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Eye lens exposure of personnel performing endovascular aortic aneurism repair (EVAR)

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ABSTRACT

Background: Endovascular aortic aneurism repair (EVAR) is an interventional procedure where endoscopic equipment¸ navigated by fluoroscopy, is used to treat an abdominal aneurism. There is growing concern regarding radiation exposure among operators due to the increasing number of procedures. ***Materials and Methods:*** Present study investigated eye lens exposure and dose distribution in terms of eye lens dose (ELD) equivalent Hp (3) over a set of three dosemeters for a team of three operators, when operators are occupying both sides of the patient table. Dose dependence on head rotation and the effect of shielding were assessed through Monte Carlo simulation. ***Results:*** All three positions were identified as high dose positions. Dose distribution over the forehead for all 3 operators was found to be uniform. Of all observed patient exposure parameters, dose area product (DAP) showed the highest degree of correlation to ELD. Dose and dose distribution depends on the operators' standing position and head rotation, further explaining observed correlations. Average value of dose reduction factor of ceiling suspended screen was found to be 95. ***Conclusion:*** When performing the procedure as a team, the operators' standing positions or head orientation will strongly influence eye lens exposure and its dependence on patient exposure parameters. Values of DAP could be useful as a parameter for monitoring eye lens exposure during EVAR. The use of a suspended shield is strongly advised.

INTRODUCTION

Endovascular aortic aneurism repair (EVAR) is an interventional procedure using fluoroscopy to navigate catheters, guide wires and stent-graft through large blood vessels in the abdomen, with the aim to prevent aortic rupture and life-threatening situation. Given the advantages compared to open surgery alternatives, the number of such procedures has been steadily increasing over the decades, at the cost of increased use of ionizing radiation. Growing concern in the past decade among vascular surgeons regarding radiation doses is evidenced by a number of papers investigating occupational radiation exposure [1-4]. Even regional surgical societies recognized the importance of radiation protection through clinical guidelines on radiation safety [5]. Most studies report exposure of the lead operator performing EVAR, while only a few investigate the exposure of assistants [1, 6, 7] where their role and position are unclear. Even less report on the assistant's eye lens exposure [8]. Some [9] state that increasing the amount of data available, the need to follow "as low as reasonably achievable" (ALARA) principle becomes clearer, expressing the need for more data based on measurements, rather than simulations.

Many factors influence the exposure of both patient and personnel, such as technique and protocols, patient related parameters, and the existence and use of protective equipment [1, 10]. Availability of protective equipment is diverse, and even when available, some elements of protective equipment may not be used properly or not at all [2, 11], leading to higher levels of the operator's exposure.

The aim of this study was to improve local radiation protection practice through investigating the exposure of the team of 3 operators working together, on both sides of the patient table, to determine eye lens dose (ELD) distribution for each operator and to investigate correlation of dose to patient exposure parameters, and finally to provide means for eye lens dose monitoring when limited resources are available.

This study examines dose and dose distribution over the forehead for operators on both sides of the patient table, and the effect of the operators' usual head rotation on dose, providing the data not available elsewhere. Present study is a first of its kind in our country, where eye lens monitoring is not routine practice in hospitals. Results of this study might serve as an example of good practice on introducing new monitoring routines in hospitals country wide, to both radiation protection officers in hospitals and to the national regulatory body. Additionally, until necessary resources for routine monitoring become available, this study provides the means for hospitals to use already available data on patient exposure to estimate ELD for the operator, as suggested by [12].

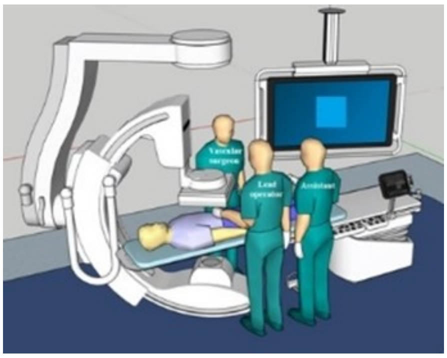

Figure 1. Operator's usual position relative to the patient table.

