



■ GENERAL ORTHOPAEDICS

Whole-body radiation exposure in Trauma and Orthopaedic surgery

**R. J. Hurley,
F. J. McCabe,
L. Turley,
D. Maguire,
J. Lucey,
C. J. Hurson**

From St Vincent's
University Hospital,
Dublin, Ireland

Aims

The use of fluoroscopy in orthopaedic surgery creates risk of radiation exposure to surgeons. Appropriate personal protective equipment (PPE) can help mitigate this. The primary aim of this study was to assess if current radiation protection in orthopaedic trauma is safe. The secondary aims were to describe normative data of radiation exposure during common orthopaedic procedures, evaluate ways to improve any deficits in protection, and validate the use of electronic personal dosimeters (EPDs) in assessing radiation dose in orthopaedic surgery.

Methods

Radiation exposure to surgeons during common orthopaedic trauma operations was prospectively assessed using EPDs and thermoluminescent dosimeters (TLDs). Normative data for each operation type were calculated and compared to recommended guidelines.

Results

Current PPE appears to mitigate more than 90% of ionizing radiation in orthopaedic fluoroscopic procedures. There is a higher exposure to the inner thigh during seated procedures. EPDs provided results for individual procedures.

Conclusion

PPE currently used by surgeons in orthopaedic trauma theatre adequately reduces radiation exposure to below recommended levels. Normative data per trauma case show specific anatomical areas of higher exposure, which may benefit from enhanced radiation protection. EPDs can be used to assess real-time radiation exposure in orthopaedic surgery. There may be a role in future medical wearables for orthopaedic surgeons.

Cite this article: *Bone Jt Open* 2022;3-11:907–912.

Keywords: Radiation, Fluoroscopy, Trauma, Safety, Image intensifier

Introduction

Orthopaedic trauma surgery requires regular use of fluoroscopic imaging. This exposes surgeons to scattered radiation from the patient.¹ Excessive radiation exposure can lead to early cataracts and cancer.²⁻⁵ Based on extensive evidence that radiation exposure can cause early cataract development, the International Commission on Radiological Protection (ICRP)⁶ have reduced recommended occupational dose limits for the lens of the eye from 150 mSv/yr to 20 mSv/yr.⁷ These regulatory limits are detailed in legislation SI-30 of 2019.⁸ Current recommendations are that all operators working in the controlled area of the orthopaedic theatre should wear a

lead apron, thyroid collar, and lead glasses along with dosimeters that are regularly analyzed.⁹⁻¹¹

Radiation exposure depends on a number of factors including the type and length of case, the orientation of the C-arm, position of the surgeon, and the personal protective equipment (PPE) worn.^{9,12} During seated procedures, the front of the lead skirt often separates, potentially allowing increased radiation exposure to the thighs (and gonads in male surgeons). Given the varied positions of the C-arm, the X-ray tube orientation plays a significant role in the exposure to the eyes and torso.¹³ The dose received by individual orthopaedic surgeons can be varied given the

Correspondence should be sent to Robert Joseph Hurley; email: robjhurley@gmail.com

doi: 10.1302/2633-1462.311.BJO-2022-0062.R1

Bone Jt Open 2022;3-11:907–912.



Fig. 1

Position of electronic personal dosimeters during standing procedures.



Fig. 2

Position of electronic personal dosimeter (EPD) 2 during seated procedures. Lead skirt placed over EPD.

diverse caseload. Few data exist within the literature to describe procedure-specific radiation exposure received by orthopaedic surgeons.

We wished to assess if current radiation protection equipment in orthopaedic trauma surgery is optimal. Additionally, we wished to evaluate the effects on surgeon radiation exposure of patient position, surgeon position, X-ray tube position, type of PPE worn, and trauma procedure type. Finally, we wished to assess if using electronic personal dosimeter (EPDs) could be used to create normative data on radiation exposure of specific cases.

