



AOA Critical Issues in Education

Improved Radiation Exposure Monitoring of Orthopaedic Residents After Institution of a Personalized Lead Protocol

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Investigation performed at Louisiana State University Health Sciences Center, in Shreveport, Louisiana.

Background: Radiation exposure of orthopaedic residents should be accurately monitored to monitor and mitigate risk. The purpose of this study was to determine whether a personalized lead protocol (PLP) with a radiation monitoring officer would improve radiation exposure monitoring of orthopaedic surgery residents.

Materials and Methods: This was a retrospective case-control study of 15 orthopaedic surgery residents monitored for radiation exposure during a 2-year period (March 2017 until February 2019). During the first 12-month period (phase 1), residents were given monthly radiation dosimeter badges and instructed to attach them daily to the communal lead aprons hanging outside the operating rooms. During the second 12-month period (phase 2), a PLP (PLP group) was instituted in which residents were given lead aprons embroidered with their individual names. A radiation safety officer was appointed who placed the badges monthly on all lead aprons and collected them at the end of the month, whereas faculty ensured residents wore their personalized lead apron. Data collected included fluoroscopy use time and radiation dosimeter readings during all orthopaedic surgeries in the study period.

Results: There were 1,252 orthopaedic surgeries using fluoroscopy during phase 1 in the control group and 1,269 during phase 2 in the PLP group. The total monthly fluoroscopy exposure time for all cases averaged 190 minutes during phase 1 and 169 minutes during phase 2, with no significant difference between the groups ($p < 0.45$). During phase 1, 73.1% of the dosimeters reported radiation exposure, whereas during phase 2, 88.7% of the dosimeters reported radiation exposure ($p < 0.001$). During phase 1, the average monthly resident dosimeter exposure reading was 7.26 millirems (mrem) \pm 37.07, vs. 19.00 mrem \pm 51.16 during phase 2, which was significantly higher ($p < 0.036$).

Conclusions: Institution of a PLP increased the compliance and exposure readings of radiation dosimeter badges for orthopaedic surgery residents, whereas the actual monthly fluoroscopy time did not change. Teaching hospitals should consider implementing a PLP to more accurately monitor exposure.

Level of Evidence: 3.

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (<http://links.lww.com/JBJSOA/A356>).

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The use of interventional radiologic techniques, such as C-arm fluoroscopy, has become routine in many orthopaedic procedures. C-arm fluoroscopy allows for real-time intraoperative images to aid as a diagnostic tool and improve procedural outcomes¹. Intraoperative fluoroscopy has decreased patient morbidity by shortening procedural time and allowing the use of smaller operative fields². Despite its benefits, there are potential risks for both the patient and the medical team associated with this intraoperative radiation exposure. Some states require training with licensing before physicians can use fluoroscopy. Although our region does not require a license for fluoroscopy use, proper training and licensing may improve radiation safety awareness. Furthermore, orthopaedic surgeons frequently use operative techniques that necessitate close proximity to the radiation source during lengthy procedures, with theoretical risk for adverse radiation-related events^{2,3}.

Intraoperative radiation exposure may manifest as stochastic effects, theoretically leading to neoplasia or genetic changes¹. Deterministic events are also possible, occurring at specific threshold radiation doses, with potential consequences including cataracts or sterility¹. Radiation exposure and these possible risks can be reduced with lead gowns, shielding, or distancing from the patient^{3,4}. It is the responsibility of the training hospital to monitor the radiation exposure of residents and ensure the safety of learners. Unfortunately, monitoring can be difficult, and oftentimes inaccurate, for a variety of reasons, such as improper placement of dosimeters or failure to wear the dosimeter or return it for assessment⁵.

A survey of 517 orthopaedic residents reported that 98% believed personal protective equipment for radiation safety should be provided; however, only 54.2% reported that equipment was provided⁶. Previously, our teaching hospital did not provide personalized lead aprons to residents, and radiation monitoring badges were given to residents monthly. Residents were solely responsible for finding communal lead aprons and placing their badges on them. We subsequently instituted a personalized lead protocol (PLP) where residents received personal lead aprons and thyroid shields with their names embroidered on the front. A radiation monitoring officer was appointed and responsible for exchanging the dosimeter badges on each resident's personal lead apron monthly.

