Mini C-Arm Fluoroscopy: Does Its Configuration Matter for Radiation Exposure to the Surgeon?

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Abstract

Background: The risk of occupational radiation exposure to the surgeon associated with the use of a mini C-arm has yet to reach a wide consensus. Using a distal radius fracture surgery model, we tested the hypothesis that radiation exposure to the surgeon's critical body parts is independent of mini C-arm configuration. **Methods:** An anthropomorphic mannequin (representing the upper body of a 60" male surgeon) was seated at a hand table as if operating on a volar-plated wrist Sawbone model. Thermoluminescent dosimeters measured radiation exposure to the surgeon's eyes, thyroid, chest, hand, and groin from a mini C-arm fluoroscopy unit in 3 commonly used configurations: vertical (source above table), inverted (source below table), and horizontal (with beam parallel to table surface). The fluoroscope scanned the wrist model for 15 continuous minutes in triplicate for each orientation. **Results:** Radiation to the hand was significantly greatest in all mini C-arm positions compared with all other anatomic sites irrespective of C-arm position. Hand radiation exposure was greatest in the horizontal position (2887.09 mrem), versus the vertical and inverted positions (59.79 mrem, 31.10 mrem, $P < .001$). Eye radiation exposure was significantly greater in the inverted position (2.33 mrem) compared with the vertical (0.67 mrem, $P = .024$), and horizontal positions (0.33 mrem, $P = .012$). No significant difference in radiation exposure was found at the thyroid, chest, and groin sites, at each of the 3 C-arm configurations. **Conclusions:** The model's hand received almost 1000 times more radiation exposure than all other anatomic sites with statistically greatest radiation exposure sustained in the horizontal position. Eye radiation exposure with the C-arm in the inverted position (below the table) was also significantly greater.

Keywords: radiation, fluoroscopy, mini C-arm, eye radiation, hand radiation, beam configuration

Background

With more than half a million upper extremity fractures occurring each year in the United States,⁷ the use of fluoroscopic C-arm units during hand surgery has become ubiquitous. While the C-arm continues to provide an invaluable tool for orthopedic surgeons and hand surgeons, occupational radiation exposure remains an ongoing concern.

Radiation exposure from standard large C-arm fluoroscopy during various orthopedic procedures has been well studied. The impact of positioning and orientation of a standard C-arm in terms of radiation scatter and exposure has been elucidated^{3,6,8,12} as has the impact of the fluoroscopy unit size (mini versus standard c-arm) and proximity to the surgeon.^{1,4,5,9,13,15} However, there is less of a consensus regarding the risk of radiation exposure from using a mini C-arm, with some studies minimizing the risk of

radiation^{2,4,11,14} and some studies cautioning against unexpectedly high levels of radiation from the mini C-arm unit.^{10,15} This is especially relevant in upper extremity surgery during which surgeons are often operating in close proximity to the fluoroscopic units and frequently without lead protection.

A significant benefit of the mini C-arm over the conventional C-arm includes the increased mobility, ease of use and storage, decreased cost, eliminating the need for a dedicated radiology technician, and the ability to position the

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Table 1. Distances of Each Dosimeter From the Fluoroscopy Source in Each Tested Configuration.

Position	Distance (cm)	Eye	Thyroid	Chest	Hand	Groin
Vertical	x	26	38	36	5	36
	y	30	12	0	21	34
	direct	39.7	39.85	36	21.59	49.52
Inverted	x	26	38	36	5	36
	y	72	54	42	21	7
	direct	76.55	66.03	55.32	21.58	36.67
Sideways	x	—	—	—	—	—
	y	—	—	—	—	—
	direct	48	47	42	27	49

unit in various configurations in order to image the extremity more effectively. However, the potential for increased radiation exposure to the surgeon in these various orientations, specifically the operator's eyes, thyroid, chest, groin, and hands, is currently unknown.

The goals of this study were 2-fold. The first was to determine the difference in radiation exposure from the mini C-arm in various beam configurations to surgeons in a simulated wrist surgery setup. The second was to evaluate how radiation exposure varies to different body parts with the mini C-arm in these different configurations.

Methods

Institutional review board exemption for this study was confirmed prior to this laboratory study. The study design was previously described by Hoffler and Ilyas.⁵

Dosimeter Placement

An anthropomorphic surgeon mannequin (MD-HMB2FK; Roxy Display, East Brunswick, New Jersey) was adorned with surgical glasses (Surgitel, Ann Arbor, Michigan), a surgical cap (Medline, Mundelein, Illinois), and a surgical mask (Medline, Mundelein, Illinois). Four badge dosimeters were placed in the surgeon's midline over the nasal bridge, thyroid prominence, sternal angle, and pubic symphysis using 1-inch surgical tape (3M, St. Paul, Minnesota). A fifth ring dosimeter was placed on the proximal phalanx of the right index finger. Distances of each dosimeter from the fluoroscopy source were standardized in each tested configuration, as shown in Table 1.

