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ORIGINAL ARTICLE

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Radiation exposure to the hands of orthopaedic surgeons: are we underestimating the risk?

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Abstract *Introduction* Previous studies reported that the radiation exposure to the hands of orthopaedic surgeons was far below the acceptable limit. However, the risk could have been underestimated as some factors were overlooked, namely monitoring trainees during average workload, placing dosimeters over the most susceptible locations, measuring the cumulative dosage of radiation and considering the dose limit for non-classified workers. *Materials and methods* We performed a prospective study in two centres to estimate the radiation dose to the hands of two consultant trauma surgeons and two trainees (one assisting and one operating) while performing 47 fluoroscopy-assisted procedures. We used validated thermoluminescent dosimeters (TLDs) rings and fingerstalls for monitoring the cumulative dosage. *Results* Trainees were at higher risk while performing intramedullary nailing and during assistance. Higher radiation doses were recorded from dominant index fingers and particularly fingertips. *Conclusion* The risk of radiation exposure appears to be higher than previously reported. Fingertips are more susceptible to radiation exposure and should therefore be monitored in forthcoming studies.

Keywords Orthopaedic trauma · Hands · Ionising radiation · Thermoluminescent dosimeter

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Introduction

The risk of radiation exposure is well recognised among radiologists, radiotherapists, cardiologists and vascular surgeons. The number of fluoroscopy-assisted orthopaedic operations is rising with the increasing workload, the introduction of new techniques and more demanding procedures. Surgeons involved in the management of orthopaedic trauma, especially orthopaedic trauma surgeons and trainees, are at higher risk, as the majority of operative procedures in trauma require the use of intraoperative fluoroscopy.

The hands of orthopaedic surgeons are more susceptible to radiation exposure due to their proximity to the primary radiation and the lack of protective shielding. Several studies [1, 5, 7, 10, 11, 12, 13, 14, 15, 16, 17, 18] investigated the risks of radiation exposure to orthopaedic surgeons, but few authors [10, 14, 15, 16, 17] have recognised that hands are at particular risk. Therefore, the hand (rather than the thyroid, body or eyes) was considered to be the limiting factor for radiation exposure. However, studies [5, 7, 10, 11, 13, 14, 15, 16, 17, 18] that estimated hand exposure reported reassuring results and stated that the radiation dose to the hands is far below the acceptable limit. This reassurance could be misinterpreted and may lead to complacent attitudes. We envisaged that the radiation dose to the hands could be underestimated as one or more of the following factors have not been considered: monitoring junior surgeons and assistants, exposure to all procedures (average workload), locating dosimeters at the most susceptible parts of the hand, measuring the cumulative dose and taking into account the dose limit for non-classified workers. The aim of this study was to test the hypothesis that radiation exposure to the hands of orthopaedic surgeons has been underestimated.

Patients and methods

We performed a prospective study in two centres to estimate the radiation dose to the hands of two consultant trauma surgeons and two trainees—one assisting and one operating—while performing 47 consecutive fluoroscopy-assisted procedures. We used validated thermoluminescent dosimeters (TLDs) from Landauer (Glenwood, IL, USA) for measuring the cumulative radiation dose. TLD rings were placed at the base of the index and little fingers of both hands, and TLD fingerstalls were placed at the tip of the dominant index finger. A control TLD was kept in an area free from radiation exposure and high temperature in order to estimate the general background radiation to the other TLDs during the wear period. The primary endpoint was the accumulated radiation dose recorded by dosimeters at the end of the study period. The radiation dose was measured in Sieverts (Sv). TLD rings and fingerstalls were cold sterilised and placed on the investigators' fingers under single gloves or between double gloves, according to the surgeons' preference. All investigators were right hand dominant. A standard radiation film badge (MDH 2025, MDH Industries) was placed underneath the lead apron to measure the body dose. The image intensifiers had an image storage memory facility: the Siemens 3 K (Siemens AG, Munich, Germany) and the Phillips BV (25 and 300). Qualified radiographers familiar with polytrauma management always controlled the image intensifier. The mean value was 68 kV.