The purpose of this study was to determine whether our PLP improved compliance with radiation dosimeter monitoring. Specifically, we hypothesized that there would be an increase in monthly dosimeter readings after instituting our PLP, suggesting that the monitoring of radiation exposure without a PLP was less accurate.

Methods

A 2-year retrospective case-control study was conducted after Institutional Review Board approval at a level 1 trauma center and teaching hospital from March 2017 to February 2019. All 15 orthopaedic surgery residents were included in this study, and each was given a radiation dosimeter monthly from March 2017 until February 2019 (24 months) according to the standard requirement. During all months, all residents in this study par-

ticipated in surgeries that used C-arm fluoroscopy, either on their rotation or on call at the level 1 trauma center. All procedures using C-arm fluoroscopy were evaluated during the study period.

The study was separated into 2 phases. The period from March 2017 until February 2018 (phase 1) was designated as the control/no PLP group. During this time, each resident was responsible for attaching a radiation dosimeter to a lead apron before each surgery using radiation-emitting imaging. Residents were also responsible for finding lead aprons from a communal source of lead aprons hanging outside of the operating rooms. At the end of the month, dosimeters were returned by the residents for evaluation in which monthly radiation levels were recorded for each resident. The period from March 2018 until February 2019 (phase 2) was designated as the PLP group. On the institution of the protocol, each resident was given a personalized lead apron with an attached thyroid shield with a tamper-proof attachment. Each lead apron had a personalized style and pattern picked by the resident, and the front was embroidered with their name. In addition, residents were fitted for their own personalized lead apron to ensure proper comfort and protection. Residents were instructed to always wear their personal lead apron along with dosimeters located on the chest during every procedure that used imaging that emits radiation. Each resident had access to, and stored, their personalized safety equipment in a room secured with a combination lock (Fig. 1). A radiation monitoring officer was appointed who was responsible for placing new radiation dosimeter badges on each lead apron monthly and collecting them (Table I). Dosimeter badges were placed on the front of each lead apron externally using the front pocket (Fig. 1).

Monthly reports on dosimeter badges were used to gather dosimeter readings in millirems (mrem). Dosimeter readings were reported by the reporting company as minimal whenever there was an exposure that was less than 10 mrem, whereas exposures of more than 10 mrem received a specific number. Dosimeter readings were recorded for deep dose equivalent (DDE), lens dose equivalent, and shallow dose equivalent. Data was additionally collected from hospital radiology records to determine the amount of time fluoroscopy was in use and levels of actual exposure during each phase of the study period. All surgeries performed by the orthopaedic service that used fluoroscopy were evaluated. The cumulative number of fluoroscopy minutes was calculated monthly to compare the amount of fluoroscopy usage in the control group vs. the PLP group to determine whether there was any difference in the amounts of radiation used during each phase of the study.

Statistical analysis was performed using SPSS version 28.0 (IBM). A Pearson χ^2 test was performed to compare categorical data, such as whether the dosimeter had a positive radiation exposure or not. Numerical data for the radiation dosimeter readings and the fluoroscopic utilization in minutes were compared between both groups using a Student's 2-sample *t*-test.

Results

A total of 15 orthopaedic surgery residents were included in each of the 2 phases of radiation exposure monitoring



Fig. 1
(Fig. 1-A) Traditional lead provided by the hospital for techs, circulators, attendings, residents, anesthesiologists, and students. Thyroid shields were not attached. Only one size was available. Everyone in the operating room had access to this lead. This was the lead available for orthopaedic residents during phase 1 for the control group. **Fig. 1-B:** Personalized lead aprons hanging in a secure room with combination lock access. Various patterns have been chosen by each resident based on individual choices. Thyroid shields are attached. Lead aprons have been fitted to the size of the resident's choice. Radiation dosimeter badges are monthly switched out on the front of the aprons.

from March 2017 to February 2017 (control group) and March 2018 to February 2019 (PLP group) for a total of 322 dosimeter badge readings. During phase 1, the control group performed 1,252 orthopaedic surgeries using C-arm fluoroscopy, whereas during phase 2, the PLP group performed 1,269 orthopaedic surgeries. The monthly number of cases averaged 104.3 in the control group and 105.7 in the PLP group with no significant difference ($p = 0.31$).