MATERIALS AND METHODS

For the purpose of this study, 15 EVARs were observed, all performed in hybrid angio suite (Philips, Azurion 7 M20, Netherlands; X-ray generator model MRC 200 0407, Philips, Germany, nominal voltage 125 kV, with filtration 2.5 mm Al @ 75 kV and focal spot sizes of 0.4 and 0.7 mm) by a team of 3 operators: two interventional radiologists, lead and assistant, and a vascular surgeon. Usual positions of staff relative to the patient, x-ray tube and monitors are shown in figure 1. ELD was measured using three (3) thermoluminescence dosemeters (TLDs) for each operator (LiF: Mg, Cu, P based detectors, DXT-100H, Thermo Fisher Scientific, USA), calibrated in terms of ELD equivalent Hp (3). Dosimeters were placed on a head-band, one in the middle, above the operator's nose, and other two approximately 6 cm left and right. The construction of the head band ensured the dosemeters to be approximately 1 cm in front of the forehead, thus not affected by the protection of lead glasses, if used. Only one operator consistently used protective eyewear, while neither over couch protection nor ceiling suspended screen (CCS) was used.

The chosen number of dosemeters is enough to cover the entire range from the left to the right eye and provide adequate mapping of eye lens dose, while increasing number of dosemeters worn above the eyes (on the forehead) will not improve the estimation of the eye lens dose. The study period of 18 months was necessary to acquire measurements for 15 procedures, due to procedure frequency, mandated by its cost and bureaucracy. Additionally, the number of available eye lens dosemeters in our country is low since eye lens monitoring is not routine practice in this country.

Dosemeters were read after each procedure on TLD reader Harshaw 6600 plus (Thermo Fisher Scientific, USA, WinREMS software). A total of 132 dosemeters were read. The measured dose was expressed in microsievert (μSv). Data regarding reference air kerma ($K_{a,r}$), dose area product (DAP) and fluoroscopy time (FT), available at the command console of the X-ray machine at the end of the procedure, were recorded by a medical physicist observing the procedure.

All operators involved in this study are categorized as occupational exposed workers and are subjected to regular dose monitoring program with whole body TLDs for planned exposure situations. By introducing additional eye lens dosemeters for operators, this study had no effect on the medical procedure in any way, for neither operator nor the patient, but was intended for improvement of local radiation protection practices, hence no ethical approval by the institution ethical committee was requested. Similar studies were performed by the same rationale [2].

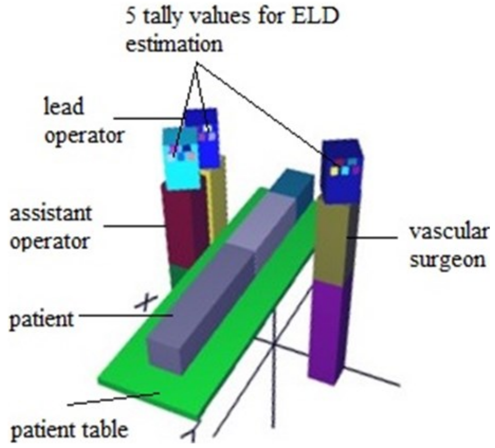

Figure 2. Simulation setting. Operators looking at monitors - 60° head orientation for lead and assistant operator, 120° for vascular surgeon. ELD – eye lens dose.

Monte Carlo (MC) code MCNPX, version 2.7.2. (Los Alamos National Laboratory, USA) [13] was used to simulate the X-ray source, phantoms for three operators and patient, TLDs, tabletop and flat-panel detector (figure 2), with all material components and densities as described in the literature [14]. X-ray tube was modeled as a photon point source, positioned below the tabletop, at the distance of 120 cm from the flat panel detector with the tabletop placed in the middle, where the centers of the source, of the lower third of the patient's torso and of the flat panel detector were aligned. Source was directed using a cone of beams and a cone beam half-angle was calculated so that field of view would cover the entire patient's torso phantom. Spectrum for the X-ray source was obtained from the Spectrum processor described in the Institute for Physics and Engineering in Medicine (IPEM) Report 78 [15] for tube voltage of

85 kV. All operators and patient bodies were modeled as a 180×20×20cm³ phantom consisting of head, torso and legs sections. Three TLDs were modeled as 5×4×1cm³ parallelepiped filled with ^{6}LiF positioned in front of the eyes: one between the eyes and two equidistantly left and right.

CCS was modeled as 73×60×2cm³ parallelepiped filled with lead glass material, equivalent to 0.5 mm of the lead protection. Simulations included different angles of orientations of the operators' heads simulate movements from looking at the patient to looking at the monitors (figure 2). MC simulation is a reliable method for estimating shielding effects of lead glass [16], so another simulation was performed to investigate the effectiveness of CSS with the operators looking at the patient. F6 tally for photons was used to obtain the results of the simulations. Number of simulated particles was 100 million, ensuring satisfactory low relative error.