The study was initially carried out over a 5-month period at a busy district hospital. The objective was to estimate the risk of radiation exposure to the hands of a first-year orthopaedic specialist registrar (operating trainee) while performing six cases of intramedullary nailing (IMN). This particular procedure usually involves excessive screening and is frequently performed by trainees. Therefore, we used this opportunity to compare between different fingers in order to identify the finger that is likely to receive the highest radiation dose and to investigate the learning curve of the operating trainee with view to the screening time. The six cases represented non-complicated isolated femoral and tibial fractures and were performed during daytime trauma sessions and under the supervision of senior surgeons. TLD rings were placed at the base of the index and little fingers of both hands. In addition to the control dosimeter and the body badge, another film badge was attached superficially to a thyroid shield to measure the radiation dose to the thyroid gland.

The study was then conducted in another busy trauma unit of a university hospital over a 2-month period. Radiation exposure to two orthopaedic trauma consultants and an assisting trainee was monitored during the performance of 41 consecutive fluoroscopy-assisted procedures (Table 2). The exposure to consecutive and different operations in the second centre was meant to represent the average workload. TLD rings were placed at the base of the index and little fingers of both hands of the two consultants and the assisting trainee. TLD fingerstalls were placed over the dominant (right) index fingers of consultant B and the assisting trainee, with its sensor at the level of the fingertip. It was not practical to measure the fingertip radiation dose for consultant A, as he was operating on some emergency and life-threatening conditions like the fixation of pelvic fractures. The dominant index finger was selected as it recorded the highest dose from the operating trainee in the first centre. As described above, a control dosimeter and a body film badge were also used.

Results

Table 1 represents the learning curve of the operating trainee in the first centre. The screening time for distal locking was markedly reduced after the first 2 cases. The total screening time for the whole procedure was variable as it was affected by the type and severity of the fracture. There was no recorded dose from the control dosimeter or body and thyroid film badges. However, there were variable doses recorded from the fingers (shown in Table 3 along with the other investigators from the second centre).

Table 2 shows the screening time for the 47 different procedures from the two centres. Limited Invasive Stabilization System (LISS) plate was used for complex fractures of the distal femur. Open Reduction and Internal Fixation (ORIF) were done for fractures of the proximal femur, tibial plateau and tibial plafond. The screening time was high in certain procedures like LISS plate (109 s) and IMN (90–660 s). The 95% confidence interval (CI) was 118–190 for the operating trainee, 42–71 for the assisting trainee, and 40–90 for consultant A. The data for consultant B were skewed by the high screening time for a difficult case of femoral IMN. Therefore, the CI was not valid, the median of these data was 32, and the mean was 167.8. Variations in the screening time for the same type of procedure were

Table 1 Screening time (seconds) for 6 intramedullary nailing procedures (IMN) by the operating trainee in chronological order

Procedure	Screening time for distal locking	Total screening time for whole nailing
Left femoral nail	107	200
Left tibial nail	81	128
Right tibial nail	53	172
Left femoral nail	56	176
Right tibial nail	53	107
Right tibial nail	56	144

possibly due to variations in the severity and the personality of fractures.

Table 3 shows a comparison of the cumulative radiation dose (mSv) at the base of the index and little fingers of both hands for all investigators. A significantly higher dose was recorded for the dominant index finger of the operating trainee than for the other fingers (25 times that of the non-dominant little finger). The results of the other three investigators confirmed that no other fingers recorded a higher dose than the dominant index finger. Therefore, the cumulative doses from the dominant index finger were used as an endpoint for estimating the radiation exposure. There was no recorded dose from the control TLD or film badges of all investigators except consultant A whose body badge recorded 0.4 mSv. This dose is estimated to be below the yearly limit for body exposure.

