ASSESSMENT OF OCCUPATIONAL EYE LENS EXPOSURE DURING IMAGE-GUIDED ORTHOPEDIC PROCEDURES

by

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This study aimed to investigate the level of exposure of eye lenses in orthopedic surgeons performing routine clinical work and to determine future monitoring practice, as Serbian radiation protection law still employs higher limits. The dose was measured monthly in terms of $H_p(0.03)$ with three different dosimeters placed on a 3-D-printed headband, worn on a forehead by three orthopedic surgeons, during all procedures involving fluoroscopy. The mean dose for the left and right eye was 271   109   Sv and 269   101   Sv, respectively, with no significant difference (*p*-value 0.977) between the left and right eye observed. Considering the highest recorded monthly value, the annual dose is expected to be 4.85 mSv without protective items, well below the new ICRP limit of 20 mSv. There was no observed correlation between eye lens dose and both fluoroscopy time and exposure parameters. Considering the cumulative impact of dose and the evidence pointing to an elevated incidence of lenticular opacities for cumulative doses exceeding 10 mSv, it is advisable to institute ongoing monitoring, especially when new surgeons incorporate image-guided procedures or when novel techniques are introduced into surgical practice.

Key words: eye lens dose, orthopedic surgery, fluoroscopy, radiation protection, individual monitoring

INTRODUCTION

While X-ray usage is primarily associated with radiology, it extends beyond the confines of the imaging department, finding applications in various other fields. Ever since fluoroscopic imaging was introduced in orthopedic operating theaters in the 1980, its use has been only increasing since it enables image guidance to surgeon's manipulations with minimal invasiveness, as it represents 8.4 % of all fluoroscopy-guided procedures in the USA according to the International Commission on Radiation Protection (ICRP) Report 117 [1].

Orthopedic surgical practice often requires an operator to stand close to the patient while X-rays are being emitted, and as a consequence, their tissues and organs get exposed not only to radiation scattered from the patient but also to the primary beam. Additionally, proximity to the patient and operating table does not allow protective screens to be positioned between the operator and the X-ray source. This manner of performing procedures, although beneficial from a medical point of view, comes with an imposed risk of potentially harmful effects of ionizing radiation to both patients and medical staff.

Although the wear rate of lead aprons and neck guards by physicians performing radiology procedures is higher than 90 %, the wear rate of lead glasses is 30-52 % [2, 3]. Moreover, despite the ability of lead-containing ceiling-mounted radiation shielding screens to reduce eye lens exposure by over 70 % [4-10], these screens are not always used appropriately in actual medical procedures [5].

The factors influencing the eye lens dose can be grouped into a few main categories: beam orientation, access route, fluoroscopy settings, operating mode, use of protective tools (shielding screens, glasses), and finally factors related to the operator such as work-

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load, skill and training [4]. 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 [11-15]. In general, a typical dose reduction factor for a single shielding tool is 5-25 and for a combination of tools is 25 or more, even up to a factor of 1000 [15, 16].

Previously, lenticular opacities induced by ionizing radiation were considered to be the strictly deterministic effect of radiation exposure with a threshold of 0.5-2 Gy for acute and 5 Gy for cumulative exposure, while visually disabling cataract was reported to have a threshold of 2-10 Gy for acute and 8 Gy for long term exposure, hence the annual limit for eye lens dose was set to be 150 mSv [17]. In a statement on tissue reactions published in 2011, as a result of various investigations, ICRP determined that the threshold dose for radiation-induced cataracts is considered to be 0.5 Gy for both acute and prolonged exposures, and hence recommended equivalent dose limit for the lens of the eye for occupational exposure in planned exposure situations to be lowered to 20 mSv per year [18].

Literature data regarding the exposure of orthopedic surgeons is scarce, but the concerns in their professional community are growing [19-22]. Cheriachan [23] provided the data from a total of 131 procedures. The mean radiation dose detected at the eye level of the primary surgeon was 0.02 mSv (SD = 0.05 mSv) per procedure. Radiation at eye level was only detected in 31 of 131 cases. The highest registered dose for a single procedure was 0.31mSv. Furthermore, Ono *et al.* [24] have shown that the average exposure dose per vertebral body was 1.46 mSv for the finger (70 m dose equivalent), 0.24 mSv for the lens of the eye (3 mm dose equivalent), 0.11 mSv for the neck (10 mm dose equivalent), and 0.03 mSv for the chest (10 mm dose equivalent) under the protective suit. In their study, the estimated cumulative radiation exposure dose of 23 cases of balloon kyphoplasty (BKP) was calculated to be 50.37 mSv for the fingers, 8.27 mSv for the lens, 3.91 mSv for the neck, and 1.15 mSv for the chest. Suzuki *et al.* [25] have reported 0.8 mSv per month and 0.66 mGy per month as the maximum equivalent dose to the eye lens and the maximum kerma, respectively. On the other hand, Romanova *et al*. [26] have found the highest mean value of the eye lens dose of 47.2 mSv and higher mean fluoroscopy time of 3 min, as well as the corresponding highest maximum values of 77.1 mSv and 5.0 min for the Fractura femoris procedure. Considering all of this, it should be noted that the design of previously conducted studies is quite diverse. Some of them observe a single procedure [26, 27], while many use only one dosimeter [23, 26-28], active or passive. In some, a dosimeter was worn on a collar [25], many measured eye lens dose in terms of Hp (0.07) [21, 26, 28], while some performed only one measurement for several months [21, 27, 28].