Monthly resident radiation exposure data were collected from dosimeters worn on lead aprons throughout the study period. After implementation of the PLP, there was an increased proportion of dosimeters with positive radiation readings from 73.1% to 88.7% ($p < 0.001$, Table II). There was also an increased percentage of badges reading more than minimal radiation from 6.2% to 23.7% ($p < 0.001$). As shown in Figure 2, the control group had an average monthly resident DDE exposure reading of $7.26 \text{ mrem} \pm 37.07$. The PLP group had an average monthly resident DDE exposure reading of $19.00 \text{ mrem} \pm 51.15$. After the PLP was implemented, there was a significant increase in the average resident dosimeter reading ($p < 0.036$). Each resident monthly dosimeter badge reading is represented before and after PLP implementation in Figure 3.

Total annual fluoroscopy time for the control group and PLP group was 2,282 and 2031 minutes, respectively. The average departmental monthly fluoroscopy usage time for all procedures was 190 and 169 minutes for the control group and PLP group, respectively (Table III). The average fluoroscopy time per case was 109 seconds vs. 96 seconds in the control group vs. PLP group, respectively. No significant difference was found in the amount of monthly fluoroscopic usage or fluoroscopic time per case between the 2 phases ($p < 0.45$ and $p < 0.27$, respectively).

Discussion

Over the course of a surgical career in a field such as orthopaedics that uses radiation-emitting imaging frequently, the accumulation of exposure to direct beam sources and scatter rays can have potential adverse effects on health^{7,8}. Many surgeons may be less sensitive to radiation safety issues because of the fact that long-term effects are not immediate or clearly observable⁹. In addition, hospitals have an obligation to follow their state's guidelines for radiation safety regarding protecting those working in areas of radiation exposure. Therefore, it is important to have protocols in place to ensure

TABLE I Personalized Lead Protocol Key Factors

Key Factor	Goal of Factor
Assigning a radiation monitoring officer	Assign someone in addition to the residents' responsibility for accurate radiation monitoring
Fitting residents for lead aprons	Ensure proper fit and comfort of personalized lead apron
Allowing residents to pick skirt and vest or single-sided apron	To make lead aprons more comfortable based on personal preference of style
Residents pick pattern of lead	Make the lead apron easy to identify as the residents' personal lead apron, also to discourage others from using it
Thyroid shield attached to lead apron with a leash	Securely guarantee the thyroid shields stays with the lead apron and is used
Radiation monitoring officer changes monitoring badges monthly	By making a nonresident officer accountable for changing the badges, this further ensures proper placement of the badges and accurate monthly measuring

TABLE II No. of Dosimeter Badges with Positive Radiation Readings for Orthopaedic Residents Before and After Implementation of a PLP*			
	Phase 1 (No PLP)	Phase 2 (PLP)	p
Number of badges with positive radiation readings	106	157	<0.001
Percent of badges with positive radiation readings	73.1%	88.7%	<0.001
Number of badges with more than minimal radiation readings	9	42	<0.001
Number of badges with more than minimal radiation readings	6.2%	23.7%	<0.001

*PLP = personalized lead protocol

the safety of everyone involved in procedures that use fluoroscopic imaging.

Part of ensuring the safety of surgeons exposed to radiation is accurate monitoring of radiation exposure. Many training programs may not be accurately monitoring orthopaedic resident radiation exposure because of a variety of reasons, including poor compliance with wearing lead aprons and/or monitoring badges⁶. It has been reported that the main factor affecting compliance with wearing lead is how difficult it is for a resident to locate a lead apron⁶. To improve compliance with lead apron wearing and monitoring, our residency program instituted a personalized lead apron program where residents were given personalized lead aprons that were kept in a locked room that only they had access to. This made access to their own lead aprons easier, improving compliance with wearing dosimeter badges. In addition, our program tasked a radiation monitoring officer with switching out the monthly dosimeter badges where it had previously been the responsibility of each resident. Our program's leadership has demonstrated that we believe resident safety is important and made an effort to make it easier to monitor their radiation exposure.

