# Patient and Surgeon Radiation Exposure: Comparison of Standard and Mini-C-Arm Fluoroscopy

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**Background:** Use of c-arm fluoroscopy is common in the operating room, outpatient clinic, and emergency department. Consequently, there is a concern regarding radiation exposure. Mini-c-arm fluoroscopes have gained popularity; however, few studies have quantified exposure during mini-c-arm imaging of a body part larger than a hand or wrist. The purpose of this study was to measure radiation exposure sustained by the patient and surgeon during the use of large and mini-c-arm fluoroscopy of an ankle specimen.

**Methods:** Standard and mini-c-arm fluoroscopes were used to image a cadaver ankle specimen, which was suspended on an adjustable platform. Dosimeters were mounted at specific positions and angulations to detect direct and scatter radiation. Testing was conducted under various scenarios that altered the proximity of the specimen and the radiation source. We attempted to capture a range of exposure data under conditions ranging from a best to a worst-case scenario, as one may encounter in a procedural setting.

**Results:** With all configurations tested, measurable exposure during use of the large-c-arm fluoroscope was considerably higher than that during use of the mini-c-arm fluoroscope. Patient and surgeon exposure was notably amplified when the specimen was positioned closer to the x-ray source. The exposure values that we measured during ankle fluoroscopy were consistently higher than the exposure values that have been recorded previously during hand or wrist imaging.

**Conclusions:** Exposure of the patient and surgeon to radiation depends on the tissue density and the shape of the imaged extremity. Elevated exposure levels can be expected when larger body parts are imaged or when the extremity is positioned closer to the x-ray source. When it is possible to satisfactorily image an extremity with use of the mini c-arm, it should be chosen over its larger counterpart.

**Clinical Relevance:** Orthopaedists should exercise caution, and consistently follow radiation safety guidelines, when using c-arm fluoroscopes because there is a real risk of radiation exposure.

The field of orthopaedics has relied on x-rays for medical imaging since Röntgen's landmark discovery in 1895[1]. Although the first fluoroscopes were designed around the time of Röntgen's initial discovery, modern adaptations, which allowed greater versatility and were more practical, were not developed until the 1950s[2]. The use of c-arm fluoroscopy as a guidance tool by surgeons during femoral nailing and hip pinning gained popularity in the early 1980s[3]. Now, nearly every medical discipline has adopted the use of c-arm fluoroscopy in some capacity.

The era of minimal-access medicine has created a heavy dependence on indirect visualization methods to attain a satisfactory outcome. Interventionalists and surgeons who champion minimal-access techniques cite multiple benefits to conducting procedures in this manner[4-12]. Among other uses that are germane to the field of orthopaedics, c-arm fluoroscopy facilitates

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precise use of instrumentation, guides implant placement, and confirms fracture reduction[3,10,13-16]. These capabilities make c-arm fluoroscopy indispensable to the modern orthopaedic surgeon.

For many years, orthopaedists have expressed concern over the amount of radiation to which they are exposed during the use of mobile c-arm fluoroscopy[3,10,13-16]. The orthopaedic literature is replete with studies that have evaluated radiation exposure during a variety of procedures[17-25]. Over the past several decades, mini-c-arm fluoroscopy has emerged as a valuable imaging tool[10,17,18,20,24-27]. In addition to its overall practicality and cost-effectiveness, the mini c-arm has radiation-dose-reducing properties that make it an even more attractive option for everyday imaging. Exposure levels have been measured during mini-c-arm fluoroscopy in a variety of studies[10,17,18,20,24-27], with the authors concluding that it results in minimal radiation exposure and essentially no risk to the patient or surgeon. However, in most studies in which exposure during mini-c-arm fluoroscopy has been measured, the data were obtained in a best-case scenario—i.e., with the specimen on the image intensifier, the c-arm in an inverted position, a small specimen size, and as large a distance from the radiation source as possible[10,17,18,20,24-27]. While such findings may help reinforce the importance of exercising these known dose-reducing measures, exposure data from these studies may be unintentionally misleading. One might inaccurately assume, on the basis of the existing data, that as long as one is using a mini-c-arm unit, the risk of being exposed to considerable radiation is minimal. On the contrary, the mini c-arm is capable of exposing the patient and surrounding staff to substantial radiation if it is used in an injudicious manner.

Prior studies of radiation exposure during the use of mini-c-arm fluoroscopy have focused primarily on the hand or wrist[10,20,25-27], with a few notable exceptions[17,18]. While the mini c-arm may be intended for imaging small body parts such as the hand or foot, indications for its use are frequently broadened. Orthopaedic trainees are especially at risk for sustaining excessive radiation exposure during their duties in the emergency department and operating room[28,29]. Often, they are unaware of the potential for amplified exposure levels while imaging larger body parts. In addition, their surgical skills are often less refined, which necessitates a greater number of images to ensure a radiographically optimal result. Radiation safety education is not typically integrated into most didactic curricula; therefore, an appropriate and consistent adherence to established dose-reducing measures is not always observed by trainees.