This study aimed to: measure monthly eye lens dose in routine clinical work of orthopedic surgeons for all procedures involving fluoroscopy, investigate the dose distribution between the left and right eye, to determine the best position for eye lens dose measurement, and provide information and recommendations for individual monitoring program in orthopedic theaters.

MATERIALS AND METHODS

The study was conducted in the Clinical Centre of Vojvodina, Novi Sad, from September 2022 until June 2023, while radiation exposure was performed using two Philips BV Endura mobile C-arms.

Each month, the surgeon was provided with three dosimeters. Dosimeters were placed on the headband warn at the eyebrow level, with the minimum possible distance between the dosimeter and eye lens, fig. 1. These three dosimeters were placed in the middle of the headband (center line of the operator's nose) and equidistantly to the left and right (near the edge of the forehead). This positioning provides the best estimate of the eye lens doses [29, 30]

The dose to the left and right eye lens was calculated as the average value from the left and center dosimeter and right and center dosimeter, respectively (no additional dosimeter was used as it would not give an increase in accuracy of the calculated eye lens dose).

The monitoring period was ten months (Sept. 2022 – June 2023) during which dosimeters were read after each month.

Detectors based on LiF: Mg, Cu, P (DXT-100H, Thermo Fisher Scientific, USA) were placed in ring holders (part number 500608, cap – 500597, Thermo Fisher Scientific, USA) that were cut-off and only left with dosemeter placement section. The readouts were done by Harshaw 6600 plus an automated TL reader (Thermo Fisher Scientific, USA). The reader was calibrated in the ^{137}Cs reference radiation field (S-Cs radiation quality), with 1 mSv reference $H_p(3)$ dose. The acquisition was controlled by WinREMS software (version 8.2.3.0) and set with the next parameters: temperature rate – 15 °C per second, temperature range – 50 °C – 250 °C, and readout time – 23 seconds. All 200 acquisition channels were used, and no preheating was set.

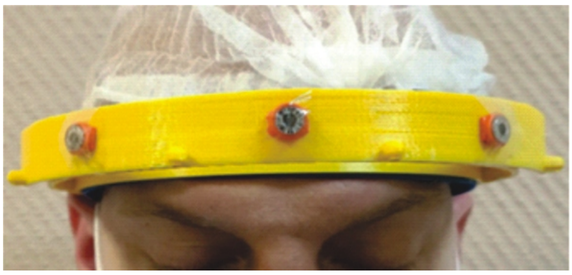

Figure 1. Three TLD secured on a headband in left, middle, and right position, worn on a forehead, approximately 1 cm above the eyebrows

Table 1. Collected exposure parameters for procedures and dosimeter readouts

Month	Total number of procedures	Total fluoro time [s]	Examination dose [mGy]	Cumulative DAP [Gycm^2]	Left TL dosimeter [μSv]	Middle TL dosimeter [μSv]	Right TL dosimeter [μSv]
1	11	416	67,9	18,1	280,1	306,0	317,7
2	14	315	24,7	6,6	196,8	210,4	167,3
3	10	407	434,1	6,1	246,6	210,9	182,2
4	10	206	21,8	5,8	214,6	183,1	227,8
5	9	167	6,9	4,5	163,1	146,8	169,3
6	8	149	30,0	8,2	190,4	219,4	239,5
7	6	125	2,9	0,8	165,5	173,3	222,8
8	4	101	4,6	1,2	439,8	352,5	388,5
9	5	87	14,0	3,8	446,5	468,4	407,7
10	4	145	58,0	15,4	408,4	391,9	403,1

RESULTS

Table 1 presents collected data from the procedures regarding exposure parameters in the form of fluoroscopic time, examination dose, and cumulative dose-area product (DAP), as well as readings from each of the three dosimeters (left, center, and right).