Our study showed that after the implementation of a PLP, dosimeter badge compliance increased because badge exposure to any amount of radiation increased from 73.1% to 88.7%. In addition, the dosimeter exposure readings increased significantly, whereas there was no change in the actual amount of fluoroscopy radiation usage or time. The increase in positive radiation dosimeter readings and the average amount of reported exposure are likely due to compliance wearing the badges, not from an actual increase in exposure. Because case volume during both phases was similar and monthly fluoroscopy time did not increase during the second phase, it is unlikely that actual radiation exposure increased. In addition, fluoroscopy time per case was not significantly different during both phases. After our PLP was implemented, our monthly resident dosimeter readings went from 7.26 to 19.00 mrem. Our post PLP average dosimeter reading of 19.00 mrem is more similar to a previous report where average resident dosimeter readings were 26.9 mrem¹⁰. This provides evidence that with traditional radiation monitoring, the dosimeter readings may have been underreported, and after PLP, readings were more accurate.

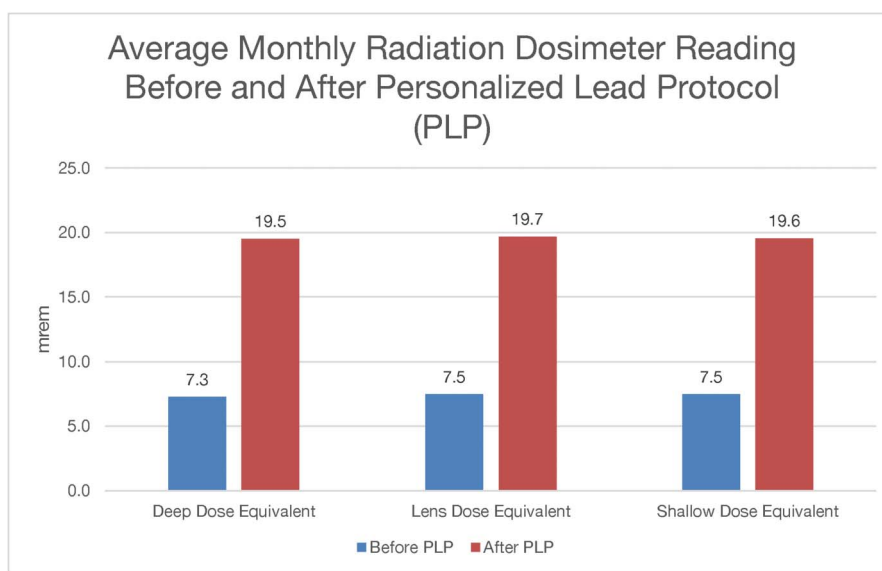


Fig. 2

Average monthly radiation exposure (mrem) for deep dose equivalent, lens dose equivalent, and shallow dose equivalent before and after the implementation of the personalized lead protocol (PLP). During phase 1, the average monthly resident dosimeter exposure reading was 7.26 mrem \pm 37.07 vs. 19.00 mrem \pm 51.16 during phase 2, which was significantly higher ($p = 0.036$).