To our knowledge, no one has attempted to obtain exposure data under worst-case conditions, as well as best-case conditions, to quantify potential exposures of surgeons and patients to radiation. Furthermore, we are not aware of any study in which patient-exposure levels during mini-c-arm fluoroscopy were directly compared with those encountered during large-c-arm fluoroscopy. It was our hypothesis that imaging a body part that is larger than a hand or wrist and altering the position of the extremity relative to the radiation source would have a considerable effect on the recorded direct and scatter radiation. Furthermore, we theorized that using the mini c-arm in an imprudent manner could expose patients and surgeons to radiation of a magnitude similar to that encountered during the use of standard c-arm fluoroscopy. Conventional wisdom dictates that a person standing well outside the imaging focus (>20 ft [>6 m]) would be subjected to negligible amounts of radiation. Because we wanted to further investigate this notion, we used a highly sensitive background dosimeter to monitor radiation exposure in this remote range. The primary objective of our study was to evaluate patient and surgeon exposures under a variety of conditions during use of large and mini-c-arm fluoroscopes to image a cadaver ankle specimen in a simulated surgical procedure.

## Materials and Methods

A cadaver ankle specimen was obtained from the anatomical gift program at our institution and used as the simulated patient. The specimen was amputated at the midtibial level, providing the ankle and foot for our investigation. Densitometry performed on the specimen ensured that it had adequate bone mass, which was 0.647 g/cm$^3$.

### *Instrumentation*

A calibrated OEC 9800 c-arm with a 30.5-cm image intensifier and a calibrated OEC mini 6800 c-arm with a 15.2-cm image intensifier (OEC Medical Systems, Salt Lake City, Utah) were used to image the cadaver specimen. An adjustable polycarbonate (Lexan; SABIC Innovative Plastics, Mt. Vernon, Indiana) platform was built to suspend the specimen in the various configurations that were tested. A series of thirteen film-badge dosimeters (Global Dosimetry Solutions, Irvine, California) were mounted onto individual arrays that were fixed to an adjustable jig. The dosimeters can accurately detect exposures ranging from 10 to 1,000,000 mrem (0.1 to 10,000 mSv). Dose equivalents from exposure were assigned deep and shallow values and are reported in millirem (1 mrem = 0.01 mSv).

### *Sensor Positioning*

The dosimeters were arranged so that four sensors were positioned on the platform (in four separate quadrants) at 90° intervals relative to the specimen (Fig. 1). Four dosimeters were placed at a 45° angle on the image-intensifier side of the platform, and four were placed at a 45° angle on the radiation-source side. Each dosimeter was placed exactly 1 in (2.54 cm) outside the cylinder of the image intensifier to standardize its proximity to the collimated beam. One dosimeter was placed at the center of the image focus on the ankle specimen to measure the entrance dose to the patient for each testing configuration. A portable pressurized ion chamber (Inovision, Cleveland, Ohio) was placed approximately 20 ft (6 m) from the imaging setup to act as a control and monitor background radiation levels at that remote location. Prior to each testing configuration, a new series of thirteen dosimeters were mounted at their respective positions. A detailed cataloging system was utilized to prevent any errors in data recording.

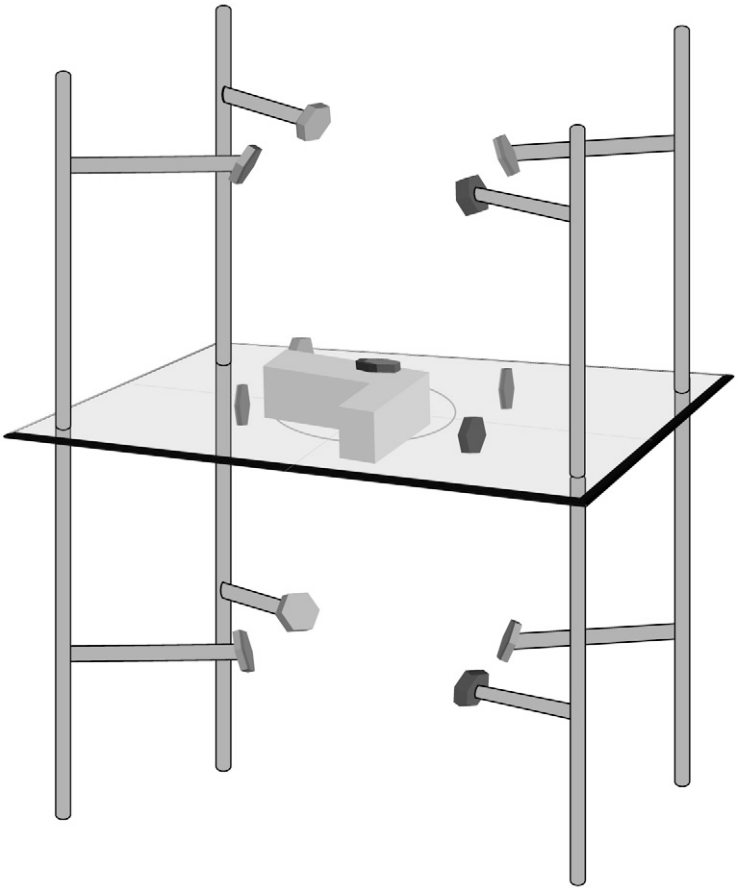

Fig. 1
Placement of the specimen and dosimeters during testing.