Figures 2-4 present left and right eye lens dose (calculated from the dosimeters readings) as a function of each of the three procedure exposure parameters collected.

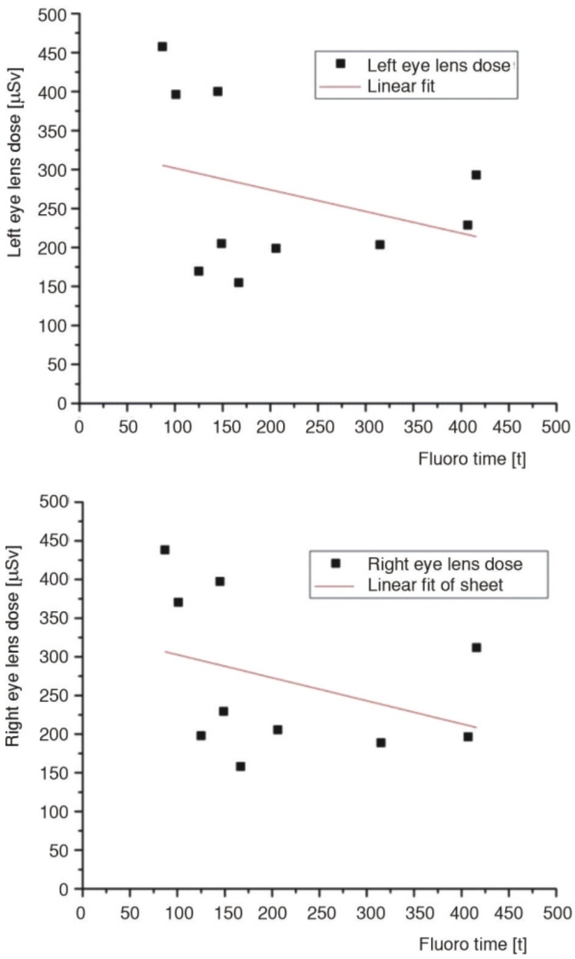

Figure 2. Left and right eye lens dose as a function of total fluoroscopy time (R^2 is 0.09811 and 0.13182, respectively)

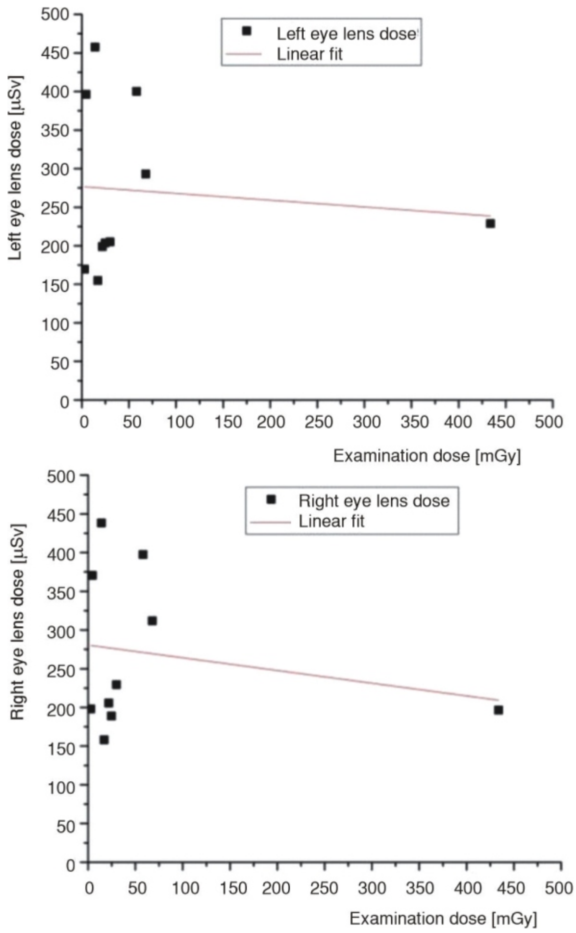

Figure 3. Left and right eye lens dose as a function of examination dose (R^2 is 0.011 and 0.04499, respectively)

DISCUSSION

The mean dose for the left eye was 271 109 Sv, ranging from 169 Sv to 457 Sv, while the mean dose for the right eye was 269 101 Sv, ranging from 158 Sv to 438 Sv. No significant difference (*p*-value 0.977) between doses for the left and right eye was observed in this work, being in good agreement with data available in [21]. This could be due to an observation that orthopedic surgeons tend to operate with equal fre-