Statistical analysis was performed using Microsoft Office Excel 2013 software (Microsoft Inc. Redmond, WA), as in similar studies [17]. Descriptive statistical parameters for numerical data analysis were applied, to present the data as mean (max, min) median values. Due to small sample sizes (15 data in each set) and non-normal distribution, statistical differences between data sets were analyzed using Mann-Whitney U test. Correlation between measured eye lens doses and patient related exposure parameters was assessed using Spearman's rank correlation coefficients (r), with the limit for statistical significance set at $p = 0.05$. Values of $r \geq 0.70$ were considered to represent strong correlation, while for those between 0.69 and 0.40, the correlation was considered moderate [17].

RESULTS

Table 1 shows the results of dosemeter readings for all operators, in the center of the forehead (C) and on both left (L) and right side (R), providing the dose distribution over the forehead of all operators. For the lead operator, ELD decreases from left to right (median values of 284, 261 and 231 µSv, respectively. Differences between medians for each position were not statistically significant (p values of 0.68, 0.82 and 0.43). For the assistant operator, the difference between the median values of dose in all 3 positions was small (L 198 µSv, C 204 µSv, R 203 µSv) and not statistically significant (p values of 0.23, 0.26 and 0.88) indicating fairly uniform distribution. Vascular surgeon's exposure was highest on the center of the forehead (median 258 µSv), while exposure on the left and right showed slight difference (medians L 216 and R 223 µSv). Difference between medians for each position were not statistically significant (p values of 0.97, 0.79 and 0.91).

Unshielded ELD, expressed as average (max, min) median, for lead operator, assistant and vascular surgeon was recorded to be 311 (949, 142) 253µSv, 261 (874, 115) 202 µSv and 298 (810, 96) 234µSv, respectively, when averaged over all 3 dosemeters.

Table 1. Results of dosemeter readings (Hp(3)) for all operators and all dosemeter positions on the forehead.

		Left	Central	Right
		all values in [µSv]		
Lead operator	Average	345	306	283
	Max	949	773	628
	Min	142	179	174
	Median	284	261	231
Assistant operator	Average	246	309	230
	Max	424	874	390
	Min	130	152	115
	Median	198	204	203
Vascular surgeon	Average	301	293	300
	Max	810	674	788
	Min	96	124	115
	Median	216	258	223

Table 2 shows the values of Spearman's rank correlation coefficients (r) between exposure parameters ($K_{a,r}$, DAP and FT) and measured doses for left, central and right eye lens dosemeter for all 3 operators. 13 out of 27 tested correlations were statistically significant, where 5 were strong and 8 were moderate. Correlations shown to be statistically non-significant were not further observed. Strong correlation was found between values of dose in all 3 positions and DAP for lead operator (L 0.873, C 0.912, R 0.811, p <0.01 for all), and between $K_{a,r}$ and central dose for the lead (0.751, p <0.01). The same type of correlation was found for the vascular surgeon's right dosimeter and DAP (0.700, p <0.01). Correlation between DAP and all 3 dose values for the assistant operator was moderate (L 0.654, p=0.01; C 0.529, p = 0.03; R 0.668, p = 0.01). The same type of correlation was found for the vascular surgeon's central ELD and DAP (0.589, p = 0.02) and right ELD and $K_{a,r}$ (0.501, p = 0.048), as well as for the lead operator's left and right dose and $K_{a,r}$ (0.661, p <0.01; 0.540, p = 0.04; respectively). Fluoroscopy time only showed statistically significant correlation with one dose value, central for the lead operator (0.552, p = 0.03), of moderate strength.

Table 2. Spearman's rank correlation coefficients (r) between exposure parameters and measured ELD of 3 operators. FT - fluoroscopy time; Ka,r - reference air kerma; DAP - Dose Area Product. Values in bold indicate statistically significant correlation (p<0.05).

