Fluoroscopic Radiation Exposure
Are We Protecting Ourselves Adequately?

C. Edward Hoffler, MD, PhD, and Asif M. Ilyas, MD

Investigation performed at the Rothman Institute, Thomas Jefferson University, Philadelphia, Pennsylvania

Background: While traditional intraoperative fluoroscopy protection relies on thyroid shields and aprons, recent data suggest that the surgeon’s eyes and hands receive more exposure than previously appreciated. Using a distal radial fracture surgery model, we examined (1) radiation exposure to the eyes, thyroid, chest, groin, and hands of a surgeon mannequin; (2) the degree to which shielding equipment can decrease exposure; and (3) how exposure varies with fluoroscopy unit size.

Methods: An anthropomorphic model was fit with radiation-attenuating glasses, a thyroid shield, an apron, and gloves. “Exposed” thermoluminescent dosimeters overlaid the protective equipment at the eyes, thyroid, chest, groin, and index finger while “shielded” dosimeters were placed beneath the protective equipment. Fluoroscopy position and settings were standardized. The mini-c-arm milliampere-seconds were fixed based on the selection of the kilovolt peak (kVp). Three mini and three standard c-arms scanned a model of the patient’s wrist continuously for fifteen minutes each. Ten dosimeter exposures were recorded for each c-arm.

Results: Hand exposure averaged 31 μSv/min (range, 22 to 48 μSv/min), which was 13.0 times higher than the other recorded exposures. Eye exposure averaged 4 μSv/min, 2.2 times higher than the mean thyroid, chest, and groin exposure. Gloves reduced hand exposure by 69.4%. Glasses decreased eye exposure by 65.6%. There was no significant difference in exposure between mini and standard fluoroscopy.

Conclusions: Surgeons’ hands receive the most radiation exposure during distal radial plate fixation under fluoroscopy. There was a small but insignificant difference in mean exposure between standard fluoroscopy and mini-fluoroscopy, but some standard units resulted in lower exposure than some mini-units. On the basis of these findings, we recommend routine protective equipment to mitigate exposure to surgeons’ hands and eyes, in addition to the thyroid, chest, and groin, during fluoroscopy procedures.

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with a distal radial volar plate to examine (1) radiation exposure to the eyes, thyroid, chest, groin, and hands of a surgeon mannequin; (2) the degree to which shielding equipment can decrease exposure; and (3) how exposure varies with fluoroscopy unit size.

Materials and Methods
Protection and Radiation Dosimeter Placement
An anthropomorphic surgeon model (MD-HMB2FK; Roxy Display, East Brunswick, New Jersey) was fitted with radiation-attenuating glasses (MX30 frame with 0.75-mm-lead-equivalent lenses at 100 kVp; Universal Medical, Norwood, Massachusetts), a thyroid shield and apron (0.35-mm lead equivalent at 100 kVp; Burlington Medical Supplies, Newport News, Virginia), and radiation-attenuating gloves (RayShield Radiation Resistant Gloves X-1, attenuation: 64% at 60 kVp; AADCO Medical, Randolph, Vermont). “Exposed” thermoluminescent dosimeters (Landauer, Glenwood, Illinois) were placed over the protective equipment at the eyes, anterior neck prominence to approximate the thyroid cartilage, chest, groin, and proximal phalanx of the index finger, and “shielded” dosimeters were placed beneath the protective equipment. The exposed finger dosimeter was placed beneath a standard polyisoprene surgical glove (Protexis PI; Cardinal Health, Waukegan, Illinois).

Model Position
The same anthropomorphic surgeon model was used and positioned for each c-arm evaluation. Model placement was standardized for all procedures. The model was placed in a standard sitting position for hand surgery, with the torso 14 in (36 cm) from the center of the fluoroscopy beam. The location approximating the medial head of the clavicle was 12 in (30 cm) above the top surface of the hand table (Fig. 1). All distances were measured with a metal ruler.
recorded with dosimeters. Five exposed and five shielded dosimeters were used for each fluoroscope.

Analysis of variance was performed with anatomic location and fluoroscope size as factors. A Tukey post hoc test was performed with alpha set to 5%. A paired t test was used to compare measurements by shielded and exposed dosimeters, again with alpha set to 5%.

Source of Funding
This study was not supported by an external funding source.

Results
Hand exposure averaged 31 μSv/min (range, 22 to 48 μSv/min), which was 13.0 times higher than other recorded exposures (p < 0.001; see Appendix). Eye exposure averaged 4 μSv/min (range, 0 to 12 μSv/min), which was 2.2 times the mean thyroid, chest, and groin exposure; however, eye exposure did not differ significantly from thyroid (p = 0.89), chest (p = 0.94), or groin (p = 0.93) exposure. Thyroid, chest, and groin exposure did not differ significantly from each other (all p = 1.00).

