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RADIATION EXPOSURE TO THE EYE LENS OF ORTHOPAEDIC SURGEONS DURING VARIOUS ORTHOPAEDIC PROCEDURES

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The aim of the present study was to assess the radiation dose to the eye lens of orthopaedic surgeons during various orthopaedic procedures and to make efforts to ensure that radiation protection is optimised. The study was performed for Fractura femoris and Fractura cruris procedures performed in orthopaedic operating theatres, as well as for fractures of wrist, ankle and hand/shoulder performed in the emergency trauma room. The highest mean value of the eye lens dose of 47.2 μSv and higher mean fluoroscopy time of 3 min, as well as the corresponding highest maximum values of 77.1 μSv and 5.0 min were observed for the Fractura femoris procedure performed with the Biplanar 500e fluoroscopy systems. At a normal workload, the estimated mean annual dose values do not exceed the annual occupational dose limit for the lens of eye, but at a heavy workload in the department, this dose limit could be achieved or exceeded. The use of protective lead glasses is recommended as they could reduce the radiation exposure of the lens of the eye. The phantom measurements demonstrated that the use of half-dose mode could additionally reduce dose to the operator's eye lens.

INTRODUCTION

Orthopaedic surgeons commonly use X rays as a diagnostic and guiding tool during various procedures. The trend to apply minimal invasiveness in orthopaedic surgery practice led to increased use of fluoroscopic visualisation[1]. The procedures require a team of several orthopaedic specialists to stay close to the patient during fluoroscopy, thus being exposed to the radiation scattered from the patient[1–9]. Reports indicate that among the orthopaedic procedures that require fluoroscopic guidance, closed locked femoral nailing is responsible for the higher level of radiation dose to the orthopaedic surgeons[1, 2, 8].

Eye lens is more vulnerable to radiation considering particularly limited use of personal protective devices. Following the recommendations of the International Commission on Radiological Protection, the occupational annual dose limit for the lens of eyes in the International Basic Safety Standards and in the new European Directive 2013/59/EURATOM has been recently lowered from 150 to 20 mSv[9–11]. These new legislative requirements set new challenges for the practical radiation protection.

The aim of the present study is to assess the radiation dose to the eye lens of orthopaedic surgeons during various procedures and to make efforts to ensure that radiation protection is optimised.

MATERIALS AND METHODS

Eye lens dose measurements were performed with an Educational Direct Dosimeter EDD30 (Unfors Instruments, Sweden), calibrated in terms of personal dose equivalent $H_p(0.07)$. Eye lens dose was measured at the level of the left eye of the main operator, which is closest to the X-ray tube side. The dose detector was secured to the operating surgeon's glasses or elsewhere near the eyes.

The study was performed in orthopaedic operating theatres of the Military Medical Academy in Sofia, with two X-ray systems: C-arm fluoroscopy system OEC Fluorostar 7900 GE Healthcare and Mobile Biplanar 500e fluoroscopy system, Swemacimaging™, Sweden. Measurements were also performed in an emergency trauma room equipped with C-arm fluoroscopy system Ziehm Compact, Ziehm Imaging GmbH, Germany. For this system, simultaneous patient dose measurements were performed with a kerma area product (KAP) meter DIAMENTOR E2, PTW FREIBURG; the KAP values were recorded in μGy m^2.

In the orthopaedic operating theatres, measurements were performed during the following procedures: Fractura femoris status post repositionem sanguine cum Nail/Placae (further referred to as Fractura femoris) and Fractura cruris status post repositionem sanguine cum Nail/Placae (further referred to as Fractura cruris). These two procedures were always performed by two orthopaedic surgeons: a main operator and an assistant. Usually, the main operator was closer to the patient and X-ray beam, but in some cases, both of them were located opposite to each other at approximately the same distance from the patient and the X-ray beam. All the staff in the room wore aprons and thyroid protective collars of 0.5 mm lead equivalent.

In the emergency trauma room, measurements were performed during the following procedures:

wrist fracture, ankle fracture and hand/shoulder fracture. Procedures in this room were always performed by only one operator. In most cases, he stepped back from the patient during the exposure, except when the manual fixation of the object required his presence close to the patient.

For each procedure, the following parameters were recorded: dose to the eye of the operator, fluoroscopy time and KAP when available.

For comparison, phantom measurements were also performed with a water phantom with the cross-sectional dimensions of 30 × 30 cm and thickness of 20 cm used to simulate a body, and a cylindrical bottle of 1.5 l water to simulate extremities. During the phantom measurements, the dose detector of the dosemeter EDD30 was positioned on a stand at the height of the operator's head, 164 cm from the floor, and at a distance of ∼50 cm from the central X-ray beam, in two different positions of the operator in respect of the table with the phantom.

