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Quantification of Radiation Exposure in Canadian Orthopaedic Surgery Residents

Calgary Orthopaedic Resident Research Group*

Introduction: Natural radiation exposure in the general population averages 3 milliSieverts (mSv) annually; however, radiation exposure in orthopaedic residents is not well defined. Despite protective measures, evidence of radiation-related diseases in orthopaedic surgeons is increasing. The purpose of this study was to quantify radiation exposure in orthopaedic residents and to determine the variability of exposure among post graduate year (PGY) of residency.
Methods: Monthly radiation exposure was measured prospectively over a 12-month period in orthopaedic surgery residents from a single program. Participants wore dosimeters above ("exposed") and beneath ("shielded") protective lead. The primary outcome measure was the absolute value of radiation exposure in mSv. Repeated measures analysis was used to assess exposure with age, sex, year of training, operating room (OR) days, and height.
Results: Mean annual occupational radiation exposure was 3.30 ± 0.64 mSv over an average of 107 ± 38 OR days. Mean exposure per OR day was 0.033 ± 0.008 mSv. PGY-2 and PGY-3 residents had the highest cumulative exposure, and PGY-5 residents had the highest mean exposure per OR day (0.044 ± 0.009 mSv/d). Number of OR days per month and PGY level were significant predictors of radiation exposure ($p < 0.05$). Sex, age, and height were not significant in predicting radiation of the exposed dosimeter.
Conclusions: Orthopaedic residents' exposure to radiation is nearly twice the general population's exposure. Given that yearly radiation exposure was highest during early residency years, but exposure based on number of OR days was highest in the final year of training, it is essential for resident education regarding radiation safety and safe clinical practices throughout their training.

Background

Minimally invasive techniques in orthopaedic surgery have become the standard of care in many areas to decrease patient morbidity by minimizing surgical exposure. Therefore, intraoperative fluoroscopy is increasingly necessary for orthopaedic management[1-3]. These techniques require the surgical team to work near the x-ray beam, resulting in increased exposure to radiation scatter[4-7]. Certain subspecialties within

*A list of the Calgary Orthopaedic Resident Research Group members is provided in a Note at the end of the article.

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orthopaedic surgery are exposed to higher amounts of radiation due to the nature of the procedures performed. For example, Gausden et al. (2017) found that attending orthopaedic surgeons specializing in trauma or deformity surgery received the highest radiation exposure[8]. Fluoroscopic intensive procedures, such as those that use locked intramedullary nailing systems, are responsible for the highest radiation doses[1,2,7].

The International Commission on Radiological Protection defines 20 mSv per year as the maximum permissible occupational exposure[1]. Exposure to this dose is associated with an additional lifetime risk of fatal cancer of 1 in 1,000[9]. For comparison, the average individual is exposed to 3 mSv per year from background radiation[9]. In addition to background radiation, surgeons are exposed to x-ray scatter intraoperatively. Scatter comprises 10% to 20% of the emitted photons from the x-ray beam[9]. Factors affecting a surgeon's radiation dose include exposure time, distance from the beam's central axis, orientation of the fluoroscopic beam relative to the patient, position of the surgeon within the operative field, and use of protective equipment[10]. Other factors that influence a surgeon's radiation exposure include increased patient body mass index and fracture complexity[11].

Documented risks associated with radiation exposure include cataract formation, skin cancer, thyroid cancer, and leukemia[12,13]. Despite protective equipment, there is an increasing incidence of radiation-related diseases in orthopaedic surgeons. The risk of developing cancer (i.e., thyroid carcinoma) is 8 times higher in an exposed worker than a shielded worker, and the risk of harmful levels of radiation at eye level is highest during pelvic fixation and femoral intramedullary nailing[14,15]. Chou et al. (2012) also suggested that there may be a correlation between radiation exposure and increased risk of breast cancer in female orthopaedic surgeons[16]. A subsequent simulation study identified higher radiation dose-equivalent rates in the upper-outer breast quadrant, the most common site of all breast cancers[17]. As the number of female orthopaedic staff and trainees increases, radiation safety in this subgroup becomes increasingly important.