Table 4 compares the screening time vs the cumulative radiation dose at the base of the index finger for each individual investigator. The operating trainee recorded a significantly higher radiation dose considering his screening time and the low number of procedures. This could be explained by the nature of the procedures he performed, as in IMN the hands are usually close to the beam. However, consultant B had no recorded dose at the finger base while he performed a difficult femoral IMN with a high screening time (660 s). This may indicate that a high radiation dose does not necessarily result from a high screening time because the radiation dose depends on how close the hands are to the X-ray beam. This also suggests that trainees could be at higher risk while performing IMN.

Table 5 shows that fingertips recorded a higher dose than the finger bases for the two investigators monitored. The dose recorded from the fingertip of the assisting trainee was surprisingly high relative to the dose recorded from the base of that finger (75 times). Consultant B also had a similar finding when his fingertip dosimeter recorded a dose that was not recordable by the dosimeter at the base of the finger. This indicates the higher sensitivity of monitoring fingertips compared with the finger base. It again indicates that trainees could be at higher risk while assisting.

Discussion

The risk of ionising radiation and its predisposition to cancer are known, and the incidence is rising [8]. The risk of local complications to extremities following overexposure of practitioners' hands to radiation is not fully appreciated. Scattered reports of complications such as acute radiodermatitis of fingers, basal cell carcinoma and even multiple amputations of digits [2, 6, 19] have been published. The effect of long-standing exposure to low-dose radiation is not known, and there is no evidence to suggest that there is a safe dose of radiation. It is widely accepted that radiation doses should be kept as low as reasonably achievable (ALARA principle). The International Commission on Radiological Protection [9] has established the standards for radiation protection including the dosage limits. The Ionising Radiation Regulation [21] has recently reduced the maximum whole-body dose, while the maximum

Table 2 List of all procedures and their screening time (seconds) for all investigators

Type of procedure	Investigators	LISS plate	IMN	Sacral screw	ORIF	Plating of pelvis	K wire & Ex Fix	Plating os calcis	Total no. of cases
No. of cases		2	10	3	12	8	9	3	47
Screening time	Operating trainee (1st centre)		200 128 172 176 107 144						6
Screening time	Assisting trainee (2nd centre)	109	117	40 51	60 60 40 14 69 100 40 20 119	40 60 30	30 86 60 66 11 30		22
Screening time	Consultant A (2nd centre)	109	90 190	51	60 40	40 60 30 30 40	30 86 60		14
Screening time	Consultant B (2nd centre)		660		95			32 26 26	5

Table 3 Comparison of the accumulated radiation dose (mSv) at the base of the index and little fingers of both hands for all investigators

	Right index	Left index	Right little	Left little
Operating trainee	10.3	1.5	1.0	0.4
Assisting trainee	0.4	0.3	0.4	0.3
Consultant A	0.7	0.4	0.7	0.5
Consultant B	0.0	0.0	0.0	0.0

extremity dose has not been revised. The current yearly dose limit for the body is 20 mSv, for the thyroid or eyes it is 150 mSv, while for the hands it is 500 mSv. However, the dose limit for non-classified workers (like orthopaedic surgeons) is only 30% of these limits (i.e. 150 mSv for the hands). Employees who are likely to exceed 30% of these limits must be registered as classified workers (like radiologists). The source of radiation may come directly from the primary beam or indirectly from scattered radiation. The hands of orthopaedic surgeons are at particular risk due to their proximity to the primary radiation and the lack of protective shielding. Previous studies [10, 14, 15, 16, 17] recognised that the hand dose is the limiting factor, in contrast to radiologists and cardiologists for whom the limiting factor is the dose to the lens of the eye. However, authors [5, 7, 10, 11, 13, 14, 15, 16, 17, 18] who measured the hand's radiation dose confirmed that it was far below the acceptable limit. These reassuring results may lead to a complacent attitude among surgeons.

We believe that the results of previous studies should be interpreted with caution. The radiation dose to the hands could be underestimated if one or more of the following factors have not been considered.