Methods

This was a prospective observational study of radiation exposure received by orthopaedic trauma surgeons (consultant or senior trainee) during a six-week period. Radiation exposure was evaluated during fluoroscopic cases using two measurement techniques: real-time EPDs manufactured by Thermo Fisher Scientific (USA) (EPD-MK2), and thermoluminescent dosimeters (TLDs) manufactured by Harshaw (TLD-100H, Harshaw 5500 TLD reader). EPDs are digital, real-time dosimeters for measuring radiation exposure – these can give

individual-case radiation exposure levels. TLDs are passive radiation detection devices that are analyzed over a defined time interval. Both methods were employed simultaneously over the study period.

In the first method, three EPDs were attached to the operator for each case (Figure 1). During standing cases, the three dosimeters were placed in the following positions: EPD number 1 at the shoulder/neck to estimate exposure to the eyes, EPD number 2 at the hip facing the C-arm to measure the exposure to abdominal organs, and EPD number 3 at the level of the knees to replicate exposure to skin/leg from proximity to tube and under-table scatter (Figure 1).

During seated cases, EPD number 1 and number 3 were placed in the same positions. EPD number 2 was placed on the waist of the scrub suit trousers to rest in the groin under the lead apron to replicate gonadal exposure (Figure 2).

In the second method, 126 TLDs were attached to a lead apron, torso, and thyroid collar. These were attached in pairs on the inner and outer layers (Figure 3, Figure 4), providing a total of two readings inside and two readings outside the lead at each point. These TLDs were left in situ

Table I. Electronic personal dosimeters mean (range) results per case type/location and associated dose area product.

Procedure (n = 60)	EPD 1 (μSv)	EPD 2 (μSv)	EPD 3 (μSv)	DAP (μGym^2)
Short cephalomedullary nail (5)	3.2 (0 to 7)	9.6 (1 to 36)	4.2 (0 to 8)	194.2 (100 to 234)
Dynamic Hip Screw (1)	7	6	4	162
Femoral nail (2)	3.5 (2 to 5)	10 (10 to 10)	9 (5 to 13)	135 (135 to 135)
Ankle (10)	0	0.4 (0 to 1)	0.3 (0 to 1)	5.9 (2 to 12.2)
Foot/Calc (5)	0.6 (0 to 2)	0.25 (0 to 2)	0.2 (0 to 2)	3 (1.2 to 7.4)
Wrist/Forearm (20)	0.7 (0 to 6)	0.25 (0 to 1)	0.6 (0 to 5)	6.35 (1 to 37)
Shoulder (7)	0.9 (0 to 3)	0.9 (0 to 5)	0.4 (0 to 2)	31.7 (2 to 126)
Hip cannulated screws (2)	2.5 (1 to 4)	1 (1 to 1)	2 (1 to 3)	171 (163 to 179)
Patella tension band wire (2)	0.5 (0 to 1)	0.5 (0 to 1)	0.5 (0 to 1)	5 (5 to 5)
Elbow (3)	0.33 (0 to 1)	0	0	3.7 (3 to 5)
Hand (2)	0	0	0	1.5 (1 to 2)
Periprosthetic distal femur ORIF (1)	0	3	2	60

DAP, dose area product; EPD, electronic personal dosimeter; ORIF, open reduction and internal fixation.

for a period of six weeks and were worn by the surgeon in theatre for two to three days per week during a routine trauma list. This was used to represent the cumulative dose to which the surgeon was exposed.

As part of the annual screening programme, the lead apron used was checked prior to the study for any deformity or damage, and was deemed intact and suitable for use. The lead aprons used were composed of bilayer lead composite material manufactured by Safety First (UK), and had a lead equivalence (LE) of 0.25 mm. The apron style were two-piece with three-quarter overlap at the front. The length/size of the lead apron was compatible with the height/size of the operating surgeons, falling to just below the knee.

