SCIENTIFIC ARTICLE

# Hand and Body Radiation Exposure With the Use of Mini C-Arm Fluoroscopy

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**Purpose** To determine whole body and hand radiation exposure to the hand surgeon wearing a lead apron during routine intraoperative use of the mini C-arm fluoroscope.

**Methods** Four surgeons (3 hand attending surgeons and 1 hand fellow) monitored their radiation exposure for a total of 200 consecutive cases (50 cases per surgeon) requiring mini C-arm fluoroscopy. Each surgeon measured radiation exposure with a badge dosimeter placed on the outside breast pocket of the lead apron (external whole body exposure), a second badge dosimeter under the lead apron (shielded whole body exposure), and a ring dosimeter (hand exposure).

**Results** Completed records were noted in 198 cases, with an average fluoroscopy time of 133.52 seconds and average cumulative dose of 19,260 rem-cm$^2$ per case. The total measured radiation exposures for the (1) external whole body exposure dosimeters were 16 mrem (for shallow depth), 7 mrem (for eye depth), and less than 1 mrem (for deep depth); (2) shielded whole body badge dosimeters recorded less than 1 mrem; and (3) ring dosimeters totaled 170 mrem. The total radial exposure for 4 ring dosimeters that had registered a threshold of 30 mrem or more of radiation exposure was 170 mrem at the skin level, for an average of 42.5 mrem per dosimeter ring or 6.3 mrem per case.

**Conclusions** This study of whole body and hand radiation exposure from the mini C-arm includes the largest number of surgical cases in the published literature. The measured whole body and hand radiation exposure received by the hand surgeon from the mini C-arm represents a minimal risk of radiation, based on the current National Council on Radiation Protection and Management standards of annual dose limits (5,000 mrem per year for whole body and 50,000 mrem per year to the extremities). *(J Hand Surg 2011;36A:632–638. Copyright © 2011 by the American Society for Surgery of the Hand. All rights reserved.)*

**Key words** Fluoroscopy radiation, mini C-arm, orthopedic surgeon, radiation.

In recent decades, hand surgeons have increased their use of fluoroscopy during surgery and in the office to more accurately diagnose and treat patients. This widening use of fluoroscopy has been advanced by the decreasing size of these diagnostic instruments and the simplicity of their use. The mini C-arm fluoroscope is the prime example of this development.

The risks of radiation exposure are well documented within the scientific literature and include skin cancer, cataracts, and leukemia.[1] In 2005, a report identified orthopedic surgeons with an increased cancer risk.[2] The analysis identified participants who were noncompliant with radiation protection and developed cancers, including whole body types and skin types. In the regression analysis, orthopedic surgeons had an odds ratio that was five times as high for malignancy as compared to unexposed workers. This epidemiologic study cautioned against the underestimation of the risk of radiation.

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In recent years, studies have evaluated radiation exposure of the mini C-arm with the use of a *phantom* (a device that approximates the physical properties of human tissue to calibrate or determine the dose of radiation applied to the tissue) or a cadaveric forearm.[3–7] The conclusions showed that the mini C-arm substantially reduced the radiation exposure to the surgeon when compared to the large C-arm, and only the body parts directly in the path of the beam, such as the surgeon's hands, had considerable exposure. Therefore, these phantom studies concluded that the mini C-arm was a safer instrument for imaging and decreased the radiation risk for the orthopedic surgeon. However, a study by Singer determined that phantoms did not accurately measure the radiation exposure to the surgeon's hands because radiation exposure changed as the surgeon repositioned his hands and the extremity under study.[8] Singer's study illustrated the importance of real-time intraoperative studies for the most accurate evaluation of radiation exposure to the surgeon. A recent review of the scientific literature discussed 3 peer-reviewed studies that evaluated mini C-arm radiation exposure to the orthopedic surgeon in the surgical arena, with varying methods and conclusions.[8–10] These studies reveal a marked disagreement in the literature about the radiation exposure risk to the hand surgeon when using the mini C-arm.