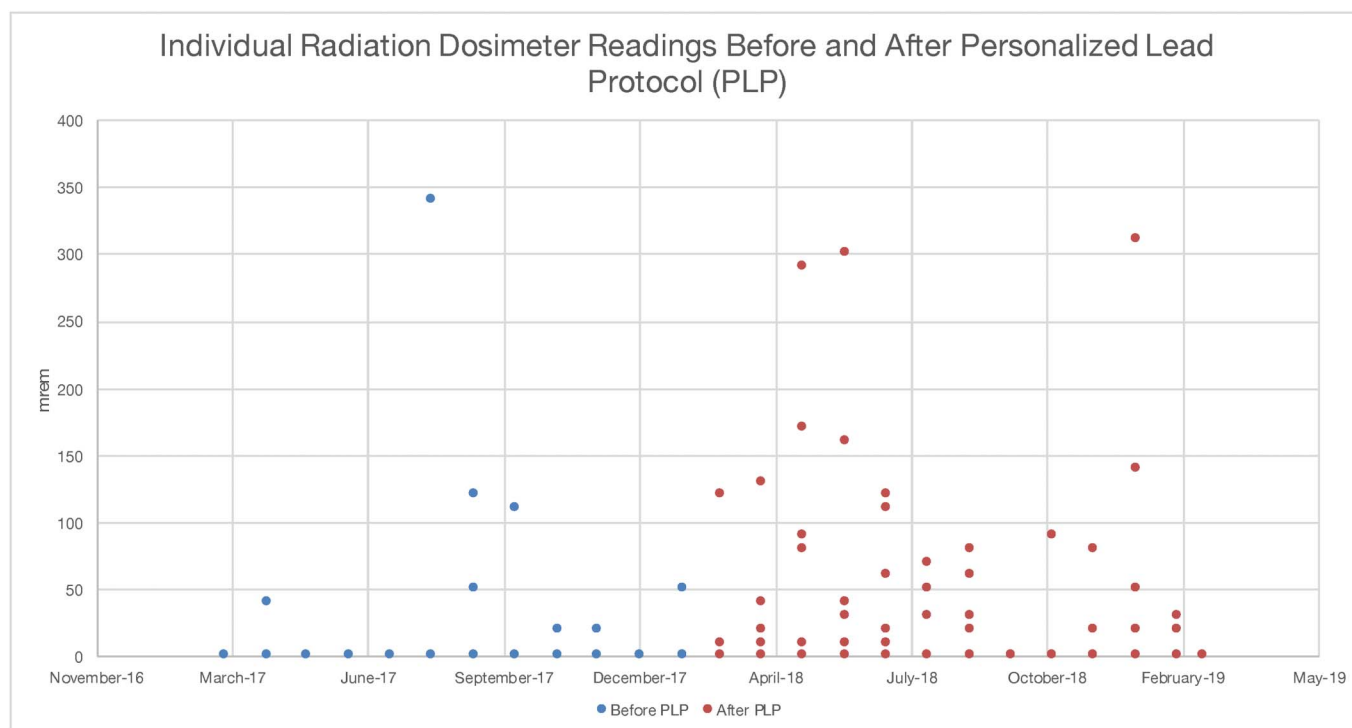


Fig. 3

Individual resident monthly dosimeter measurements (mrem) before and after personalized lead protocol (PLP).

Studies have shown that exposure to junior surgeons or trainees exceeds that of the senior surgeons^{11,12}. Lead aprons and dosimeters are important for protection and ensuring that exposure to vital organs remains below the annual limits¹³. However, it is challenging to obtain precise measurements of radiation exposure even when wearing proper protective equipment¹¹. A study conducted by Hafez et al. discussed the underestimation of radiation exposure received to the hands of orthopaedic surgeons because of overlooking specific factors. Accuracy of radiation exposure can be skewed from not including all procedures involving fluoroscopy in the measurement, not placing dosimeters on the most susceptible areas, and measurement of the dose per single procedure rather than the cumulative dose after several exposures resulting in underestimation⁵. During the second phase

of our study, we improved compliance and consistent measuring by having the badges placed on a consistent location on the exterior of the personalized lead aprons.

Unquantified radiation exposure accumulates over time, and there is not a defined dose at which, once surpassed, harmful radiation effects occur^{8,14}. Although long-term low-dose radiation exposure effects are largely unknown, hospital radiation safety protocols rely on the principle of using ionizing radiation doses that are “as low as reasonably achievable” to create image quality that is adequate.^{1,5,9,15-17}

In a survey of 517 orthopaedic residents conducted by Bowman et al., it was shown that 98% thought that personal protective equipment should be provided to them and that overall, however, only 54.2% reported being provided with

TABLE III Monthly Case Numbers, Fluoroscopy Usage Time, and Dosimeter Readings for Orthopaedic Residents Before and After Implementation of a PLP*