RESULTS AND DISCUSSIONS

Procedures in orthopaedic operating theatre

Totally, 26 orthopaedic procedures performed in the operation theatres were recorded: 13 Fractura femoris and 13 Fractura cruris procedures. Table 1 summarises the mean values, range in parentheses and median of the total fluoroscopy time and the eye lens dose for the Fractura femoris and Fractura cruris procedures, performed with the C-arm and Mobile Biplanar 500e fluoroscopy systems. The procedure Fractura femoris was performed only with the Biplanar 500e system, while the Fractura cruris was performed both with Biplanar 500e and Fluorostar 7900 C-arm. When visualisation during complex orthopaedic procedures was needed, Biplanar system was used, while the Fluorostar system was mostly used for status control before or after the procedure.

Fluoroscopy time for the Fractura femoris varied between 1.4 and 5 min, and for the Fractura cruris between 0.13 and 3 min. The mean fluoroscopy time was 3 min during Fractura femoris procedures and 0.28 and 2.1 min for Fractura cruris procedures performed, respectively, with C-arm and Biplanar 500e fluoroscopy systems. These differences in fluoroscopy time for the same procedure performed with the two systems well reflect their different usage as explained in the previous paragraph.

Radiation dose to the operator's eye lens varied between 20.7 and 77.1 μSv for the Fractura femoris procedures and between 1.2 and 43 μSv for the Fractura cruris procedures. The mean radiation dose to the eye lens of orthopaedic surgeons was, respectively, 47.2 μSv during Fractura femoris procedures and 2.7 and 23.2 μSv for Fractura cruris procedures performed correspondingly with C-arm and Biplanar 500e systems.

The highest mean value of the eye lens dose of 47.2 μSv and higher mean fluoroscopy time of 3 min, as well as the corresponding highest maximum values of 77.1 μSv and 5.0 min, were observed for the Fractura femoris procedure performed with the Biplanar 500e fluoroscopy systems. This is not only due to the complexity of procedures requiring relatively longer fluoroscopy time but also because of the simultaneous use of two X-ray planes.

Fluoroscopy time and operators' eye lens dose values during Fractura cruris procedures performed with the Fluorostar system were significantly lower than the corresponding values during the same procedures performed with the Biplanar system, explained by the use of the Biplanar system for more complex procedures performed in the operating theatre, while the Fluorostar system was used mostly for status control at the beginning or at the end of procedures.

Figure 1 shows the correlation between the measured operator's eye lens dose and fluoroscopy time for Fractura femoris and Fractura cruris procedures, performed with C-arm and Mobile Biplanar 500e fluoroscopy systems in orthopaedic operating theatre. Good correlation was found between these two parameters for Fractura cruris procedures ($R^2 = 0.94$ and 0.76 correspondingly for both systems), while no correlation was observed for Fractura femoris procedure, probably due to its complexity.

Phantom measurements performed for the Biplanar fluoroscopy system, with each C-arm separately and with both C-arms simultaneously showed dose rate at the operator's eye lens position to be between 8.7 and 32.4 μSv min^{-1}, depending on the fluoroscopy mode

Table 1. Summary of results for fluoroscopy time and eye lens dose for Fractura femoris and Fractura cruris procedures, performed with C-arm and Mobile Biplanar 500 fluoroscopy systems in orthopaedic operating theatre.

Procedure	Fluoroscopy system Fluorostar 7900 C-arm, mean (min.–max.) median	Fluoroscopy system Mobile Biplanar 500, mean (min.–max.) median
Fractura femoris	Not performed	Fluoroscopy time: 3.0 (1.4–5.0) 3.9 min Eye lens dose: 47.2 (20.7–77.1) 42.9 μSv
Fractura cruris	Fluoroscopy time: 0.28 (0.13–0.41) 0.32 min Eye lens dose: 2.7 (1.2–3.9) 2.5 μSv	Fluoroscopy time: 2.1 (0.5–3.0) 2.8 min Eye lens dose: 23.2 (1.2–43.0) 29.0 μSv

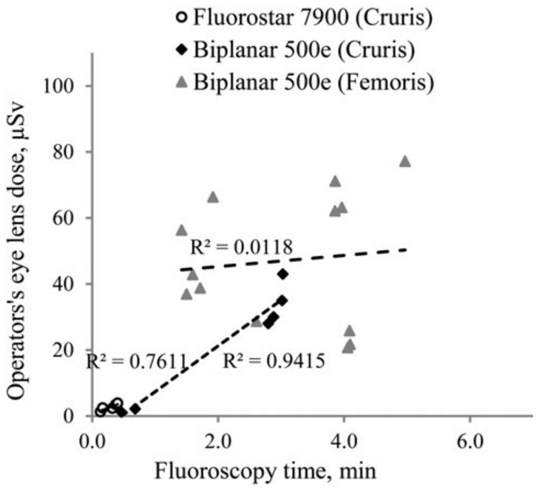

Figure 1. Correlation between the measured operator's eye lens dose and fluoroscopy time for Fractura femoris and Fractura cruris procedures, performed with C-arm and Mobile Biplanar 500e fluoroscopy systems in orthopaedic operating theatre.

and 'operator' position in respect of the phantom. The lowest dose rate of 8.7 μSv min^{-1} corresponded to the use of '1/2D' mode with 'yellow tube' in which tube voltage was in the range of 69–70 kV and tube current was 2.3–2.4 mA. At the simultaneous, use of both tubes in the normal fluoroscopy mode mean dose rate was correspondingly 14.4 and 32.4 μSv min^{-1} in two opposite positions of the operator in respect of the phantom.