To our knowledge, radiation exposure has not been studied in orthopaedic surgery residents working in the Canadian public health care system. The purpose of this study was to (1) quantify the amount of radiation exposure throughout orthopaedic residency and (2) determine the variability of radiation exposure through different years of training.

Methods

Following local research ethics board approval (REB17-2030), all orthopaedic surgery residents from postgraduate year (PGY) 1 through PGY-5 were invited to enroll in this study. Exclusion criteria were pregnant residents, and residents taking a nonsurgical year (i.e., leave of absence or research year). All residents who met inclusion criteria and provided informed written consent were enrolled in the study.

Each participant was provided with 2 dosimeters to wear in a standardized fashion. One dosimeter was worn underneath protective lead ("shielded dosimeter"), to capture expected environmental exposure, while the other was worn outside protective lead ("exposed dosimeter"), to quantify the additional intraoperative occupational exposure. Dosimeters were exchanged monthly for analysis, as per standardized protocols at our institution. Each month, residents reported their rotation, number of days spent in the operating room (OR), and whether they wore dosimeters for at least 80% of their OR days. When residents did not wear their dosimeters for a minimum of 80% of their OR days in 1 month, their average radiation exposure was used as a surrogate estimate for that month. In the case of missing dosimeter data for a given month, a surrogate estimate of radiation using the shielded dosimeter or an average of the other shielded dosimeter measures in the same month was used. If a resident did not wear their dosimeters for a minimum of 80% of their OR days across the total study period, their results were excluded from the analysis. Dosimeter data were collected on a monthly basis, as per our institutional regulations; however, the academic year is divided into 13 blocks. Therefore, monthly rotation-specific analysis was completed when there were 28 days or greater on the rotation dedicated to a certain subspeciality. At the study's institution, all residents wore the appropriate lead protective equipment including, vest, skirt, and thyroid collar.

The primary outcome measure was the absolute value of radiation exposure in mSv, as measured by the difference in radiation detected by exposed and shielded dosimeters and reported as per OR day. Secondary outcomes included radiation exposure based on age, sex, year of training, and dosimeter compliance.

Continuous variables are reported as means and standard deviations. Categorical variables are reported as proportions. Repeated measures analysis was used to determine which variables correlated with radiation exposure. Mean monthly radiation was calculated per individual, and continuous variables were assessed using linear regression, and categorical variables were assessed using analysis of variance (ANOVA) and Tukey adjusted pairwise comparisons. A one-way repeated measures ANOVA was conducted to examine the effect of rotation on radiation exposure. p values were considered significant at $\alpha \leq 0.05$ and β of 0.2. Statistical analyses were completed using the statistical software R 4.0.5.

Results

Twenty-one orthopaedic residents from a single Canadian institution were enrolled in this study. Three residents who reported less than 80% compliance for the duration of the study were removed from analysis. There were 18 data points (of a possible 216 data points) that required imputation because of missing data, using either the shielded dosimeter data (n = 14) or an average of all other shielded dosimeters in the same month (n = 4). Subject characteristics are presented in Table I.

Table II presents the mean data for number of OR days, yearly occupational radiation exposure, and radiation exposure per OR day. PGY-3 residents participated in the highest number of OR days at 166 ± 16 days within the 1-year study period. PGY-3 and PGY-2 residents were exposed to the highest yearly radiation doses (4.03 ± 0.48 mSv and 3.70 ± 0.28 mSv,

TABLE I Subject Characteristics

	n = 18
Age, mean (SD)	28.4 (2.5)
Sex, n (%)	
Female	7 (38.9)
Male	11 (61.1)
Residency year, n (%)	
1	4 (22.2)
2	3 (16.7)
3	3 (16.7)
4	4 (22.2)
5	4 (22.2)
Personal lead, n (%)	
Yes	1 (5.6)
No	17 (94.4)
Lead glasses, n (%)	
Yes	5 (27.8)
No	13 (72.2)
Children, n (%)	
Yes	1 (5.6)
No	17 (94.4)

SD = standard deviation.

respectively); however, PGY-5 residents were exposed to the highest radiation doses per OR day (0.044 ± 0.009 mSv) compared with other residency years (Fig. 1). Repeated measures analysis determined that sex, age, and height were not significant in this analysis when the outcome is the exposed dosimeter reading or the difference between exposed and shielded dosimeter readings.

