]. Because of that, there is a need for the adequate protection of workers, in interventional cardiology (IC) and interventional radiology (IR), from ionizing radiation.

The eye lens is more sensitive to radiation than previously considered. Numerous epidemiological studies, conducted over the past decade, have indicated that radiation damage to the eye can occur at dose levels far lower than the previously established threshold [4], especially in the case of chronic and prolonged exposure to small doses, as is the case with professionally exposure in medicine [5-8]. Until recently, the occurrence of cataract was considered a typical tissue reaction, with an equivalent dose threshold of 5 Gy in the case of chronic exposure and 2 Gy in the case of acute exposures [4, 9]. However, based on new epidemiological evidence, the International Commission on Radiological Protection (ICRP) reduced the dose threshold for the effects of ionizing radiation on the eye lens at 0.5 Gy, bearing in mind the latent period and the fact that cataract can occur at far lower doses than previously established threshold, especially in the case of chronic exposure to relatively small doses.

A new dose threshold for tissue reactions also resulted in reduction of the annual dose limit for eye lens from 150 mSv to 20 mSv [10]. It has been shown that for certain categories of professionally exposed persons in medicine, the dose threshold may be exceeded if appropriate personal and collective protective tools are not used, or if the use of these devices is not adequate [11]. Bearing in mind the new exposure limit, dosimetry for eye lens has become one of the most important research topics in the field of radiation protection, challenging the scientific community for development of new calibration procedures, eye lens dosimeters and eye lens monitoring procedures, in order to implement them in workplace situations with sufficient level of practicality and accuracy [11-16].

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During interventional procedures the medical staff wears a lead apron, thus, two whole body dosimeters (one above, and one below the apron) are needed for correct estimation of effective dose (so called double dosimetry method). As the torso area is shielded with lead apron, extremities are more exposed to direct and scattered radiation thus, in some cases, extremity dosimeters are also used for the staff members dose monitoring. Moreover, for protection purposes, the staff in interventional procedures is asked to wear lead thyroid collar and to use ceiling suspended shield and/or lead glasses. Therefore, in such complex work environment, there is a need to establish a simple and practical eye lens monitoring procedure, without increasing the number of dosimeters worn by the medical staff.

Many options are available and their advantages and disadvantages are widely discussed in the literature [16, 17]. One of the options is conversions of the whole body dose, measured by a whole body dosimeter, to the eye lens dose. In particular, if the measurements of dose using a whole body dosimeters, worn outside the lead apron (or dosimeters worn on thyroid collar) from medical staff is available, then the dose to the eye lens can be calculated using a conversion factor from the whole body to the eye lens dose, for different setups, taking into account reduction factors for the shielding tools.

Monte Carlo method provides a way to get an estimatione of doses to the eye lens simulating the work environment of the staff involved in interventional procedures [15, 18]. Parameters that affect dose to the workers, beside the number of procedures and exposure time in a single procedure, can also be the geometry, collimation, the distance of the image intensifier, distribution of scatter radiation (projection of X-ray tube).

In the present study, Monte Carlo simulations were used to derive conversion factors in order to correlate eye lens doses with the whole body and thyroid doses in the conditions that reflect a typical clinical environment, during fluoroscopically guided interventional procedures in cardiology or radiology.

MATERIALS AND METHODS

Monte Carlo simulations were performed using MCNPX code [19]. Geometry for simulations included X-ray source, body phantoms for first operator and patient, tabletop and flat-panel detector, personal and collective protective equipment, and thermoluminescent dosimeters (TLD) necessary to calculate conversion factors.

X-ray tube was modeled as a photon point source directed in cone of beams. Source was positioned at a distance of 120 cm from flat panel detector and 60 cm below tabletop, with the center line of the cone going through the center of the patient torso

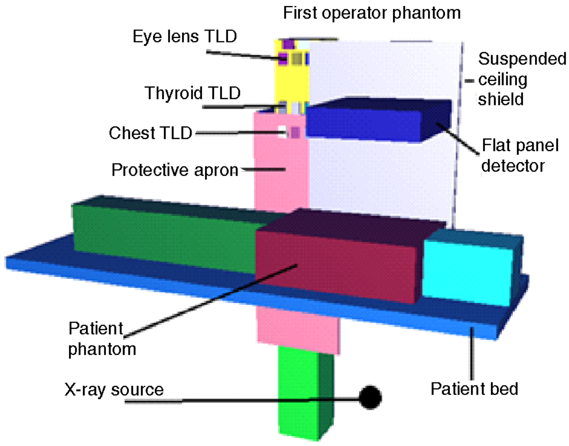

Figure 1. Schematic presentation of the PA geometry used for Monte Carlo simulation

phantom and center of the flat panel detector. Half-angle for the cone of beams was calculated so that the field of view would cover the entire patient torso phantom. X-ray tube spectrum was obtained using Spectrum processor described in IPEM Report 78 [20], for tube voltages ranging from 80 kV to 110 kV (with 10 kV increment).