		Left		Central		Right	
		r	p-value	r	p-value	r	p-value
Lead operator	$K_{a,r}$	0.661	0.01	0.751	<0.01	0.540	0.04
	DAP	0.873	<0.01	0.912	<0.01	0.811	<0.01
	FT	0.428	0.11	0.552	0.03	0.252	0.36
Assistant radiologist	$K_{a,r}$	0.283	0.29	0.414	0.11	0.305	0.25
	DAP	0.654	0.01	0.529	0.03	0.668	0.01
	FT	0.365	0.16	0.544	0.03	0.351	0.18
Vascular surgeon	$K_{a,r}$	0.109	0.69	0.345	0.19	0.501	0.048
	DAP	0.382	0.14	0.589	0.02	0.700	<0.01
	FT	0.369	0.16	0.361	0.17	0.437	0.09

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Table 3 gives the result of the MC simulation of energy deposition ratios averaged over a cell (F6 tally values) for 5 different angles of head rotation. For the lead and assistant operator, angle of 0° represents the position of the head when the operator is looking at the patient's body, 60° angle corresponds to the position when looking directly at the monitors, while angles of 15°, 30° and 45° represent the positions in between. For the vascular surgeon, standing on the opposite side of the table from previous two, angle of 0° represents the position of the head when the operator is looking at the patient's body, but angle of 120° corresponds to the position when looking directly at the monitors. Angles of 30°, 60° and 90° represent head rotations in between. The data show the decrease of energy deposited over a cell, corresponding to dose, with the increase of head rotation angle, i.e. whenever the operator turns the head away from the patient's body and toward the monitors. Exception is found for the lead operator's dose on the left of the forehead for two positions (15° and 30° head rotation), due to the fact that, for small angles of rotation, dosimeter placed on the left of the forehead actually becomes closer to the source of scatter radiation i.e. the patient. When the vascular surgeon is looking at monitors, behind his left shoulder, the dose for his eyes decreases 30 to 100 times, since the eyes are turned away from the radiation source and in part shielded by the back of the operator's head.

Table 3. Ratios of F6 tally values for different angles of head rotation. 0° - looking at a patient; lead and assistant operator looking at monitors - 60°; vascular surgeon looking at monitors - 120°. TLD - thermoluminescent dosemeter.

Operator	TLD position	Rotation angle [°]				
		0	15	30	45	60
Lead	Left	1.00	5.78	5.34	0.77	0.65
	Center	1.00	1.01	0.89	0.72	0.54
	Right	1.00	0.94	0.88	0.77	0.46
Assistant	Left	1.00	0.89	0.59	0.60	0.34
	Center	1.00	0.81	0.59	0.55	0.12
	Right	1.00	0.81	0.58	0.51	0.06
Operator	TLD position	Rotation angle [°]				
		0	30	60	90	120
Vascular	Left	1.00	0.84	0.57	0.04	0.02
	Center	1.00	0.86	0.47	0.08	0.03
	Right	1.00	0.54	0.06	0.02	0.01

The effect of the introduction of CSS between the patient and the operator are given in the table 4, represented as dose per simulated particle [Sv] for TLDs with and without the use of CCS, obtained through MC simulation. The results show strong protective capability of CCS, with ELD reduction between 77 and 98 times for the lead operator, between 79 and 140 times for the assistant, and between 69 and 107 times for the vascular surgeon.

Table 4. Dose per simulated particle [Sv] for dosemeters of all participants without any protective equipment, and after ceiling suspended screen (CSS) is used. Dose reduction factor for CSS is given in the last column. TLD - thermoluminescent dosemeter.

Operator	TLD position	Dose per simulated particle [Sv].		Dose reduction ratio of CSS
		Without CCS ($\cdot 10^{-18}$)	With CSS ($\cdot 10^{-20}$)	
Lead	Left	2.3058	2.9855	77.23
	Center	2.2703	2.3222	97.76
	Right	2.0540	2.2464	91.43
Assistant	Left	1.6478	2.0898	78.85
	Center	1.4563	1.0392	140.14
	Right	1.2273	1.0191	120.43
Vascular	Left	1.9956	2.9305	68.89
	Center	2.2916	2.1439	106.89
	Right	2.3643	2.8926	80.68

DISCUSSION

Unshielded ELD corresponds well with previously published relevant data [3, 19], for the lead operator and the assistant. On the other hand, some authors are reporting significantly lower eye lens doses of the order of several μSv per EVAR [6, 20]) with the use of additional upper body shielding equipment.