The predictors mean monthly OR days and experience (PGY level) explained 56% of the variance in radiation exposure (adjusted R2 = 0.56, F(5,12) = 5.37, p = 0.008). Monthly OR days significantly predicted total radiation (β = 0.008, p = 0.001). ANOVA was used to determine significance between radiation and PGY level (p = 0.028). Significant pairwise comparisons were PGY-2 to PGY-1 (mean diff = 0.068, p.adj = 0.049) and PGY-3 to PGY-1 (mean difference = 0.066, p.adj = 0.066).

Evaluation of the mean radiation exposure per OR day demonstrated the highest mean radiation exposure during the foot and ankle rotation (0.013 ± 0.0081 mSv) and the lowest during the hand and wrist rotation (0.001 ± 0.0018 mSv; Fig. 2 and Table III). Results showed that the rotation did not lead to statistically significant differences in radiation exposure (F(7,10) = 2.661, p = 0.078).

Discussion

The purpose of this study was to determine the dose of occupational radiation to which orthopaedic residents are exposed and to characterize differences in radiation exposure by year of training. Our results demonstrate that annually, orthopaedic residents are exposed to double the radiation dose as the general population[9]. However, this annual dose is still below the safe yearly occupational exposure limit of 20 mSv. We also found that radiation exposure varies by training level. More junior residents, specifically those in PGY-2 and PGY-3, were exposed to the highest doses of yearly radiation, while PGY-5 residents were exposed to the highest doses of radiation per OR day. We hypothesize that the increased exposure among PGY-2 residents may result from their increased involvement as a primary surgical assist, necessitating closer proximity to the image intensifier during procedures. Interestingly, although PGY-3 residents faced elevated yearly radiation doses, likely because of the intensive nature of their rotation schedule requiring more frequent OR days, they exhibited the lowest exposure per OR day (Table II). We attribute this discrepancy to the nature of rotations completed during PGY-3, which includes predominately arthroscopic procedures in sports and less fluoroscopy-intensive surgeries in oncology, characterized by more open resection procedures (Supplementary Table). Moreover, the elevated radiation exposure observed in PGY-5 residents per OR day can likely be attributed to the rotation schedule during this year of training. Specifically, PGY-5 residents

TABLE II Mean Radiation Exposure Per Residency Year

Training Year	n*	OR Days, Mean ± SD	Yearly Occupational Radiation Exposure† (mSv), Mean ± SD	Radiation Exposure Per OR Day† (mSv), Mean ± SD
PGY-1	4	86 ± 23	2.95 ± 0.72	0.035 ± 0.002
PGY-2	3	116 ± 17	3.70 ± 0.28	0.032 ± 0.004
PGY-3	3	166 ± 16	4.03 ± 0.48	0.024 ± 0.002
PGY-4	4	119 ± 9	3.35 ± 0.17	0.028 ± 0.003
PGY-5	4	66 ± 23	2.73 ± 0.51	0.044 ± 0.009

*Residents with <80% compliance were excluded from summative data. †Exposure quantified as absolute value of exposed dosimeter—shielded dosimeter. mSv = millisievert, OR = operating room, PGY = postgraduate year, and SD = standard deviation.