This study's purpose is to determine whole body and hand radiation exposure to the hand surgeon wearing a lead apron during routine intraoperative use of the mini C-arm fluoroscope. Our study was a real-time observational study during surgical cases to address the inaccuracy of the use of phantoms in previous studies.[3–7] In addition, badge and ring dosimeters were used to more accurately determine radiation exposure to the whole body and the surgeons' hands. This methodology and the large number of cases would provide data to resolve the present conflict about actual radiation exposure from the mini C-arm.

## MATERIALS AND METHODS

This study monitored the radiation exposure of 4 surgeons (3 hand attending surgeons and 1 hand fellow) at an outpatient surgery center. Approval from the Institutional Review Board was granted before the onset of the study. In this investigation, radiation exposure was defined as the quantity of radiation measured with a dosimeter (badge or ring), and a dosage was the radiation emitted from the mini C-arm.

**FIGURE 1:** Shielded whole body exposure badge at surgeon's waist and external whole body exposure worn on outside breast pocket.

Each of the 4 participating surgeons agreed to monitor their radiation exposure for 50 consecutive surgical cases, for a total of 200 cases. All cases used two identical mini C-arm fluoroscopes (OEC Miniview 6800; GE Healthcare-Americas, Salt Lake City, UT). The fluoroscopes were calibrated before the start of the study by the manufacturer, and each was designated with an identification number. This number was recorded for each case to determine any radiation emission differences between the mini C-arms during analysis. During the collection period, all participating surgeons wore a new lead apron of 0.5-mm lead thickness (Bar-ray Products Inc., Littlestown, PA). One article recommended an apron of 0.25 mm with the use of the mini C-arm; however, the authors did not provide exposure data to support this guideline.[11] Each surgeon monitored their whole body radiation exposure during each procedure with two badge dosimeters (Luxel+ badge with a dose measurement range of 1 mrem to 1000 rem; Landauer, Inc., Glenwood, IL). One badge was designated as the shielded whole body control and was worn on the surgeon's waist, underneath their lead apron (Fig. 1). The second badge was for the external whole body exposure and was worn on the left outside breast pocket of each lead apron (Fig. 1). Each surgeon measured their hand radia-

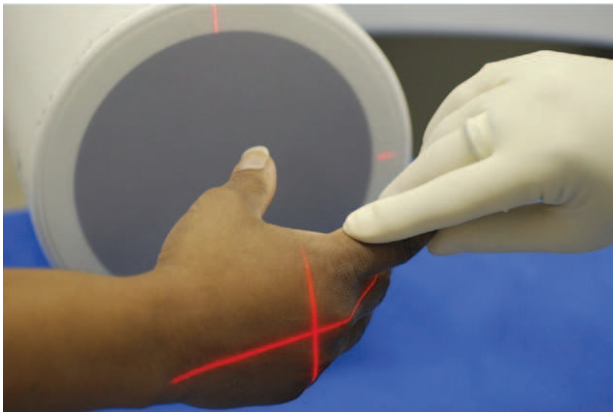

**FIGURE 2:** Ring dosimeter.

tion exposure with a ring dosimeter (dose measurement range of 30 mrem to 1000 rem; Landauer, Inc.). A sterilized ring dosimeter was worn for each case on one of the middle three digits of the surgeon's dominant hand, between two sterile gloves or underneath a single sterile glove (Fig. 2).

During the study, radiation exposure was measured from each surgeon's dosimeters after each surgeon participated in each of their first 10 cases. This initial evaluation was to determine the safety of the surgeon from the radiation and to ensure that the radiation badges were properly collecting any radiation exposure. Each surgeon used 2 badge dosimeters (1 outside and 1 underneath their lead apron) and 1 ring dosimeter during each surgical case. Three ring dosimeters per surgeon were used to allow for the collection of data from a maximum of 3 cases per surgeon per surgical day. All badge and ring dosimeters were sent to the manufacturer (Landauer, Inc.) for measurement of radiation exposure.

For the remainder of the study period (the next 40 cases), each surgeon received 2 new badge dosimeters (1 for external whole body radiation, worn outside the lead apron, and 1 for shielded whole body radiation, worn underneath their lead apron) and 6 new ring dosimeters. Each surgeon's shielded whole body and external whole body radiation badge dosimeters were used for the final 40 cases. One of the 6 new ring dosimeters was chosen randomly, used for a surgical case, and sterilized after the case, according to the manufacturer's specifications. Therefore, 6 ring dosimeters were available per surgeon to allow up to 6 consecutive surgical cases to be evaluated in a day. The badge and ring dosimeters were worn in the previously outlined manner for each surgeon's next 40 cases and sent to the manufacturer (Landauer, Inc.) for radiation measurement.