Monitoring junior surgeons and assistants Only a few studies [5, 10, 14, 16, 18] have monitored junior surgeons and assistants. It is expected that radiation exposure for senior surgeons would be less than that for trainees or unsupervised junior surgeons. Tasbas et al. [20] found that the assistant received a higher radiation dose than the orthopaedic surgeon, but he monitored thyroid and body badges rather than hands. Our results showed that the fingertip dosimeter from the assistant recorded the highest dose (Table 5). It also showed that the operating trainee received a relatively higher radiation dose while performing IMN (Table 4). The average radiation dose received by our operating trainee for every IMN is 1.86 mSv, and the yearly dose limit would be exceeded if he performed 81 IMN per year. Previous studies estimated that the dose limit would only be exceeded if more than 407 IMN [14] or 7614 fluoroscopy-assisted procedures [17] are carried out per year.

Table 5 Comparison between the accumulated dose (mSv) at the base and the tip of the dominant index fingers for consultant B and assisting trainee

	Finger base	Fingertip
Consultant B	0.0	0.2
Assisting trainee	0.4	29.98

Exposure to all procedures (average workload) Some studies monitored only certain procedures like IMN and forearm manipulation [4, 5, 11, 13, 14, 16]. Although these procedures may carry a higher risk of exposure, they do not represent the total exposure from all procedures and should not be used to estimate the yearly dose. Moreover, new percutaneous and minimally invasive procedures are being routinely introduced and may lead to more radiation exposure than IMN. The number of monitored procedures has to be large enough to represent the average workload. Smith et al. [18] reported that a fourfold increase in their workload would increase the dose received by two of their surgeons to above the limit. In the first part of our study, the recorded dose from the trainee who was exposed to only 6 cases of IMN was about 18% of the dose limit for his 5-month study period. The dose would have been much higher if we had monitored all the fluoroscopy-assisted procedures that he was involved in during the 5-month period. In the second part of our study, the exposure to different and consecutive surgical procedures was meant to represent the average workload during the 2-month study period. Therefore, the yearly dose could be calculated as six times the recorded dose.

Table 4 Number of cases per investigator, screening time and highest accumulated radiation dose (mSv) at the base of index fingers

	No. of cases	Total screening time	Accumulated dose	Average radiation dose per procedure (mSv)
Operating trainee	6 IMN (in 5 months)	927 (mean 154.50, SD 34.37)	11.2	1.86
Assisting trainee	22 cases (in 2 months)	1252 (mean 56.91, SD 32.23)	0.4	0.018
Consultant A	14 cases (in 2 months)	916 (mean 65.43, SD 43.36)	0.7	0.05
Consultant B	5 cases (in 2 months)	839 (mean 167.80, SD 276.68)	0.0	0.0

Locating dosimeters at the most susceptible parts of the hand The primary endpoint in estimating radiation exposure should be the recorded dose from the most susceptible part of the hand. This endpoint was not constant in these studies [5, 7, 10, 11, 13, 14, 15, 16, 17, 18] as variable locations were selected for the dosimeters: wrist, dorsum of the hand, metacarpals or the base of the fingers (commonly the dominant index finger using TLD rings). No scientific explanation was made for the selection of the dosimeter sites. Orthopaedic surgeons usually use their fingers to maintain reduction and to hold instruments or implants while screening. Their fingertips could receive a higher dose due to their proximity to the primary beam. The dosage to the fingertips of orthopaedic surgeons has not been measured or compared with other sites in any studies that estimated the yearly dose. To our knowledge, only one study [4] measured the radiation dose to the fingertips, but this was done while investigating the efficacy of protective gloves. That study monitored only one type of procedure (manipulation of forearm fractures) and did not compare the fingertip dose to other locations on the hand.

Our results compared doses between different fingers and also between finger base and fingertip to identify the most susceptible location. It showed that the dominant index finger recorded a relatively higher radiation dose than the other fingers (Table 4). A significant difference was also observed between the recorded radiation dose at the base and the tip of the dominant index finger (Table 5). Although the number of investigators is small, the finding is too important to be ignored. For the assisting trainee the fingertip dose was 75 times the finger base dose. The fingertip dose is alarming, while that of the finger base is below the acceptable limit and reassuring. One explanation is that the fingertip could be exposed to the primary beam. Though surgeons and assistants are aware that their hands should never be exposed to the primary radiation, it is not unusual for fingers to be accidentally caught in the beam. Jones and Stoddart [10] found that the surgeon's hand was caught in the fluoroscopy beam in 15% of procedures. Muller et al. [14] reported that the majority of their recorded dose occurred during brief exposure of the hands to the beam. Arnstein et al. [2] conducted an in vitro study and estimated that if the surgeons' hands enter the primary beam, the dose increases 100 times compared with that at 15 cm from the beam.