All fluoroscopic cases were recorded during the six-week measurement period, and the dose area product (DAP) per case was documented. DAP is a method of radiation dose monitoring used in fluoroscopic cases, and is an indication of the dose received by the patient. The cumulative dose from the TLDs was measured using an in-house TLD reader. Both the reader and each of the TLDs were calibrated to ensure accurate dose measurement.

Results

Overall, 60 fluoroscopic trauma procedures were performed during the study period. Total DAP from all 60 procedures was 2,135.5 μGym^2 . The cumulative recorded dose at the position of EPDs 1, 2, and 3 were 60 μSv , 94 μSv , and 70 μSv respectively for these 60 cases. A breakdown of procedure locations/types/numbers and their associated EPD and DAP results are presented in Table I.

TLD data showed that the lead aprons were effective in reducing radiation dose significantly, as evidenced by the radiation dose maps of Figures 5 and 6. Lead aprons attenuate more than 90% of the incident radiation and this was evident in the measurements where the incident dose to the outside of the lead apron using TLDs was compared with the dose measured under the lead apron

(Figure 5, Figure 6). A table of these results (average) is provided in Table II.

The dose measurements were then extrapolated to a 48-week period to represent a year's exposure to the surgeon.

The individual procedure EPD measurements were documented per case; the EPD results were extrapolated in a different manner. The lead investigator's (RH) logbook of a previous year in a trauma unit was used as a template. The mean recorded EPD result per procedure was then multiplied by the number of those procedures performed. Additionally, a 'theoretical' busy trauma job logbook was created, and EPD doses were extrapolated for this in an effort to show that EPD measurements can be used to create normative data for surgical procedures.

When TLD data were extrapolated to annual dose, the maximum torso dose on the inside of the apron was estimated to be 0.14 mSv/yr. This is a low level of exposure, substantially below the 6 mSv limit for category B workers as defined in SI-30 of 2019. The maximum exposure to the lens of the eye was estimated (based on results from thyroid collar) to be 0.7 mSv/yr without eye protection. If the surgeon is wearing lead glasses, this can be expected to reduce by a factor of 2.5 to 4.5,¹⁴ with the annual exposure to the lens of the eye estimated to be less than 0.28 mSv/yr based on a typical workload as outlined in Table I. Again, this is a low level of exposure, significantly below the 15 mSv dose limit to the lens of the eye for category B workers. The maximum dose to the knee and inner thigh was estimated to be 2.7 mSv/yr, which is higher than the whole-body dose recorded and likely reflects the parting of the lead apron folds during seated procedures.

EPD average results for different cases at EPD 1, 2, and 3 are summarized in Table I. This also includes the average DAP for these cases. It was noted that higher patient DAP measurements correlated with higher EPD results. Certain outliers in the EPD data were assessed



Fig. 3

Position of thermoluminescent dosimeters on lead apron.



Fig. 4

Position of thermoluminescent dosimeters on lead skirt.

Table II. Mean (range) outside versus inside thermoluminescent dosimeter results and percentage reduction.

Mean outside (μGy)	Mean inside (μGy)	Percentage reduction
163 (335 to 2)	14.4 (37 to 0)	91.1

and found to be associated with patients with high BMI (classified as $> 30 \text{ kg/m}^2$; the noted outliers were $> 35 \text{ kg/m}^2$), however there was insufficient evidence to correlate this statistically, as case complexity also played a key part. Hip procedures and femoral nails had the highest patient DAP measurements, and therefore highest scatter to the surgeon, as evident from the EPD data.

Discussion

Radiation protection equipment in orthopaedic trauma theatre adequately reduced radiation exposure to surgeons to below recommended thresholds. This study quantifies the radiation dose to operator's torso, eyes, and lower limbs for individual surgical procedures. This study sought primarily to identify if current protective devices are adequate, and if there were any gaps in protection, particularly for situations where the operator is seated. It also assesses if there are certain aspects of orthopaedic surgery or if there are certain procedures that have higher exposure. Finally, it demonstrates the usefulness of EPDs in providing real-time measurement of radiation exposure for individual cases in orthopaedics.