Radiation-attenuating gloves reduced hand exposure by a mean (and standard deviation) of 69.4% ± 11.8% (p = 0.0001), which exceeded the manufacturer’s claim of 64% (see Appendix). Radiation-attenuating glasses decreased eye exposure by a mean of 65.6% ± 17.5%, but this was not significant (p = 0.12). Thyroid (p = 0.18), chest (p = 0.18), and groin (p = 0.27) shielding did not significantly reduce exposure (Table II).

Analysis of variance showed no significant difference in mean hand exposure between the mini (27 ± 5 μSv/min) and standard (35 ± 12 μSv/min) fluoroscopes (p = 0.20) or in mean eye exposure between the mini (2 ± 2 μSv/min) and standard (6 ± 5 μSv/min) devices (p = 0.16). There was also no significant difference in overall exposure between the mini (6.6 ± 11 μSv/min) and standard (9.6 ± 14 μSv/min) fluoroscopes (p = 0.51) (see Appendix).

Discussion
We present a model of surgeon radiation exposure during fixation with a distal radial volar plate. We focused on the relevance of this model to surgeon exposure, but any medical personnel in similar proximity to the hand table and fluoroscope will experience similar exposure. This simple anthropometric model captures the radiation scatter from the metal plate but not the smaller contribution of scatter from the soft tissues. Both the mini and standard fluoroscope positions represent typical configurations for distal radial fracture surgery; therefore, these data are relevant to actual intraoperative exposure. Some surgeons use horizontal and inverted fluoroscope configurations, but these positions were not tested. Surgeon position and fluoroscope position can influence exposure rates even when the same fluoroscope unit is used. While positioning is an important strategy for reducing radiation exposure4,7,8,12-14, the current report focuses on personal protective equipment and fluoroscope unit size.

In a recent prospective intraoperative clinical study, Vosbikian et al.16 compared the exposure of surgeons’ hands to radiation between a surgeon who used a single large unit exclusively and another who used a single mini-unit exclusively. Fluoroscopic output was recorded, and hand exposure was measured with use of dosimeter rings. The median large-unit output (0.02 mGy/s) was significantly less than the mini-unit output (0.28 mGy/s). The corresponding hand exposure was also significantly less for the surgeon who used the large unit (380 mrem [3.8 mSv]) than it was for the one who used the mini-unit (1000 mrem [10 mSv]) over the fourteen-month

$$\text{TABLE I Fluoroscopy Units, Sizes, and Settings}$$

<table>
<thead>
<tr>
<th>C-Arm</th>
<th>Manufacturer</th>
<th>Model</th>
<th>kVp</th>
<th>mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini</td>
<td>OrthoScan</td>
<td>HD 1000-0004</td>
<td>60</td>
<td>0.074</td>
</tr>
<tr>
<td>1</td>
<td>Fluorocan</td>
<td>InSight 2</td>
<td>60</td>
<td>0.100</td>
</tr>
<tr>
<td>2</td>
<td>OEC Medical Systems*</td>
<td>MiniView 1600</td>
<td>60</td>
<td>0.069</td>
</tr>
<tr>
<td>Standard</td>
<td>General Electric</td>
<td>OEC 9900 Elite</td>
<td>60</td>
<td>0.800</td>
</tr>
<tr>
<td>3</td>
<td>Philips</td>
<td>BV Pulsera</td>
<td>60</td>
<td>0.830</td>
</tr>
<tr>
<td>4</td>
<td>OEC Medical Systems*</td>
<td>9600</td>
<td>60</td>
<td>0.800</td>
</tr>
</tbody>
</table>

*OEC Medical Systems was acquired by General Electric.

$$\text{TABLE II Radiation Exposure for Exposed and Shielded Anatomic Locations}$$

<table>
<thead>
<tr>
<th>Location</th>
<th>Exposed Mean (Standard Deviation) (μSv/min)</th>
<th>Shielded Mean (Standard Deviation) (μSv/min)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye</td>
<td>4.1 (4.3)</td>
<td>0.8 (1.1)</td>
<td>0.12</td>
</tr>
<tr>
<td>Thyroid</td>
<td>1.6 (0.8)</td>
<td>1.2 (0.3)</td>
<td>0.18</td>
</tr>
<tr>
<td>Chest</td>
<td>2.0 (1.7)</td>
<td>1.3 (0.0)</td>
<td>0.18</td>
</tr>
<tr>
<td>Groin</td>
<td>1.9 (2.1)</td>
<td>1.3 (0.0)</td>
<td>0.27</td>
</tr>
<tr>
<td>Hand</td>
<td>31.0 (9.2)</td>
<td>9.1 (2.7)</td>
<td>0.0001*</td>
</tr>
</tbody>
</table>

*A significant difference.
Fluoroscopic Radiation Exposure

The median fluoroscopy time per surgical case with the mini-unit was eighty-eight seconds, which was significantly greater than the 37.7 seconds with the large unit. These data indicate that, in clinical practice, a mini-fluoroscope may output more radiation, may be used for longer time periods, and may result in more hand radiation exposure. Our study complements the work of Vosbikian et al. by controlling factors that are impractical to manage in the clinical setting. These include surgeon hand position relative to the radiation beam, radiation output settings, multiple fluoroscopy units, exposure time, and type of surgical procedure and surgical implant. In addition, we explored radiation exposure at other anatomic sites.