Before each surgeon's case, the ring and badge dosimeter identification numbers were recorded on a study data sheet. At the completion of the case, the type of procedure, total case time, fluoroscopy time, and fluoroscopy cumulative dose were recorded on the same data sheet. This allowed the specific case to be cross-referenced to each ring dosimeter and badge dosimeter at the completion of the study.

The radiation measurements by the manufacturer (Landauer, Inc.) for the badge dosimeters included a deep depth, an eye depth, and a shallow depth, whereas the ring dosimeters included only a shallow depth. The shallow depth is radiation energy that penetrates the skin to a depth of 0.007 cm; the eye depth records radiation penetration to the lens of a depth of 0.3 cm; and the deep depth measures radiation penetration to the whole body to a depth of 1 cm. The badge dosimeters record these different penetration depths for the universal use with different radiation sources (alpha, beta, and gamma radiation types) that have variable energy emission. Furthermore, the National Council on Radiation Protection and Measurements sets different annual limits of radiation exposure for the different radiation depth levels.

### Statistical methods

All data in this study were entered and analyzed in Microsoft Excel 2003 (Microsoft Corp., Redmond, WA). Sum totals and averages were calculated within the standard statistical software package. An unpaired 2-tailed Student's *t*-test ($p < .05$) was used to determine any difference between the attending surgeons and the fellow for fluoroscopy dose or fluoroscopy time. The comparison of fluoroscopy time and dose with the radiation exposure for each ring dosimeter was evaluated with a Pearson correlation coefficient ($p < .05$). Statistical analysis was performed for all ring dosimeters, as well as separate analysis for the ring dosimeters that had reached the minimum 30-mrem threshold for radiation exposure.

## RESULTS

The study began in October 2006, with the first 10 cases for the 4 surgeons analyzed for safety precautions and the effectiveness of radiation exposure measurement. The radiation exposure for the first 40 cases was minimal for the shielded whole body badge dosimeters underneath the lead apron,

**TABLE 1. Data Summary Table**

| Surgeon | Cases | Average Case Time (min) | Average Fluoroscopy Time (sec) | Fluoroscopy Dose/Case (rad-cm$^2$) |
|---|---|---|---|---|
| Attending 1 | 50 | 87.97 | 136 | 18,864 |
| Attending 2 | 49 | 98.49 | 104 | 10,890 |
| Attending 3 | 50 | 81.37 | 114 | 13,386 |
| Fellow | 49 | 96.22 | 125 | 20,089 |
| Total | 198 | 90.26 | 133 | 19,260 |

**TABLE 2. Badge and Ring Dosimeter Radiation Exposure**

| Surgeon | Badge—Shallow (mrem) | Badge—Eye (mrem) | Shielded Badge—Shallow (mrem) | Shielded Badge—Eye (mrem) | Ring (mrem) |
|---|---|---|---|---|---|
| Attending 1 | 11 | 7 | 0 | 0 | 30 |
| Attending 2 | 2 | 0 | 0 | 0 | 50 |
| Attending 3 | 2 | 0 | 0 | 0 | 0 |
| Fellow | 1 | 0 | 0 | 0 | 90* |
| Total | 16 | 7 | 0 | 0 | 170 |

*Designates a total value from 2 ring dosimeters (30 mrem and 60 mrem).

minimal for the external badge dosimeters on the outside of the lead apron, and showed 30-mrem shallow depth exposures for the ring dosimeters. Only one of the 12 ring dosimeters had radiation exposure of greater than 30 mrem. The remaining 11 ring dosimeters had radiation exposure of 29 mrem or less. The "minimal" level of radiation exposure documented by the manufacturer meant that the threshold level of 1 mrem for the badge dosimeters and 30 mrem for the ring dosimeters was not reached. The single ring with 30 mrem of detectable radiation exposure was used by one of the attending surgeons for a total of 3 cases. The 3 cases were an open reduction and internal fixation of a proximal humerus fracture, an open reduction and internal fixation of a humeral shaft fracture, and an ulnar shortening osteotomy.