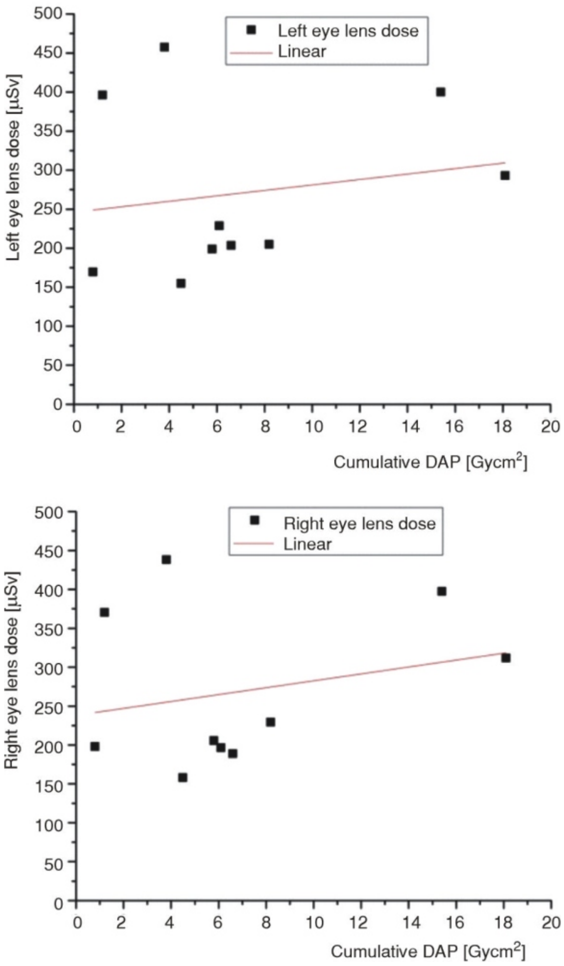

Figure 4. Left and right eye lens dose as a function of cumulative DAP (R^2 is 0.03311 and 0.06196, respectively)

quency on both the left and right sides of patients' bodies, adjusting their position accordingly.

Taking into account the highest recorded monthly dose for eyes of 441 Sv, as an average of doses for the left and right eye, the annual eye lens dose for an orthopedic surgeon, for 11 months, is expected to be 4.85 mSv, assuming no protective eyewear was used. Other authors reposted this value to be in the range of 1 to 35.5 mSv, considering many different clinical scenarios. Romanova *et al*. [26] state that the mean annual eye lens dose could achieve 16.2 mSv or even 35.5 mSv assuming a very large number of operations of only one type (fractura femoris) to be performed, putting operators at risk of overrunning the annual limit set by the ICRP. However, the authors state this approach to be very conservative and rather unrealistic. Suzuki *et al.* [25] report a maximum lens equivalent dose of 9.6 mSv for one year, involving surgeries mostly performed on the feet. On the other hand, Apelmann *et al.* [28] showed no significant difference between the values from the eye dosimeter and reference dosimeter, kept in the wardrobe during the study, indicating an expected maximum annual lens dose in the range of 1-1.3 mSv. Cuenca *et al.* [21] also show a maximum annual dose to be 1.4 mSv in various types of procedures.

No correlation between eye lens dose and fluoroscopy time, fig. 2, exposure dose, fig. 3, or cumulative DAP, fig. 4, was observed, for neither left nor right eye for the available data. This was no surprise, considering the study design that included diverse procedures and all the different scenarios that could happen during clinical work. There are many factors influencing the amount of radiation reaching a surgeon, such as his position relative to the patient and X-ray beam during imaging, a cross-section of the patient's body being imaged, and the orientation of the C-arm. In some cases operator needs to secure the position of a limb or piece of surgical equipment during imaging, requiring him to stand close to sources of radiation, while in others they may step back, even for a couple of meters, during exposition. In both cases, values of fluoroscopy time, exposure dose and cumulative DAP will increase, while it is obvious that in the first case surgeon would receive a certain dose to the eye lens, and in the second he wouldn't. In a similar setting, for surgeons with different work experience, Suzuki *et al.* [25] found weak to no correlation between eye lens dose and fluoroscopy time ($R^2 = 0.509$ and $R^2 = 0.021$ for more and less experienced operators), while Romanova *et al*. [26] finds a good correlation for Fractura cruris, and no correlation for Fractura femoris type of surgery, stating it is probably due to the complexity of the latter one. Cheriachan [23] describe the correlation between eye dose and fluoroscopy time, using Spearman's rho coefficient, as weak positive (0.29), and between eye dose and DAP as positive (0.34). With the values of –0.38, 0.17, and 0.23 describing the correlation between lens dose and fluoroscopy time, examination dose, and DAP, respectively, data collected for this study show no correlation through this parameter. The reasons are probably the same as previously described, while a low number of measurements may present a limitation.