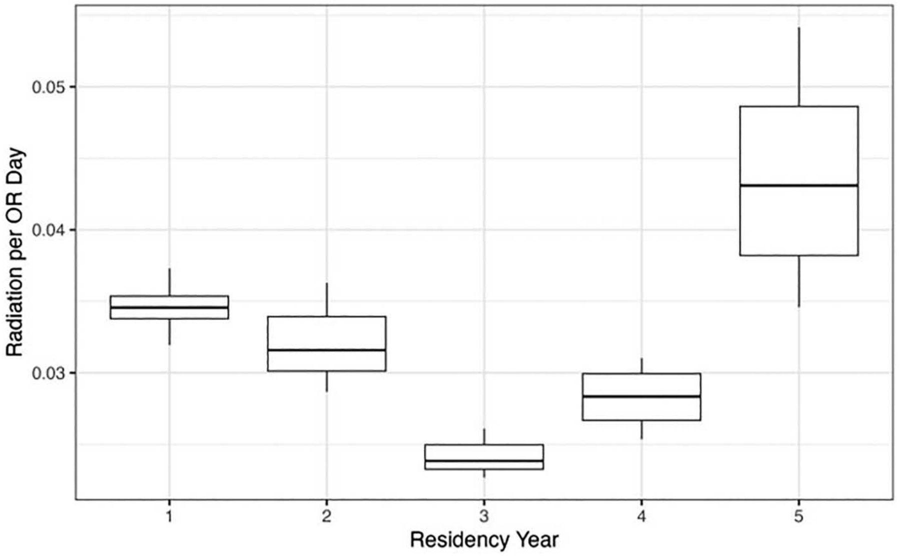

Fig. 1
Radiation exposure per operating room day by residency year.

undergo 3 months of senior trauma rotations, where they are entrusted with greater operative independence, to facilitate a transition into independent practice, potentially leading to increased exposure to radiation (Supplementary Table). Furthermore, their 3-month pediatric rotation could also be contributing to this higher exposure, as trauma cases and certain elective pediatric subspecialities often necessitate significant use of radiation during these procedures. While PGY-4 residents displayed similar OR days as PGY-2 residents, their radiation exposure was lower, this could be the result of less on-

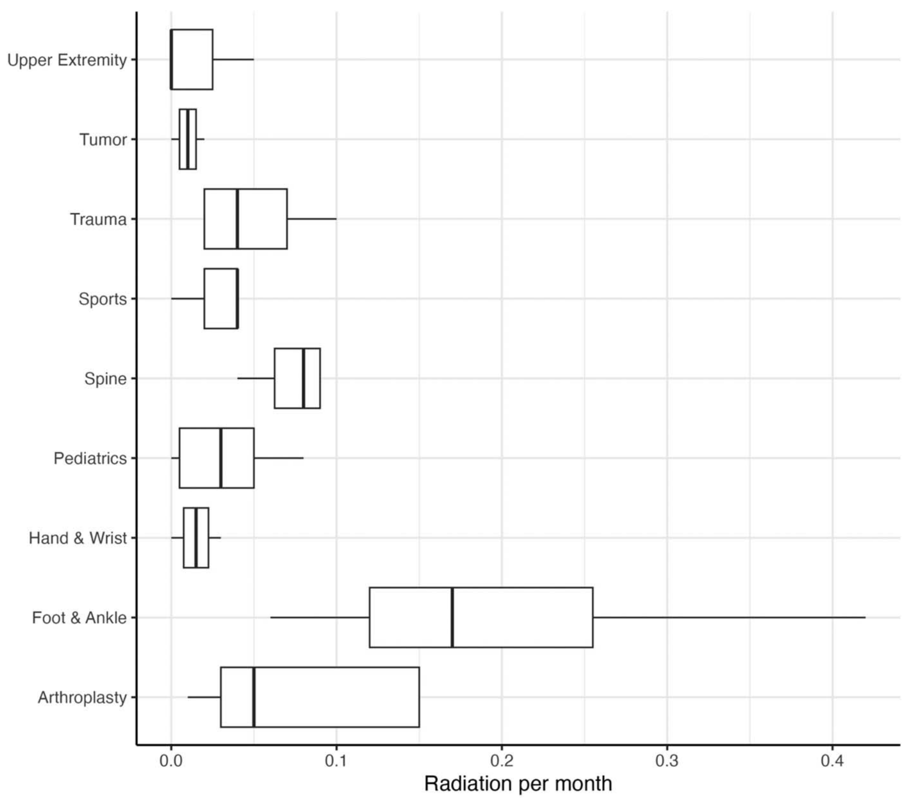

Fig. 2
Mean radiation exposure per month based on surgical training rotation.