Positioning

The surgeon mannequin's positioning and dosimeter placement remained fixed throughout all procedures (Figure 1). The surgeon was seated in an operating position at a

Figure 1. Anthropomorphic surgeon model with dosimeters, mini-C-arm fluoroscopy unit, and Sawbones model with a distal radial plate.

radiolucent 46 × 82-cm hand surgery table. A Sawbones left wrist model (Pacific Research Laboratories, Vashon, Washington) with a volar-plated distal radius lay supinated with the volar plate centered at 23 cm and 41 cm from the short and long edges of the table, respectively. The surgeon's hands were pronated and rested on the Sawbones model, with the distal phalanges of its index fingers 5 cm proximal and 5 cm distal to the center of the volar plate. The sternal angle of the mannequin was horizontally 36 cm from the center of the table and 25 cm above its surface. No part of the mannequin was not captured directly in the x-ray beam.

Fluoroscopy Settings and Recording

A mini C-arm fluoroscope (OrthoScan, Scottsdale, Arizona) scanned the wrist model for 3 continuous 15-minute trials at each of 3 commonly used C-arm configurations: vertical (source above the table), inverted (source below the table), and horizontal (source parallel on the table) (Figure 2). At each configuration, the fluoroscopy beam was aimed directly at the center of the volar plate, such that the eye, thyroid, chest, and groin dosimeters were in the same vertical plane as the beam in the upright and inverted configurations, and the hand dosimeter was in the vertical plane of the beam with the C-arm horizontal. Fluoroscopic settings were held constant at 60 kVp and 0.074 mAs per the standard manufacturer settings. Used dosimeters were replaced with a new set after each trial.

Figure 2. Sample positioning of the 3 beam orientations of the mini C-arm: vertical (source above the table), inverted (source below the table), and horizontal (beam parallel to the table).

Figure 3. Radiation to the hand was significantly greater than all other body parts regardless of beam orientation.

Statistical Analysis

Parametric paired *t* tests were used to compare the cumulative radiation exposure at each anatomic site between each of the configuration groups. Analysis of variance compared cumulative exposure between the various anatomic sites. Alpha was set to 0.05. All values are expressed as mean values $\pm$ the standard error of the mean.

Results

Regardless of configuration of the mini C-arm beam, radiation exposure to the hand was significantly greater compared with all other sites irrespective of orientation of the mini C-arm ($P < .05$; 95% confidence interval [CI]) (Figure 3). When all configurations were averaged together, the hand was exposed to 993.66 mrem, the groin was exposed to 1.67 mrem, the thyroid was exposed to 1.44 mrem, the eye was exposed to 1.11 mrem, and the chest was exposed to 1.11 mrem.

Relative to the configuration, hand radiation exposure was greatest in the horizontal position (2887.09 mrem), versus the inverted (source below the table) position (31.10

Figure 4. Relative to the configuration of the mini C-arm beam, hand radiation exposure was greatest in the horizontal position.

mrem) and the vertical (source above the table) position (59.79), ($P < .001$; 95% CI) (Figure 4; Table 2). In addition, eye radiation exposure was significantly greater from the mini C-arm in the inverted position (2.33 mrem) compared with the vertical positions (0.67 mrem, $P = .024$; 95% CI), and the horizontal position (0.33 mrem, $P = .013$; 95% CI) (Table 2). No significant difference was found to radiation exposure to the thyroid, chest, and groin between

Table 2. Comparison of Radiation to Different Body Sites Based on Mini C-Arm Beam Orientation.

	Vertical (mean mrem)	Inverted (mean mrem)	SE of difference	P value	Vertical (mean mrem)	Sideways (mean mrem)	SE of difference	P value	Inverted (mean mrem)	Sideways (mean mrem)	SE of difference	P value
Eye	0.667	2.333	0.471	.024	0.667	0.333	0.471	.519	2.333	0.333	0.471	.013
Thyroid	1.0	2.0	0.577	.158	1.0	1.333	0.667	.643	2.0	1.333	0.882	.492
Chest	0.667	1.333	0.471	.230	0.667	1.333	0.471	.230	1.333	1.333	0.471	1.0
Hand	59.79	31.1	22.53	.272	59.79	2887.09	305.3	.0007	31.1	2887.09	304.59	.0007
Groin	2	1.667	0.333	.374	2	1.0	0.158	.158	1.667	1.0	0.333	.116

Note. Radiation to the eye was significantly greater in the inverted orientation compared with the vertical and horizontal orientations. Radiation to the hand was significantly greater in the horizontal orientation compared with the vertical and inverted orientations. Bolded values represents $p < 0.05$. SE = standard error.

the 3 configurations, and relatively low levels of radiation were observed throughout.