	Phase 1 (No PLP)	Phase 2 (PLP)	p
Average monthly dosimeter readings (mrem)	7.26 ± 37.1	19 ± 51.2	0.036
Monthly fluoroscopy time (min)	190 ± 55.3	169 ± 73.2	0.45
Average fluoroscopy time per case (s)	109 ± 272.6	96 ± 332.9	0.27
Average monthly number of cases	104.3 ± 13.7	105.7 ± 11.0	0.31
Annual number of cases	1,252	1,269	
Total annual fluoroscopy time (min)	2,282	2031	

*PLP = personalized lead protocol, and mrem = milirem.

their own lead apron and thyroid shield⁶. The leading reason for not wearing lead aprons was forgetting (42%). The most important factor influencing compliance of the use of lead aprons and a thyroid shield was availability. The authors found that difficulty in locating protective equipment led to decreased use in the operating room (4-5 times). Neither type nor frequency of education was shown to positively influence compliance. However, it is still necessary to have a program in place to educate on the occupational hazards of radiation exposure.

Our results, along with other studies, show that the annual exposure limits have not been exceeded^{2,9,12,15,18}. However, caution is still recommended because of the unknown effects of long-term low-dose radiation. Without proper protection and monitoring, the harmful effects of ionizing radiation may accumulate over a long career and lead to increased cancer risk in the future^{19,20}. Possible increased risk for malignancies of the brain, skin, thyroid, bone marrow, and organs, such as liver, spleen, gonads, and cataracts, has been reported in medical personnel who uses C-arm fluoroscopy^{1,18,21-23}. Two studies showed an increase in prevalence of breast cancer among female orthopaedic surgeons when compared with the general US population, which emphasizes the importance of protective shielding and education.^{24,25}

Limitations

There are several limitations to our study. First, radiation exposure is time and dose dependent. The amount of fluoroscopy time for all surgeries was measured during both phases of the study, but this is not a complete measurement of radiation exposure. Other factors can affect the amount of radiation exposure to the dosimeter badge. Scatter radiation is the nonuniform distribution of radiation around the room after striking the scatter source. In most cases, the scatter source is the patient because they are the first object struck by radiation after it leaves the emitter. The angle of the C-arm and the side on which a person is standing can all affect the shape of the radiation "scatter cloud" and how much radiation a person is exposed to²⁶. Although different surgeries may have had different resident behaviors, our sample size of 1,252 and 1,269 procedures for the control group and PLP group is large, which likely fairly captured all types of exposures. In addition, our residents knew that during the PLP phase, we were trying to decrease exposure and improve monitoring. This unavoidable bias created by the Hawthorne effect may have falsely elevated the amount of recorded radiation exposure during the PLP phase because residents were more mindful to wear their

personal lead apron, knowing that their usage was being more closely monitored. Residents' behaviors may have also changed over the 2-year study period, which could have affected the dosimeter badge readings. For example, a resident may have become more concerned during the PLP phase and taken several steps back before taking an x-ray. It is likely that if any behaviors changed, they were more likely to move further away from the fluoroscopy machine and the patient; however, our study showed an increase in dosimeter readings. Finally, it is possible that more radiation was used during the PLP phase, resulting in a higher average monthly dosimeter reading for the residents. This factor is unlikely due to the fact that the total number of procedures, the monthly number of fluoroscopy minutes, and fluoroscopy time per case were very similar between both groups. Finally, this study did not address the impact of the PLP on resident behaviors. Our study focused solely on the monitoring of radiation, but we did not measure resident behaviors such as whether they stood further from the C-arm while taking x-rays. Future studies could study how the implementation of a program affects resident behaviors. Surveying resident behaviors may be difficult and too subjective, so dosimeter badges were used as an objective measurement of dosimeter usage.

Conclusion

Institution of a PLP increased the compliance and exposure readings of radiation dosimeter badges for orthopaedic surgery residents, whereas the actual monthly fluoroscopy time did not change. Teaching hospitals should consider implementing a PLP to more accurately monitor exposure. ■

Note: *** Blinded by JBJS ***

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