Results from the phantom measurements correspond well with those from clinical procedures performed with the same fluoroscopy system, the latest showing operator's eye lens dose to vary between 5.1 and 39.6 μSv (mean value of 18.6 μSv per minute fluoroscopy time) for Fractura femoris procedure and between 2.6 and 14.2 μSv (mean value of 8.7 μSv) for the Fractura cruris procedure. For the Fractura cruris procedure performed with the C-arm, variations were between 7.2 and 14.6 μSv (mean dose of 9.9 μSv) per minute fluoroscopy time.

The annual operator dose was approximated based on the assumption of 10 procedures performed per week in 46 working weeks per year, or totally 460 procedures per year. Conservative approach was applied assuming all procedures are performed with only Mobile Biplanar 500 fluoroscopy system.

Table 2 summarises the mean, minimum and maximum dose per procedure and mean, minimum and maximum annual dose for correspondingly 230 or 460 procedures of the same type.

If in 1 year 230 procedure of each type are performed by the same operator, the mean annual eye lens dose would achieve 16.2 mSv (10.9 from Fractura femoris and 5.3 mSv from Fractura cruris). At the extreme case when assuming all 460 procedures are of the maximum dose of 77.1 μSv, the annual dose will increase to 35.5 mSv, but this is rather unrealistic situation.

Table 2. Estimated annual eye lens dose for Fractura femoris and Fractura cruris procedures, performed with Mobile Biplanar 500 fluoroscopy systems in orthopaedic operating theatre.

	Fractura femoris	Fractura cruris
Dose per procedure, mean (min.–max.), μSv	47.2 (20.7–77.1)	23.2 (1.2–43.0)
Annual dose for 230 procedures, mean (min.–max.), mSv	10.9 (4.7–17.7)	5.3 (0.3–9.9)
Annual dose for 460 procedures, mean (min.–max.), mSv	21.7 (9.5–35.5)	10.6 (0.6–19.8)

Table 3. Fluoroscopy time and eye lens dose for three procedures performed with C-arm Ziehim Compact fluoroscopy system in emergency trauma room.

Procedure	Fluoroscopy time, min, mean (min.–max.) median	Eye lens dose, μSv, mean (min.–max.) median
Wrist fracture	0.18 (0.01–0.31) 0.24	—
Ankle fracture	0.1 (0.04–0.22) 0.08	0.13 (0–0.2) 0.13
Hand/shoulder fracture	0.16 (0.02–0.4) 0.15	0.34 (0–0.89) 0.06

Emergency trauma room

Twenty-three procedures performed in the emergency room were recorded. The highest mean and median values of KAP were, respectively, 4.35 and 4.6 μGy m^2 recorded during hand/shoulder fracture, but the number of patients was small and this may be not representative.

Table 3 shows the mean values, range in parentheses and median of fluoroscopy time and eye lens dose for all three procedures, performed with the C-arm Ziehim Compact. Dosemeter response was recorded in only a small number of procedures, when the operator was close to the patient and the X-ray beam. In the rest, no dose was recorded.

The mean estimated annual eye lens dose in the emergency room was 0.05 mSv for the ankle fracture and 0.14 mSv for the hand/shoulder fracture. The phantom measurements for the same fluoroscopy system approximated the mean annual eye lens dose to 0.18 mSv for the ankle fracture and to 0.41 mSv for the hand/shoulder fracture, both performed in the half-dose fluoroscopy mode.

The analysis of the results in Table 3 and the phantom measurements indicated that eye lens dose to the operator during wrist, ankle and hand/shoulder fracture procedures is very low, due to the small thickness of the object, the short fluoroscopy time and the distant operator position.

CONCLUSIONS

The study confirmed the expected variations in the radiation dose to the eye lens of orthopaedic surgeons, depending on the type and complexity of procedures and the fluoroscopy system. The eye lens dose was relatively higher for the Fractura femoris procedure performed in the orthopaedic theatre with a biplane fluoroscopy system. At a normal workload, the estimated mean annual dose values would not exceed the annual occupational dose limit for the lens of eye, but at a heavy workload in the department, this dose limit could be achieved or exceeded. The use of protective lead glasses is recommended as they could reduce the radiation exposure of the lens of the eye. The phantom measurements demonstrated that the use of half-dose mode could additionally reduce dose to the operator's eye lens.

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