The study continued until each surgeon had participated in a total of 50 cases. The methodology of data collection between the first 40 cases and the remaining 158 cases was identical. Each surgical participant used 2 shielded badge dosimeters underneath their apron, 2 external badge dosimeters outside their apron, and 9 dosimeters during the study period. Therefore, there were 8 shielded badge dosimeters, 8 external badge dosimeters, and 36 ring dosimeters available for analysis. The total number of cases was 198 cases for the 4 surgeons because 1 case that involved both the hand fellow and an attending had no recorded exposure data and could not be included in the data total. The number of cases involving the digits, hand/wrist, forearm, elbow, and humerus were 65, 91, 11, 16, and 15, respectively.

The average fluoroscopy time and average cumulative radiation dose were 133.52 seconds and 19,620 rem-cm$^2$ per case (Table 1). The total measured radiation for external whole body exposure with the badges outside the lead apron was 16 mrem (for shallow depth), 7 mrem (for eye depth), and less than 1 mrem (for deep depth), for an average measured exposure of less than 1 mrem per case. The shielded whole body badge dosimeters underneath the lead aprons measured less than 1 mrem of radiation for the entire study. The total radiation exposure for the 4 ring dosimeters that had registered a threshold of 30 mrem or more of radiation exposure was 170 mrem at the skin level, for an average of 42.5 mrem per dosimeter ring or 6.3 mrem per case (Table 2). The remaining 32 ring dosimeters did not reach the minimum 30 mrem threshold for radiation exposure.

Further analysis was performed, comparing the average fluoroscopy time and average fluoroscopy dose between the attending hand surgeons and the hand fellow using an unpaired 2-tailed Student's *t*-test. These were the radiation data collected from the mini c-arm after each of the 198 cases. The results showed no statistical difference for fluoroscopy time ($p = .56$) or fluoroscopy dose ($p = .83$) between the two groups. Additional statistical analysis compared the fluoroscopy time and the fluoroscopy dose with the radiation exposure for all ring dosimeters using a Pearson correlation coefficient. Neither the fluoroscopy time ($r = 0.22$) nor the fluoroscopy dose ($r = 0.27$) showed a strong statistical relationship to the radiation exposure for each ring dosimeter. The Pearson correlation coefficient was repeated, using only the 4 ring dosimeters with recorded radiation exposure. This more specific analysis did not show a direct relationship with fluoroscopy time ($r = -0.55$) or fluoroscopy dose ($r = -0.97$).

## DISCUSSION

The goal of this study was to determine the amount of whole body and hand radiation exposure to the hand surgeon wearing a lead apron during routine intraoperative use of the mini C-arm fluoroscope. As expected, the shielded badge dosimeters worn underneath the lead aprons recorded minimal (less than 1 mrem) radiation exposure for all cases. The total radiation exposure for 198 cases for the external badge dosimeters outside the lead apron was 16 mrem at the shallow depth (skin/hands), 7 mrem at the eye depth, and less than 1 mrem at the deep depth (whole body) for the 198 cases. Four ring dosimeters exceeded the 30-mrem threshold level of radiation exposure, resulting in 170 mrem of radiation exposure at the skin level, for an average of 42.5 mrem per ring dosimeter or 6.3 mrem per case. The remaining 32 ring dosimeters did not reach the 30-mrem threshold level of radiation exposure. However, radiation exposure below the 30-mrem level for the remaining 32 ring dosimeters might have occurred. The current National Council on Radiation Protection and Measurements annual limits are 5,000 mrem for whole body, 15,000 mrem for eyes, and 50,000 mrem for hands. From our study results, the highest radiation exposure rate was from the ring dosimeters. The rings with recordable radiation exposure were used in 27 cases, with a radiation exposure rate of 6.30 mrem/case. Thus, a surgeon's hand radiation exposure would reach the annual limit the fastest, but only after performing more than 7,900 cases in a year. One study[2] postulated an increased cancer risk to orthopedic surgeons exposed to higher radiation doses. This study found a higher cancer incidence in orthopedic surgeons (29%) compared to non-orthopedic physicians (11%), radiation-exposed non-physicians (6%), and unexposed workers (4%). However, estimated cumulative radiation doses for individuals were reconstructed using various past hospital procedures and were not directly measured.