When our surgeon model’s hands were adjacent to a distal radial plate in a clinically relevant position, they received more exposure than the eyes, thyroid, chest, or groin. Other studies have demonstrated that hand placement directly within the radiation beam or immediately beyond it increases exposure rates. While we did not directly measure the beam radius relative to the position of our model, the hands were placed in a clinically relevant position for procedures involving a distal radial plate, which allowed us to capture clinically relevant exposure data. Surgeons often place their hands into the fluoroscopy beam to control the limb and/or the implants during fluoroscopy, although they have the option to move their hands further from the beam. Finger dosimeters were not visible in the fluoroscopic view, which is consistent with the clinical practice of surgeons moving their hands beyond the perimeter of direct radiation exposure. However, the focus of the study was to determine the risk when the surgeon model’s hands were maintained in a consistent, albeit high-risk, position regardless of the fluoroscope used and its corresponding beam diameter. Singer reported a mean intraoperative hand exposure of 23.5 mrem/min (235 μSv/min) during use of an OEC 6800 MiniView fluoroscope. The procedures included treatment of distal radial fractures and malunions and scaphoid nonunions, small-joint arthrodesis, and metacarpophalangeal joint arthroplasty. We measured a mean hand exposure of 2.7 mrem/min (27 μSv/min) for mini-fluoroscopes and 3.5 mrem/min (35 μSv/min) for standard fluoroscopes.

The difference in exposure between the current report and the one by Singer may indicate that distal radial plate fixation is a lower-exposure procedure in the field of hand surgery. The International Commission on Radiological Protection (ICRP) currently recommends a maximum of 50 rem (500 mSv) of occupational hand exposure annually, which is more than 10,000 times a single minute of exposure in our study and more than 2000 times a minute of exposure in Singer’s study. Together these data suggest that surgeons may not approach the recommended annual hand exposure limit if they are not performing close to 2000 fluoroscopic hand surgery procedures a year. The effect of consistent exposure that does not exceed the annual limit, but continues for a multiple-decade career, is unknown.

Given the uncertainty regarding long-term hand exposure, personal protective equipment may have a role in decreasing the potential cumulative risk of long-term subclinical exposure. Hand exposure was reduced by nearly 70% with the use of radiation-attenuating surgical gloves in our study. This is a simple and effective intervention for reducing radiation exposure, particularly for procedures requiring greater fluoroscopy use.

In this study, the surgeon model’s eyes received the second highest exposure. The ICRP recommended an annual eye exposure limit of 15 rem (150 mSv), which is greater than 35,000 times a single minute of exposure in our model. Despite this being the accepted exposure limit, there are data suggesting that the threshold may be much lower. Chodick and coworkers studied a prospective cohort of more than 35,000 radiologic technologists for twenty years and determined that cataract risk may be increased with a lifetime occupational dose of 6 rem. Our model indicates that, if a surgeon performed 500 fluoroscopic hand procedures yearly, he or she could approach this cataract risk threshold in thirty years.

Radiation-attenuating glasses reduced exposure by a dramatic 66%, but this was not a significant difference given the data variance and low baseline exposure. Burns and coworkers also noted a large reduction in eye exposure (90%) when protective eyewear was worn during pelvic and hip surgery. Eye exposure was less than hand exposure in our model, which contrasts with measurements during lower-extremity fracture surgery (dynamic hip screw, or femoral or tibial nail, insertion) that showed eye exposure to be greater. These data emphasize the influence of the type of procedure, anatomic location, and implant type in determining the surgeon’s relative radiation exposure.

Personal protective equipment in this study did not significantly decrease thyroid, chest, or groin exposure. Exposures in these three locations ranged from 0.16 to 0.20 mrem/min (1.6 to 2.0 μSv/min) in our study when shields were not used. The ICRP recommends a limit of 2 rem (20 mSv) of occupational radiation exposure averaged over five years, with a maximum of 5 rem (50 mSv) in any individual year. Our data indicate that 10,000 minutes of fluoroscopy would be required to approach the ICRP limit. These data suggest that the thyroid, chest, and groin may be at lower risk for developing radiation-related health issues than the hands or eyes. We still recommend personal protective equipment given that the exact threshold for avoiding health effects from long-term intermittent exposure to low-dose fluoroscopy radiation is unknown.