The study is reassuring in its demonstration that the use of lead aprons reduces the radiation exposure to the torso to optimal levels. It also shows that estimated exposure to the eyes is minimal in this series of cases. However it highlights an area of increased risk to the seated operator where a lead skirt does not fully overlap once the surgeon is seated. This study estimates an annual exposure of 2.7 mSv/year to the inner thigh. While not exceeding the dose limit, this is not optimal, and a change to the PPE specification has been suggested to reduce the dose to the legs during seated procedures. An additional protective lead panel for the operator's legs has been included in the revised PPE specification for orthopaedics as well as urology theatres. An increase to the length of the apron by 10 cm has also been introduced to better protect operators who will be seated for some exposures. Overall, the observations from this study have resulted in a notable change in the PPE specification for seated procedures in theatre at our institution.

By extrapolating the above mean results to a previous trauma job completed by said lead investigator, the annual dose was found to be at an acceptable level. In a year where 25 short cephalomedullary nails, 26 dynamic hip screws, and 18 femoral nails were used, the annual exposure to the eyes, torso (outside lead), and legs (edge of skirt) were estimated to be 0.3 mSv , 0.58 mSv , and 0.45 mSv , respectively. These are well below the occupational dose limits.

In an effort to ascertain if the EPD results would be beneficial to show surgeons their anticipated radiation exposure based off logbook data, the results were extrapolated to a busy trauma job, where one might operate three days per week, 48 weeks of the year, and use two short cephalomedullary nails, one dynamic hip screw, and one femoral nail on average per day. Based on our EPD results the annual exposure to the eyes, torso