Both first operator's and patient's body were modeled as a 180 cm   40 cm   20 cm phantom of muscle tissue separated in three sections: head, torso and legs. Protective lead apron, 0.5 mm thick, was modeled to cover the torso and one third of the legs of the first operator. Material for protective glasses and ceiling suspended shield was lead glass with such dimensions to cover eye region and torso of the first operator, respectively, both with lead equivalence of 0.5 mm. TLD used in simulations were divided into three groups: (1) five were positioned in front of the eyes (one is placed between eyes, two on the outside and two above the eyes), (2) three were positioned at the height of thyroid and (3) three at the chest level. TLD were modeled as 5 cm   4 cm   1 cm parallelepiped filled with ^{6}LiF [21]. All material components and densities are given in literature [22].

Simulations included three projections of the X-ray tube. Projections were posterior anterior (PA) in which the tube is directly beneath the patient and two anterior oblique projections, left (LAO) and right (RAO), in which the X-ray tube is positioned to +45 and –45 degrees. Following combinations of protective equipment (PE) were simulated: (1) both ceiling suspended protection panel and protective glasses are applied, (2) only ceiling suspended protection panel, (3) only protective glasses, and (4) none of the protective tools.

Results of the simulations were obtained using F6 tally for photons. F6 tally provides the user with energy deposition averaged over cells in terms of MeVg^{-1}, which can easily be converted to mSv. Number of simulated particles was 300 million which ensured that relative error was satisfactory low and that tallies passed all statistical tests.

Dose to each eye lens is estimated as an average of three tallies in cells that simulate TLD positioned to surround the eye. Then the ratio between the eye lens dose and the dose simulated by six tallies, positioned on chest and thyroid, was calculated.

Finally, the average value of these ratios (averaged on the total number of simulations), and the spread to the mean ratio (coefficient of variance) were calculated considering all configurations.

To validate Monte Carlo simulations and calculated Hp(3)/Hp(10) ratio, a set of measurements was performed using ionization chamber calibrated in term of H*(10) at the level of chest, thyroid and eyes.

RESULTS

The best correlation is given by the lowest spread on eye lens dose and average whole body dose ratio.

Table 1 shows reduction factor for the doses to the lenses of the eye, for the first operator, for three typical projections and different combinations of the protective tools.

In tab. 2 ratios and spreads for conversion from position of whole body dosimeter to the position of the eye lens dosimeter, are given.

DISCUSSION

The factors influencing the eye lens dose can be grouped into a 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 [16]. As presented in tab. 1, there are evident differences between the effect of protective equipment to the left and to the right eye lens, depend-

Table 1. Reduction factor for the doses to the lens of the eye for the first operator for three typical projections and different combinations of the protective tools

Projection*		PA		RAO		LAO	
Tube voltage	Protective equipment	Eye lens		Eye lens		Eye lens	
		Left	Right	Left	Right	Left	Right
80	Glasses	3	4	2	2	4	5
	Ceiling shield	52	2	70	5	3	1
	Both	134	8	166	15	16	8
90	Glasses	3	4	2	2	4	5
	Ceiling shield	46	2	73	5	3	1
	Both	121	8	178	16	21	6
100	Glasses	3	4	2	3	4	5
	Ceiling shield	49	2	51	4	4	1
	Both	140	8	94	15	13	7
110	Glasses	3	4	2	3	4	5
	Ceiling shield	47	2	60	4	4	1
	Both	120	7	112	16	17	6

* Projection: PA – posterior anterior, RAO – right anterior oblique, LAO – left anterior oblique

Table 2. Ratio and spread for conversion from position of whole body dosimeter to the position of the eye lens dosimeter

			TLD position*					
Tube voltage	Eye lens		TL	TC	TR	CL	CC	CR
80	Left	Ratio	0.65	0.16	0.12	0.58	0.18	0.13
		Spread	0.41	0.55	0.99	0.25	0.50	0.94
	Right	Ratio	2.64	0.45	0.29	2.20	0.55	0.33
		Spread	0.85	0.14	0.31	0.73	0.20	0.26
90	Left	Ratio	0.70	0.19	0.13	0.76	0.21	0.15
		Spread	0.25	0.45	0.91	0.31	0.41	0.90
	Right	Ratio	2.33	0.50	0.31	2.54	0.56	0.35
		Spread	0.63	0.11	0.38	0.68	0.12	0.37
100	Left	Ratio	0.75	0.18	0.12	0.76	0.20	0.16
		Spread	0.25	0.39	0.84	0.28	0.37	0.94
	Right	Ratio	2.47	0.49	0.29	2.55	0.55	0.36
		Spread	0.66	0.15	0.29	0.71	0.18	0.40
110	Left	Ratio	0.84	0.20	0.13	0.79	0.22	0.17
		Spread	0.25	0.44	0.85	0.18	0.41	0.93
	Right	Ratio	2.84	0.53	0.30	2.58	0.57	0.37
		Spread	0.73	0.18	0.28	0.64	0.17	0.37