The mean standard radiation exposure that we measured was generally greater for the standard fluoroscopy units, although some mini-fluoroscopy units led to greater exposure than some standard units. Exposure is proportional to the kilovolt peak squared (kVp²) and to the milliampere-seconds (mAs) and is inversely proportional to the square of the distance from the source. The kVp was constant for all tests, and mAs values were lower for the mini-fluoroscopes. One might anticipate that this would result in all of the standard units leading to greater exposure than the small units. However, the distance from the source to the distal part of the radius—i.e., the point of radiation scatter—was much shorter for the smaller units. Again, the effect of distance is inversely proportional by a power of two, so small decreases in distance may cause large increases in radiation exposure in association with the smaller units. The position of the source within the fluoroscope housing may also play a role. Radiation sources located closer to the surface of the housing may be at a shorter...
distance from the patient and lead to more radiation exposure. The inverse square law for distance is relevant to direct radiation exposure but does not describe radiation scatter.35

Another factor affecting exposure is the fluoroscopy mode, which may be continuous or pulsed. Traditional continuous fluoroscopy is based on a thirty frame per second display, with each fluoroscopic image displayed for 33 ms (1/30th of one second)36. In pulsed mode, the generator may produce an x-ray pulse that is much shorter than 33 ms. A short pulse can reduce the total exposure time and therefore the total radiation exposure. A longer pulse may produce exposure that approaches that associated with a continuous mode. Some manufacturers have abandoned the traditional continuous fluoroscopy in favor of a pulsed protocol with a longer pulse but still refer to it as “continuous.” None of the mini-fluoroscopes in this study had a pulsed mode. Because of the proprietary nature of continuous x-ray generation, it is not known which standard fluoroscopy units use a traditional continuous or a pulsed “continuous” mode. In summary, a standard fluoroscope may modulate the intensity of its x-ray generation to decrease radiation output and combine this with a larger source-to-patient distance to reduce radiation exposure. Mini-fluoroscopes may use less current, which decreases milliampere-seconds, decreases radiation exposure, and decreases radiation exposure. Standard and mini-fluoroscopes use different strategies to decrease radiation exposure, and one type did not consistently produce less radiation exposure than the other in the vertical configurations tested.

In the current study, we compared radiation exposure at different anatomic locations with and without shielding and using different fluoroscopes. We determined the statistical significance of differences between study groups but the relationship between statistical significance and the amount of radiation exposure sufficient to increase medical risk is unclear. While following the ICRP guidelines for exposure limits is recommended, the health effects of long-term intermittent low-dose radiation exposure from fluoroscopy are unknown.

Surgeons may minimize their exposure by understanding the basic physics of x-ray radiation and maximizing all of the safety technologies that their specific fluoroscopy units offer. Specific interventions include altering fluoroscopic configuration and surgeon position to maximize the distance from the radiation source, limit radiation intensity and exposure time, use collimation, remove one’s hands from the radiation beam path, and use personal protective equipment. Our study has focused on surgeon safety, but these same strategies should be applied to all operating room personnel and patients.

Appendix

Figures showing radiation exposure at each anatomic location, of the hands and eyes with and without personal protective shielding, and for each of the tested mini and standard fluoroscopes are available with the online version of this article as a data supplement at jbjs.org.

References


6. Vano E, Gonzalez L, Fernández JM, Haskal ZJ. Eye lens exposure to radiation in fluoroscopy in favor of a pulsed protocol with a longer pulse but still associated with a continuous mode. Some manufacturers have abandoned the traditional continuous fluoroscopy in favor of a pulsed protocol with a longer pulse but still refer to it as “continuous.” None of the mini-fluoroscopes in this study had a pulsed mode. Because of the proprietary nature of continuous x-ray generation, it is not known which standard fluoroscopy units use a traditional continuous or a pulsed “continuous” mode. In summary, a standard fluoroscope may modulate the intensity of its x-ray generation to decrease radiation output and combine this with a larger source-to-patient distance to reduce radiation exposure. Mini-fluoroscopes may use less current, which decreases milliampere-seconds, lowers radiation output, and decreases radiation exposure. Standard and mini-fluoroscopes use different strategies to decrease radiation exposure, and one type did not consistently produce less radiation exposure than the other in the vertical configurations tested.

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C. Edward Hofller, MD, PhD
Asif M. Ilyas, MD
Rothman Institute,
Thomas Jefferson University,
1025 Walnut Street,
College Building, Room 516,
Philadelphia, PA 19107.

E-mail address for C.E. Hofller: CE_HofllerII@yahoo.com