TABLE III Mean Radiation Exposure Per Month Based on Surgical Training Rotation

Rotation	n*	OR Days (sum)	Average OR Days	Radiation Exposure Per OR Day† (mSv), Mean ± SD	Max Radiation Exposure Per OR Day† (mSv)
Arthroplasty	5	68	13.6	0.006 ± 0.0045	0.15
Foot and ankle	4	61	15.3	0.013 ± 0.0081	0.42
Hand and wrist	2	21	10.5	0.001 ± 0.0018	0.03
Pediatrics	7	60	8.6	0.003 ± 0.0031	0.08
Spine	4	42	10.5	0.010 ± 0.0090	0.09
Sports	3	24	8.0	0.005 ± 0.0050	0.04
Trauma	4	56	14.0	0.004 ± 0.0039	0.10
Tumor	2	32	16.0	0.001 ± 0.0009	0.02
Upper extremity	3	25	8.3	0.002 ± 0.0029	0.05

*Residents with a minimum of 1 month's time on the specific rotation. †Exposure quantified as absolute value of exposed dosimeter—shielded dosimeter. mSv = millisievert, max = maximum, OR = operating room, and SD = standard deviation.

call shifts relative to PGY-2 residents, as well as potentially some increased awareness for radiation safety practices that develop with experience.

Our Canadian study results are consistent with previously published studies from around the world that reported that orthopaedic surgeons, and residents do not exceed the safe yearly occupational exposure limit of 20 mSv per year, which equates to 0.05 mSv per day[1,2,8,11]. Given that the highest yearly radiation exposure in our study occurred during junior years, an important opportunity for radiation safety training exists early in residency. Training initiatives should emphasize the importance of wearing all commercially available components of personal protective equipment, including leaded vests and aprons, leaded eyewear, and thyroid collars. Though not specifically examined in this study, the effectiveness of leaded eyewear and thyroid shields has been demonstrated by Cheon et al., who highlighted the meaningful attenuation of radiation provided by both these pieces of personal protective equipment[18].

The highest radiation exposure per OR day occurred during PGY-5, with the mean daily exposure for PGY-5 residents, at 0.044 ± 0.009 mSv, approaching the maximal recommended daily value. Recently, orthopaedic resident radiation exposure was investigated in a private practice setting in the United States[8]. This study demonstrated a wide range of average monthly OR radiation exposure (0.002 to 0.79 mSv). Their results showed that senior residents were exposed to significantly higher annual doses of radiation than junior residents. This finding is contrary to our results and may reflect the difference between public and private health care training models. At our institution, residents are exposed to the OR very early in training, particularly in the trauma setting, where fluoroscopy is used frequently (Supplementary Table). The correlation between radiation exposure and the surgeon's years of OR experience has been consistently demonstrated, as the surgeon gains more experience in the OR, there is a discernible trend of reduced radiation exposure[2,8,11]. In our study, PGY-2 and PGY-3 residents had the highest annual radiation exposure, suggesting greater radiation exposure with less experience.

Rotation-specific differences were observed between rotations, with the foot and ankle rotation demonstrating the highest exposure per day and the hand and wrist rotation having the lowest exposure, which supports our hypothesis about the rotations that require more fluoroscopy resulting in higher resident radiation exposure.

There are some limitations to this study. Though the sample size was small, all orthopaedic surgery residents participated in the study. While our study relied on self-reported dosimeter use, there was good compliance, and we excluded those participants with less than 80% adherence. Variation in placement of the exposed and shielded dosimeter, as well as participant height, and proper lead sizing may have affected the exposure measurements, and we also did not account for variations in radiation safety habits, such as stepping away from the radiation source, and the use of lead glasses. As our dosimeter data were collected on a monthly basis, while rotations lengths varied, we can only report monthly radiation exposure for those months where the dosimeter measurement aligned with a full month of rotation-specific exposure. We did not include case logs for specific procedures, which limits our ability to correlate radiation exposure with procedure type. However, the heterogeneity of our study participants, the prospective cohort design, and standardized rotation schedule mitigated some of these issues and made the results more generalizable to real-world applications.

Conclusions

Orthopaedic residents' occupational exposure to radiation is high, resulting in nearly twice the general population's annual exposure. Total number of OR days and experience

(PGY level) were responsible for the variance in average annual exposure. While highest yearly exposure occurred in PGY-2 and PGY-3, highest daily exposure occurred in PGY-5 and approached the maximum daily occupational exposure limit. This study provides novel prospective data that highlight the critical need for radiation safety training early in residency training but also during the final year, where more autonomy occurs in preparation for transition into practice. This study also supports the need for the use of effective protective equipment for all orthopaedic surgery residents.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A635). This content was not copyedited or verified by JBJS. ■

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