* Position: first letter: T – thyroid, C – chest; second letter: L – left, C – center, R – right

ing on the origin of scatter radiation. The origin of scattered radiation reaching the eyes was proved to be a reason for variation in the protection efficiency of different eyewear models [15]. In many interventional procedures, in particular hemodynamic interventional cardiology procedures, left eye is more irradiated due to the fact that the source of scatter radiation is positioned at the left side of the first operator. It is obvious from the results, that for the position of the first operator, greater reduction in dose is accomplished with proper positioning of the ceiling suspended shield (reduction factor of 3-70) than by protective glasses alone (reduction factor of 2-5). However, combined use of protective equipment still gives the greatest reduction factor, from 13 to 178, for all projections and voltages of the X-ray tube. In addition, the effect of the lead glasses depends on the operator's head orientation, which is related to the position of the monitors in the X-ray room. The doses were found to be lower, for both left and right eyes, when the operator is facing away from the X-ray tube [23].

For the left eye lens, results indicate two possible positions for whole body dosimeter, which would give the best estimate of the eye lens dose. Both thyroid left and chest left positions have lowest spread for two out of four tube voltages. For thyroid left position the spread is 25 %, for both tube voltages, while for the chest, at the left position, the spread is 25 % and 18 %, for two tube voltages, giving this position advantage for eye lens dose estimate. For the right eye lens, results also indicate two possible positions for the whole body dosimeter, which would give the reasonable estimate of the eye lens dose. However, thyroid central position has the lowest spread for three out of four tube voltages and for fourth tube voltage the center chest position is better by 1 %, which in terms of doses involved in interventional cardiology and radiology, is negligible.

Over the 80 kV-110 kV tube voltage range, typically used in interventional procedures, the results indicate that the whole body dosimeter, worn at the thyroid center position, gives the best estimate of the eye lens dose, with spread from 11 % to 18 % for left eye lens and an average conversion coefficient of 0.18. The spread for right eye ranged from 39 % to 55 %, whereas the average conversion coefficient was estimated to 0.49. Study carried out by Farah *et al*. [14] also showed that TLD, worn at the thyroid level, gives the best estimate of the eye lens dose, with differences in ratio values due to Monte Carlo simulation approximations used in this study.

CONCLUSION

In this work, the efficiency of different combinations of protective equipment used in interventional procedures is presented. The efficiency was assessed for different X-ray beam projections. In addition, a computational algorithm for eye lens dose assessment, using whole body dose values, is presented. From the presented results, choosing the center position at the height of the thyroid, would give the best estimate for the eye lens dose, which can be then calculated using conversion factor for that position and reduction factor for the combination of applied protective equipment.

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AUTHORS' CONTRIBUTIONS

P. M. Božović designed and performed the numerical experiment, including data analysis and figures' preparation. Manuscript was written by P. M. Božović and partly O. F. Ciraj-Bjelac and critically reviewed by J. S. Stanković Petrović. All authors analyzed and discussed the results and reviewed the manuscript.

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ПРИМЕНА МОНТЕ КАРЛО СИМУЛАЦИЈА У ПРОЦЕНИ ДОЗЕ ЗА ОЧНО СОЧИВО ПРОФЕСИОНАЛНО ИЗЛОЖЕНИХ ЛИЦА У ИНТЕРВЕНТНОЈ КАРДИОЛОГИЈИ И РАДИОЛОГИЈИ НА ОСНОВУ ДОЗИМЕТРА ЗА ЦЕЛО ТЕЛО

Особље које обавља интервентне процедуре у кардиологији и радиологији сматра се професионалном групом изложеном високим дозама јонизујућег зрачења. Са новим епидемиолошким сазнањима и недавно смањеном граничном вредношћу дозе за очно сочиво, процена дозе за очно сочиво у интервентној кардиологији постала је једна од најизазовнијих тема истраживања. У овом раду су приказани резултати процене дозе за очно сочиво у интервентној кардиологији применом метода компјутерске дозиметрије. С обзиром да постављање и ношење наменског дозиметра за очно сочиво запосленима представља оптерећење у раду, Монте Карло симулације могу пружити тачну и ефикасну методу за добијање индикације о дозама за очна сочива. Дозе за очна сочива процењене су за три типичне пројекције рендгенске цеви (RA, LAO и RAO) и за вредности високог напона од 80 kV до 110 kV са различитим комбинацијама заштитне опреме за интервентног кардиолога. Симулације су урађене применом програмског пакета MCNPX. Резултати процене дозе показују да је позиција која даје најбољу процену доза за оба очна сочива централна позиција у висини штитне жлезде.

Кључне речи: доза за очно сочиво, интервентна кардиологија, X-*зрачење, расејано зрачење, Монте Карло метода*