Discussion

The purpose of this study was to test the hypothesis that radiation exposure to critical body parts is independent of mini C-arm configuration and that the operator's hand is subjected to the highest load of fluoroscopic radiation. Our findings here demonstrate that the surgeons' hands received significantly greater doses of radiation than other sites, regardless of the position of the fluoroscope. In fact, surgeons' hands received on average almost 1000 times more radiation exposure than all other sites. However, previous studies demonstrate no clear consensus about mini C-arm position in terms of minimizing radiation exposure to the surgeon. When the C-arm is used in a vertical position, there are conflicting reports as to whether the emitter should be positioned above or below the patient to minimize scatter-radiation exposure to the surgeon. Although some traditional radiation safety teaching advises against placing the image intensifier below the patient and the emitter above (in an inverted position), there is little literature that directly quantifies radiation exposure resulting from this configuration.

One prior study examined mini C-arm radiation exposure to the patient and to the surgeon with the beam in an inverted position.¹³ They found that the amount of radiation exposure to both the surgeon and the patient was significantly less when the C-arm was used in the inverted position ($P < .0001$). The radiation dose to the patient's hand was reduced by 59%. The radiation exposure to the surgeon's head, body, and groin with the inverted C-arm technique was 67%, 45%, and 15% of the measured doses with x-ray in the standard configuration. These results were not necessarily replicated by our study. While radiation to the surgeon's hands was decreased by 48% in the inverted configuration compared with the standard configuration, radiation to the eyes actually increased 3.5-fold.

Another group used a cadaveric model to determine radiation exposure to the surgeon at the waist and neck levels during simulated closed reduction and percutaneous pinning of a pediatric supracondylar fracture with the mini C-arm beam in a standard and inverted position.⁶ When the image intensifier was used as the operating surface, they saw 16% less scatter radiation at the waist level of the surgeon but 53% more neck-level scatter radiation compared with when the hand table was used as the operating surface and the image intensifier was positioned above the table. Therefore, they concluded that neither C-arm configuration was safer. Again, these results were not replicated in our study, as we saw no significant difference in the amount of radiation to the chest, groin, or thyroid in either of these positions.

When using a large C-arm in a horizontal position, it is generally accepted that the surgeon should avoid standing opposite the image intensifier to avoid scatter radiation.^{3,12} The majority of this scatter radiation is back scatter and forward scatter is minimal, as the majority is attenuated by the tissue as it passes through.³ In terms of large C-arm positioning, standard teaching states that the image intensifier is on the surgeon side of the patient, with the emitter on the opposite side. However, this dogma does not necessarily hold true in the setting of using a mini C-arm in a horizontal configuration given the closer proximity of the surgeon to the beam. In fact, in our study, radiation to the hand was the only site that increased with the beam in a horizontal position despite the fact that the dosimeters were not behind the image intensifier.

The current National Council on Radiation Protection and Measurements (NCRPM) annual limits are 5000 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 with the C-arm in a horizontal configuration; however, average radiation exposure to the hands in all 3 positions was also high (993.66 mrem). This dose was achieved over 15 minutes of fluoroscope time that was a simulated 1 month exposure for a hand surgeon. Therefore, to extrapolate exposure out to a year, based on our study, a surgeon's hands would be exposed to 11 923.92 mrem, which is still well under the recommended 50 000 mrem dose limit put forth by the NCRPM. Consequently, it may not be necessary to monitor radiation levels in this context. In addition, given the extremely low levels of radiation registered by the groin, thyroid, and the eye dosimeters, surgeons may decide whether or not to utilize protective equipment for these sites.

There are some limitations to this study. The first is that our anthropomorphic model and Sawbones setup may not truly simulate real-time usage of a mini C-arm. The lack of soft tissue in the Sawbones model alters scatter of radiation and potential exposure to the surgeon. It is also possible that with a different type of Sawbones model, we would see a different pattern of radiation scatter. In addition, in our study the position of the surgeon's hands and the target extremity were fixed, when in reality that may not be true. A surgeon often moves his or her hands and body position closer and farther from the beam in order to image different views of the extremity. Because of this, we are potentially underestimating or overestimating radiation exposure to the surgeon. Furthermore, dosimeter sensitivity and detection capability may be limited and may not be able to ascertain more subtle differences in radiation exposure. This study also had a set fluoroscopic radiation time, when in reality, surgeon radiation exposure may vary, but it is infrequently 15 continuous minutes of C-arm radiation exposure as in this study. This study also only examines a single mini

C-arm model. The standard fluoroscopic settings may change with different models and different uses and therefore incidental radiation exposure may also vary.

Ultimately, our findings suggest that the surgeon's hands can incur the greatest radiation exposure compared with other body parts during routine mini C-arm utilization regardless of the configuration of the beam; however, radiation exposure of the hand was greatest in the horizontal position. In addition, we found a small increase in eye radiation exposure with the C-arm in the inverted (source below the table) position compared with the vertical (source above the table) position. While the clinical implications of this study remain unclear, surgeons may consider wearing protective equipment especially for the eyes and hands, and also consider limiting the use of horizontal positioning of the C-arm to minimize radiation exposure.

Ethical Approval

Each author certifies that their institutions have approved the reporting of this case report and that all investigations were conducted in conformity with ethical principles of research.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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