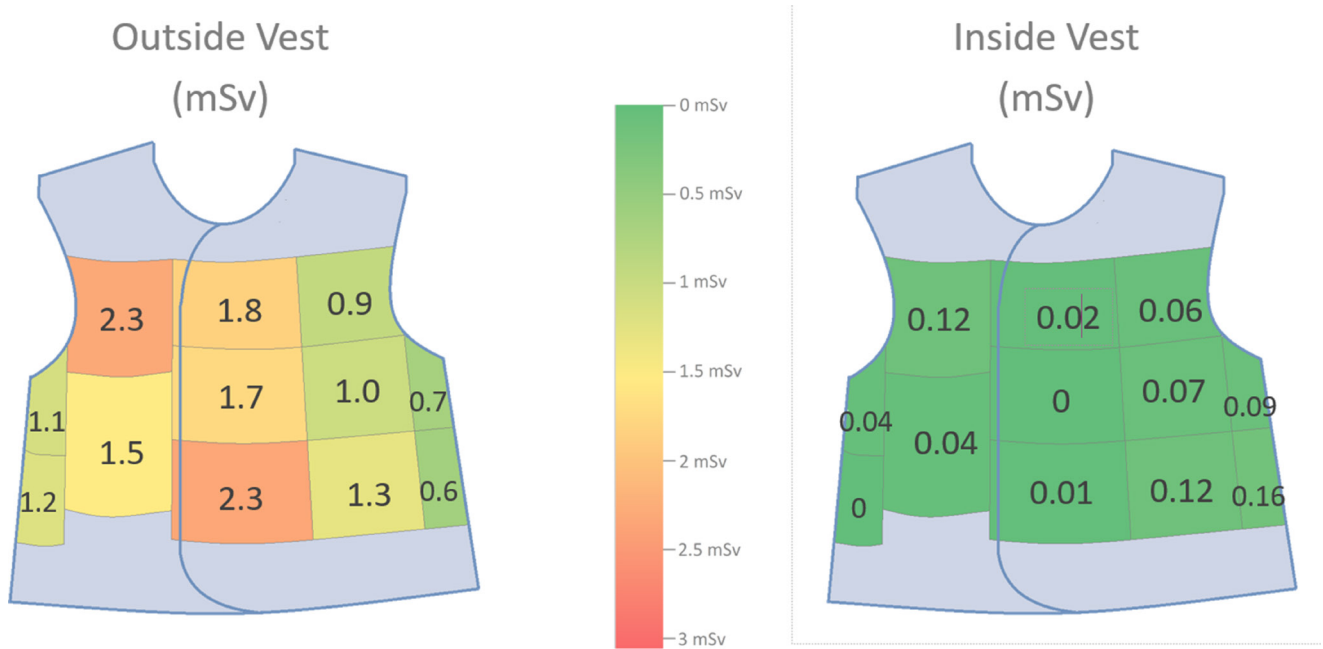


Fig. 5

Thermoluminescent dosimeter results outside (left) and inside (right) of gown.

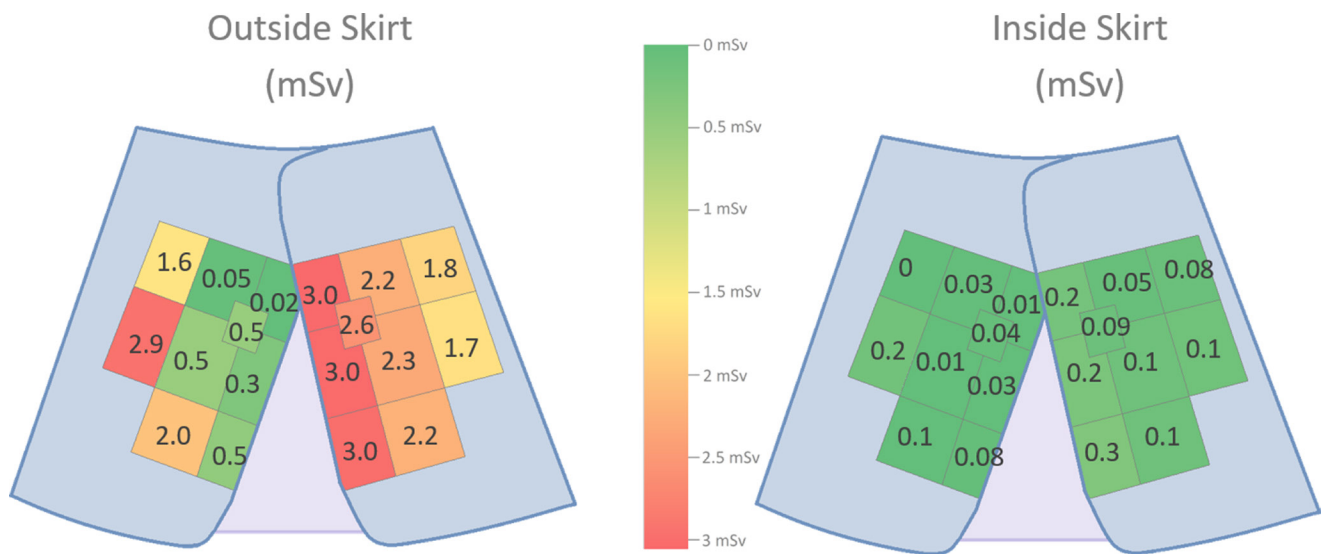


Fig. 6

Thermoluminescent dosimeter results outside (left) and inside (right) of apron.

(outside lead), and leg (edge of skirt) would be 2.4 mSv, 5.3 mSv, and 3.8 mSv, respectively. Our study shows the use of lead aprons would mitigate the risk to the torso and leg (as lead aprons will attenuate more than 90% of the dose) and reduce the whole-body dose to 0.4 mSv. Although not directly measured, it would also support the use of lead glasses to minimize the risk to the eye in higher dose procedures. Lead glasses typically reduce the dose to the lens of the eye by a factor of 2.5 to 4.5, which would re-estimate the eye dose to approximately 1 mSv.