Measuring the cumulative dose For an accurate determination of radiation exposure, researchers should measure the accumulated dose at the end of several exposures rather than the dose per single procedure. TLDs have a detectable dose range (10 μSv to 30 Sv), and therefore any dose below the minimum will not be recorded. Sanders et al. [17] estimated that a surgeon would be able to perform 7614 fluoroscopy-assisted procedures per year before reaching the dose limit for hands. They used a different TLD for every operation, but only 8 (12%) out of 65 procedures showed positive recordings. Their estimation was based on extrapolation of the mean dose from the eight positive TLDs. No cumulative dose was measured from the other 57 procedures that had negative TLDs. If every negative TLD represented an exposure that was just below the recordable dose, the cumulative dosage would have been two and half times the dose recorded from positive TLDs. We measured the cumulative dose at the end of the study period to avoid underestimation.

Taking into account the dose limit for non-classified workers The yearly dose limit for classified workers (like radiologists) is 500 mSv, but for non-classified workers (like orthopaedic surgeons) it is 150 mSv. Some orthopaedic studies [7, 14] have mistakenly related their recorded dose to the dose limit of classified workers, thus underestimating the risk. In our study the 2-month cumulative dose for the assisting trainee based on the recording at his fingertip was 29.98 mSv. This dose is just above the dose limit for non-classified workers, but it would have been estimated to be below the limit if we had considered the classified workers' dose.

Although we disagree with the authors of previous studies [5, 7, 10, 11, 13, 14, 15, 16, 17, 18] that the hand's exposure is far below the acceptable limit, we agree with them that body exposure is below the acceptable limit. Only one surgeon in our study had a recordable dose from his body badge, which was below the limit. We believe like other authors [3, 18] that a lead apron is effective, and wearing routine film badges under a lead apron is an inadequate method of monitoring radiation exposure. In view of the results of this study and those of previous studies [10, 14, 15, 16, 18] and because of the proximity of the hands to the primary beam and the lack of an effective and convenient shielding, hands should be considered the limiting factor for orthopaedic surgeons.

Our study has some limitations. The number of investigators and hospitals is small, and the study is not necessarily representative. Smith et al. [18] stated that no study could be universally representative considering that workload, spectrum of procedures and surgeons' experiences are different. The result of this study, however, is a cause for concern, and we recommend raising awareness of the radiation risk and the protection measures. There are several factors that influence the received dose and the risk from radiation. Some of them are related to the type of image intensifier and the radiographer's experience. The factors that could be controlled by the surgeons are screening time, distance from the radiation source and shielding. This leads to some questions about how to control these factors. How could we reduce the screening time? Perhaps we need more supervision for trainees, more hands-on courses, workshops and surgical simulators. It is prudent to improve our operative techniques to reduce the screening time and increase the distance from the radiation. In hand and wrist surgery it is possible to use finger traps or similar methods to hold the patient's fingers, thus keeping the surgeon's hands away from the beam. How could we protect our hands? There are lead-lined gloves [4], but they are expensive, relatively thick and do not provide full protection. Is there an alternative to intraoperative fluoroscopy? Perhaps computer-assisted surgery [22] could be one option, but it is still experimental for the time being.

In conclusion, our study indicates that the risk of radiation exposure to the hands of orthopaedic surgeons is higher than previously reported. Trainees were at greater risk while performing IMN and while assisting. Dominant index fingers and particularly fingertips recorded a relatively higher radiation dose and should therefore be monitored in forthcoming studies. We call for strict measures to reduce radiation exposure and advise repeatedly estimating the risk of radiation.

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