A review of the literature found 8 studies evaluating radiation exposure with the use of the mini C-arm fluoroscope.[3–10] However, 5 of the studies used phantoms or cadaveric limbs in a simulated surgical environment to estimate radiation exposure.[3–7] The other 3 studies used a variety of methods to evaluate radiation exposure during consecutive surgical cases using the mini C-arm fluoroscope.[8–10] Singer measured only hand radiation exposure with ring dosimeters in 81 cases.[8] He found an average fluoroscopy time of 51 seconds per case and 20 mrem of radiation per case. From this reported radiation exposure, the annual hand radiation limit would not be reached until 2,500 cases. Recently, Shoaib et al published another study comparing the radiation exposure from the large C-arm and mini C-arm for the same types of cases.[9] Their conclusions advocated the use of the mini C-arm to reduce radiation exposure. However, the retrospective case control study of Shoaib et al could not provide accurate radiation exposure rates because the data were calculated indirectly from C-arm dosage emission and measurements made by the medical physics department using phantoms. The most recent published study using intraoperative dosimeters, by Thomson and LaLonde, measured radiation exposure with a ring dosimeter for 26 consecutive cases using the mini C-arm fluoroscope.[10] The cumulative amount of radiation in the study was less than 1 mrem, with no reported radiation dose or time from the mini C-arm. The authors concluded that 12,000 cases could be done annually without exceeding the annual exposure limit. From this literature review, a wide range of results exist for the exposure rate to the hand surgeon using the mini C-arm. However, radiation exposure times and quantities were not available for analysis to explain the differences between studies.

Analysis of the data in our study revealed no statistically significant difference between the fluoroscopy time or the fluoroscopy dose between the fellow and the attending hand surgeons. Also, there was no relationship between radiation exposure and the fluoroscopy time or the dose. This indicates exposure is related to a different variable. Two previous studies elucidate this variable.

Singer's study evaluated actual exposure to the surgeon and scatter with a standard wrist phantom.[8] The study demonstrated the radiation exposure was 0.8 mrem/min at 10 cm (directly at the perimeter of the body of the image intensifier), 0.15 mrem/min at 15 cm, and 0 mrem/min at 20 cm and greater. In a separate study, Giordano et al performed a similar scatter experiment with the mini C-arm and an upper extremity phantom.[7] The study used 13 badge dosimeters in a variety of positions and distances from the phantom placed in the mini C-arm. The results of their study were similar, in which only the badge in direct line on the phantom recorded any measurable exposure. Thus, these studies confirm that the surgeon is exposed to recordable radiation only when his or her hands are in the radiation field of the mini C-arm.

The results of radiation exposure with phantoms have 2 major differences from studies that evaluate radiation exposure in actual surgical cases. First, a surgeon using fluoroscopy might be moving his or her hands while stabilizing the anatomical site of interest. Hence, the radiation exposure to the surgeon's hands might be changing during fluoroscopic imaging. Second, phantom studies use a fixed radiation dose from the mini C-arm on a nonmoving structure. In the actual surgical arena, the radiation dose emitted by the mini C-arm increases or decreases automatically for optimal penetration and image production. Therefore, as the surgeon rotates the wrist from an anterior-posterior view to a lateral view during an actual surgery, the mini C-arm increases the radiation emitted to penetrate the thicker tissue mass, potentially changing the radiation exposure to the surgeon. These differences illustrate why phantom studies do not accurately determine actual radiation exposure to the surgeon and also explain the exposure differences in the different studies. Therefore, radiation exposure will depend on the location of the surgeon's hands during stabilization of the patient's extremity, as well as the effect of radiation dose adjustment by the mini C-arm for the position of the patient's extremity.