Our study was limited in that no EPD data on hand exposure could be collected, as the EPDs were not suitable to be sterilized or worn under theatre gowns. The EPD data for eyes were estimated based on the EPD placed on the thyroid collar. The EPD used in this study was too large to place at the level of the eye.

The total numbers of cases are small. More cases would be beneficial to obtain normative data for all procedures. The extrapolation of low number cases (e.g.

DHS/Femoral nail) may compound any error as there is a low number of these cases in the study.

Patient BMI for hip procedures appeared to be linked with higher DAP and EPD results. Further studies to measure the effect that BMI has on DAP and EPD and the increased dose to the operator should be undertaken. Given the increasing BMI in most populations,¹⁵ this would be of benefit to surgeons.

This study supports the use of EPDs to collect this data. This may be used in conjunction with a surgeon's logbook to measure exposure to radiation for new procedures or when optimizing existing procedures. In the era of wearable medical technology, there may be a role for more regular use of EPDs in higher-exposure surgeries.

In conclusion, this study demonstrated that current protective equipment used in orthopaedic theatres is sufficient to protect against radiation exposure during procedures using fluoroscopy. It shows that occupational exposure to the eye and torso is well below category B dose limits, but that the dose to the surgeon's legs during seated operating was elevated – likely due to the gap in lead protection. This resulted in a change in PPE specification for seated procedures in theatre. It identified higher doses in certain procedures, and a connection with higher patient BMI and higher radiation exposure to staff.

We believe this study confirms the validity of using EPDs to provide real-time information of radiation exposure for different orthopaedic cases so as to optimize staff radiation protection measures. It is the plan of the investigators to continue to collect EPD results of different procedures in an effort to obtain more normative data on specific procedures. There may be a role in using EPDs for higher exposure procedures. There is a role in identifying and quantifying the link between patient BMI and surgeon's exposure to radiation.



Take home message

- Current radiation personal protection equipment when used appropriately in orthopaedic trauma surgery is safe.
- There may be some positions that increase risk and exposure which may benefit from enhanced radiation protection.
- Electronic personal dosimeters can assess real-time radiation exposure and may have a role in future medical wearables for orthopaedic surgeons.

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Author information:

- R. J. Hurley, MB BCh, BAO, MCh, FRCS (Tr&Orth), Specialist Registrar in Trauma and Orthopaedics
- F. J. McCabe, MB BCh, BAO, MCh, MRCSI, Specialist Registrar in Trauma and Orthopaedics
- L. Turley, MB BCh, BAO, MSc, Registrar in Trauma and Orthopaedics
- C. J. Hurson, MB BCh, MCh, AFRCSI, FRCSI (Tr&Orth), Consultant Trauma and Orthopaedic surgeon
Department of Trauma & Orthopaedics, St. Vincent's University Hospital, Dublin, Ireland.
- D. Maguire, BSc, MSc, Senior Medical Physicist
- J. Lucey, BSc, PhD, Chief Medical Physicist
Medical Physics and Clinical Engineering, St. Vincent's University Hospital, Dublin, Ireland.

Author contributions:

- R. J. Hurley: Data curation, Investigation, Methodology, Project administration, Writing – original draft.
- F. J. McCabe: Investigation, Writing – review & editing.
- L. Turley: Investigation, Writing – review & editing.
- D. Maguire: Formal analysis, Investigation, Visualization.
- J. Lucey: Conceptualization, Methodology, Formal analysis, Writing – review & editing.
- C. J. Hurson: Conceptualization, Methodology, Project administration, Writing – review & editing.

Funding statement:

- The authors received no financial or material support for the research, authorship, and/or publication of this article.

Acknowledgements:

- The authors wish to thank all the staff in theatre, medical physics and radiology in St Vincent's University Hospital in their assistance in completing this project.

Open access funding

- The authors confirm that the open access fee for this study was self-funded.

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