Observing a total of 81 procedures, the mean eye lens dose per procedure was 33.5 Sv, aligning closely with previously reported values of 0.09 mSv [23] and 50 Sv [7]. It has been shown that procedure type and complexity, among other things, could significantly influence the dose to the eye [26]. Suzuki *et al*. [25] reports average monthly doses for eye lenses to be 0.41 0.21 mSv and 0.22 0.16 mSv, for more and less experienced surgeons, respectively. In their work, a higher dose for experienced surgeon may come as a surprise, but, as stated, this might be because more experienced surgeon performs more complicated procedures. With all this in mind, it is clear that differences in values reported by different authors may be large, depending on the study design and the type of procedures observed. When operating on a spine or pelvis, an X-ray beam passes through a large cross-section of the patient's body, creating a larger amount of scatter using higher imaging parameters than during extremity imaging, so one could argue that in this type of procedure increased exposure of both patient and operator could be expected [28]. The majority of procedures observed in the present study were performed on the limbs.

Copeta *et al*. [31] found an increased risk of lenticular opacities associated with cumulative eye lens doses over 10 mSv and exposure for more than 10 years. In recent studies, [32, 33] it has been shown that a small percentage of orthopedic surgeons use assigned TLD or radiation protection garments. Nevertheless, reported data state that 85 % of respondents never used lead protective glasses [32]. With an expected working life of approximately 30 years as an orthopedic surgeon, threshold doses for the occurrence of lenticular opacities and cataracts could be easily achieved. Therefore, more radiation protection care should be paid to the eyes of an exposed professional.

CONCLUSION

The average recorded dose for the left and right eye lens was 271 109 Sv and 269 101 Sv, respectively, and no significant difference was observed between left and right eye exposure. Taking into account the highest recorded monthly dose value, the dose for one year is expected to be 4.85 mSv without the use of protective equipment, which is significantly below the new dose limit of 20 mSv per year. No correlation was identified between the eye lens dose values and both the total fluoroscopy time and parameters characterizing the patient's exposure. In the light of cumulative dose effect and the observed rise in lens opacification incidence for cumulative doses surpassing 10 mSv, it is justified to implement monitoring of lens dose in image-guided orthopedic procedures.

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AUTHORS' CONTRIBUTIONS

J. J. Samac, P. M. Božović, and B. Petrović designed the experiment which was executed during planned image-guided orthopedic procedures by orthopedic surgeons M. N. Vranjes, P. V. Rašović, and M. M. Obradović. The manuscript was prepared by J. J. Samac, P. M. Božović, B. Petrović, and J. S. Stanković Petrović. All authors analyzed and discussed the results and reviewed the manuscript.

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ПРОЦЕНА ДОЗЕ ЗА ОЧНО СОЧИВО У СЛИКОМ ВОЂЕНИМ ОРТОПЕДСКИМ ПРОЦЕДУРАМА

Циљ овог истраживања био је да се испита ниво изложености очног сочива код хирурга ортопеда током обављања различитих операција у рутинском раду, као и да се установи да ли постоји потреба за даљим праћењем. Доза за очно сочиво мерена је на месечном нивоу као величина $H_p(0.03)$, помоћу три дозиметра постављена на рајф, штампан 3-D штампачем, који су три хирурга носили на челу током свих процедура које су вршили уз употребу јонизујућег зрачења. Просечна забележена доза за лево и десно очно сочиво била је 271 ± 109 μSv и 269 ± 101 μSv, респективно, и притом није примећена значајна разлика између изложености левог и десног ока (*p*-вредност 0.977). Узимајући у обзир највишу забележену месечну вредност дозе, очекивано је да доза за годину дана износи 4.85 mSv без употребе заштитних средстава, што је значајно испод нове границе дозе од 20 mSv годишње. Установљено је да не постоји корелација између вредности дозе за очно сочиво и укупног времена флуороскопирања, као ни параметара који описују експозицију пацијента. Имајући у виду кумулативан ефекат дозе, као и доказе о постојању повећане инциденце замућења очног сочива за кумулативне дозе веће од 10 mSv, и у будућности је оправдано спроводити мониторинг дозе за очно сочиво, посебно у случајевима када нови ортопеди започињу сликом вођену праксу или се уводи нова процедура која укључује сликом вођене процедуре или нове технике.

Кључне речи: доза за очно сочиво, ортопедска хирургија, флуороскопија, заштита од јонизујућег зрачења