This explanation of the radiation exposure is supported in our data in this study. Attending 1 had the longest case times and highest radiation doses per case but the second lowest exposure from the ring dosimeters. In contrast, attending 2 had the second highest case time and the lowest radiation dose per case but the second highest hand exposure. Finally, the Pearson correlation coefficient for the ring dosimeters with exposure and the fluoroscopy dose ($r = -0.97$) showed a strong negative correlation. This illustrates that radiation doses during a case do not directly correlate to the radiation exposure to the surgeon when using the mini C-arm. The radiation exposure to the surgeons' hands depends on whether their hands are directly in the radiation field.

There are a few limitations in our study. The rings in this study had a minimum level of radiation detection of 30 mrem, which was not as sensitive as the badges (1 mrem). In response to this problem, we used the rings for multiple cases, hoping to accumulate enough radiation exposure above the minimal level for detection. Despite this effort, a majority of the rings in the study were not exposed to the minimum sensitivity level of radiation. Therefore, the rings with 0 mrem of detectable radiation exposure could actually have had 0 to 29 mrem of radiation exposure. To address this limitation, the calculated radiation exposure rate of 6.30 mrem per case for ring dosimeters with recordable radiation levels was a worst-case scenario. This radiation exposure rate would allow a surgeon to perform more than 7,900 cases without exceeding the annual limit of 50,000 mrem.

Another analytical limitation of the ring dosimeters for multiple cases pertained to exposure comparison between the attending surgeons and the fellow. The cases in which the fellow was a participant always involved an attending surgeon. In addition, the cases that the attending surgeons performed without the fellow usually involved the participation of a resident from the orthopedic surgery program. For these combined cases, no pattern of behavior was followed in relation to who held the extremity during use of the mini C-arm fluoroscope. This led to the assumption that a comparison of the radiation exposure from all of the attending surgeons' and the fellow's cases should have been sufficiently randomized for comparison. Ideally, a single ring worn in every case during the study could have increased the accuracy, but with the risk that the radiation exposure would not exceed the minimum sensitivity level of each ring dosimeter.

This study, of radiation exposure with actual cases performed, demonstrated the mini C-arm can be used safely in routine surgical cases by the hand surgeon with minimal recordable radiation exposure.

## REFERENCES


1. Hendee WR. History, current status, and trends of radiation protection standards. Med Phys 1993;20:1303–1314.
2. Mastrangelo G, Fedeli U, Fadda E, Giovanazzi A, Scoizzato L, Saia B. Increased cancer risk among surgeons in an orthopaedic hospital. Occup Med 2005;55:498–500.
3. Gehrke JC, Mellenberg DE, Donnelly RE, Johnson KA. The Fluoroscan imaging system in foot and ankle surgery. Foot Ankle 1993; 14:545–549.
4. Wilson CR. Letter to the editor: Potential radiation hazard associated with the unprotective use of mini C-arm fluoroscopy units. Med Phys 1997;24:1331.
5. Athwal GS, Bueno RA, Wolfe SW. Radiation exposure in hand surgery: mini versus standard C-arm. J Hand Surg 2005;30A:1310–1316.
6. Badman BL, Rill L, Butkovich B, Arreola M, Vander Griend RA. Radiation exposure with the use of the mini C-arm for routine orthopaedic imaging procedures. J Bone Joint Surg 2005;87A: 13–17.
7. Giordano BD, Ryder S, Baumhauer JF, DiGiovanni BF. Exposure to direct and scatter radiation with the use of mini-C-arm fluoroscopy. J Bone Joint Surg 2007;89A:948–952.
8. Singer G. Radiation exposure to the hands from mini C-arm fluoroscopy. J Hand Surg 2005;30A:795–797.
9. Shoaib A, Rethnam U, Bansal R, De A, Makwana N. A comparison of radiation exposure with the conventional versus mini C-arm in orthopedic extremity surgery. Foot Ankle Int 2008;29: 58–61.
10. Thomson CJ, LaLonde DH. Measurement of radiation exposure over a one-year period from Fluoroscan mini C-arm imaging unit. Plast Recon Surg 2007;119:1147–1148.
11. Sinha S, Evans SJ, Arundell MK, Burke FD. Radiation protection issues with the use of mini C-arm image intensifiers in surgery in the upper limb. J Bone Joint Surg 2004;86B:333–336.