Kirkwood *et al.* [2] state that, for vascular interventional procedures in general, the dose for assistant, standing right next to the operator, further away from X ray tube, is approximately half of the operator dose. Wilson-Stewart *et al.* [6] report the ELD for Scrub, standing by the table commands, to be 3μSv per procedure. Present study found ELD for the assistant operator to be comparable to the lead operator's lens dose. Greater distance from the source and the use of additional shielding in [6] might encounter for this difference. To the best of the authors knowledge, no study was published reporting eye lens exposure of an operator standing on the opposite side of the table during EVAR, although some [6, 19] mention and recognize this spot as the high dose position. The present study shows an average exposure of eye lens at this position to be comparable to the exposure of the lead operator.

Based on the result of previous studies examining ELD distribution between operators in interventional radiology, one could expect the decreasing order of the dose going further away from the X-ray tube [8]. Findings of this study are different and can be explained by the regular behavior of the team members in the theatre. The operators would spend most of the time during procedures in their primary positions (figure 1). However, procedural demands or complexity would require or allow the operators to change positions. Harbron [21] showed that many factors, including the operator's distance to the primary field, influence the dose they receive.

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This study showed uniform distribution of ELD over the forehead. When resources are limited, one dosimeter worn on the forehead, positioned for the operator's best comfort, could give a proper measurement of ELD.

It has been previously shown that $K_{a,r}$ and DAP can be a good quantifier of operator exposure, while fluoroscopy time could be used as an indicator of procedure complexity [9, 12]. The results of this study agree with previously published data, while observed correlation coefficients for all operators show stronger correlation than those published in [4] and [6]. This supports the claim of [12] that this kind of factors should be acquired locally, at hospital level, or even for each X-ray suite. When employees exibit poor adherence to wearing dosemeters, as in the studies of Mohd Ridzwan *et al.* [11] and Ekran *et al.* [22], or when the resources are limited, DAP could be used as a parameter to monitor eye lens exposure.

Changes in the operator's head posture (looking down and up) have been shown to have a significant influence on the eye lens exposure [23]. During EVAR, all the operators spend some time following the progress of endoscopic equipment by looking at the monitors. This research shows that head orientation also influences the dose distribution along the forehead (table 3). The decrease in dose with head rotation could encounter for lower correlation coefficients between lens dose and exposure parameters for vascular surgeons compared to the lead operator. When the vascular surgeon is looking at the monitors, his eyes are turned away from the radiation source, and partially shielded by the back of his head.

The results of MC simulation, (table 4), show strong protective effect of CSS (average factor of 95, 0.5 mm Pb lead equivalence). Harbron *et al.* [21] reports the dose reduction factor of 10, for 0.25 mm Pb equivalence shield. The difference in this factor between two studies agrees with the different lead equivalency used in the simulation. However, incomplete shielding during clinical procedures causes overestimation of simulated effectiveness of CSS [21]. Indeed, the ideal position of the shield, as simulated, would be hard to achieve in clinical practice, and the shield would often need to be moved during the procedure and repositioned again, possibly compromising its effectiveness [9]. One available CSS in the present operating theatre, if used, could provide shielding for operators only on one side of the table. Since occupation of both sides of the table is a routine setup in our hospital, adding a second CSS could be recommended. On the other hand, according to [9] without the proper planning of a hybrid room, in order to avoid conflict with other equipment and operators themselves, adding another screen in the existing setup might be challenging. Nevertheless, this and previous studies show that the use of CSS is of high importance and effective for eye protection. The use of CSS or other additional shielding to protect the operators' upper body is strongly advised in a present setup.

Lead goggles provide significant eye lens dose reduction [23]. Although the presented dose for unprotected eye lens might be an overestimation, given the poor adherence of the operators to use all available protective means, in our study and in others [11, 24], the assessment of unprotected eye lens dose is a way to avoid an underestimation. It also ensures that the dosemeter will be exposed to doses corresponding to its sensitivity range [7].

Larger number of observed procedures would improve the statistics of the calculation. However, increasing this number would further prolong the study beyond the reasonable time period.

CONCLUSION

In all of the analyzed operator's positions, eye lens exposure was comparable; hence all three positions can be considered high dose positions, mandating their individual monitoring. When performing a procedure as a team, the operator's body and head positions will not be constant and this behavior strongly influences the eye lens exposure. When resources are limited, DAP could be used as an indicator of eye lens exposure. Other authors report lower values of ELD; hence the use of all available radiation protection equipment is strongly advised to optimize radiation protection.

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Authors contribution: J.S., experiment design, overview of the experiment, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – review & editing; P.B., experiment design, Monte Carlo simulations, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – review & editing; J.S.P., B. P., Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. D.I., V.T., Writing – review & editing.

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