*C-Arm Settings*
The mini and large-c-arm units were set to the automatic mode so that technique factors adjusted automatically to optimize image quality and specimen penetration. This was thought to represent a realistic procedural setting. The specimens were then imaged with a 300-second exposure. The exposure was centered on the ankle joint. The x-ray-tube technique factors (i.e., milliamperes and kilovolt peak) were recorded for each test.

*Dose-Mapping Scenarios*
The standard c-arm was tested in three different configurations. These were designated as the best-case scenario, the 10-in (25.4-cm) (or midway) position, and the worst-case scenario, on the basis of a continuum of projected exposure doses (Fig. 2). For the worst-case scenario, the specimen was placed within 2 in (5.1 cm) of the radiation source. For the best-case scenario, the jig was adjusted so that the specimen was nearly in contact with the image intensifier. The third scenario involved placing the specimen 10 in from the image intensifier—i.e., at an equal distance from the radiation source and the image intensifier.

The three dose-mapping configurations were then repeated with use of the mini c-arm (Fig. 3).

Dosimeters were cataloged and collected in a similar fashion for the two testing methods. Once all of the dosimeters had been collected, they were sent to a private dosimeter collection firm (Global Dosimetry Solutions), where they were analyzed. Data were then sent back to our institution for further scrutiny.

All personnel involved in the study wore badge dosimeters. A member of the radiation safety team was present for the study. The study dosimeters were stored in another room before and after use. The study was conducted in a facility with no other radiation sources in use at the time.

*Source of Funding*
No outside funding was received for this study.

## Results

Dose results are reported in deep and shallow equivalents and are summarized in Tables I and II. The data can be extrapolated to apply to exposure sustained by the patient (direct exposure) and exposure sustained by the surgeon (scatter exposure detected at 1 in outside the collimated beam).

*Patient Exposure*
The amount of exposure recorded by the dosimeter placed directly on top of the specimen provides an estimate of the entrance dose that would be sustained by an actual patient (over a five-minute imaging interval). This correlates to the

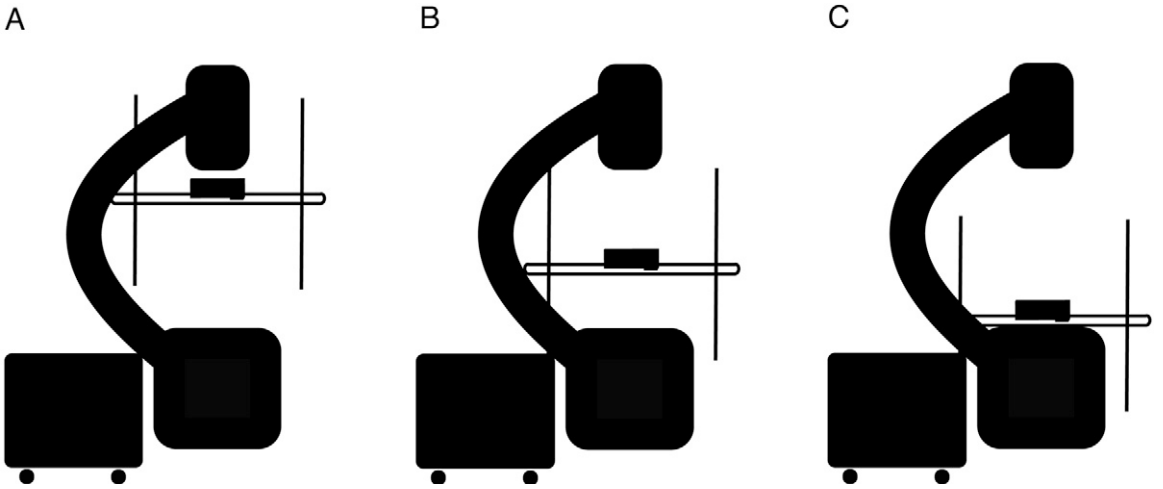


Fig. 2

The three positions tested with the standard c-arm fluoroscope, including the worst-case scenario with the specimen placed 2 in from the radiation source (A), the midway position with the specimen placed 10 in from the image intensifier (B), and the best-case scenario with the specimen positioned at the image intensifier (C).

"shallow" dose, or the dose at the skin. The shallow dose is the dose measured at a 0.7-mm depth in the skin; the deep dose is measured at a 1-cm depth. In the worst-case configuration, with the specimen positioned within 2 in of the x-ray source, patient exposure during use of the standard c-arm was dramatic, measuring 8988 mrem (89.88 mSv) (Table I). The worst-case scenario also resulted in a considerable exposure when the mini c-arm was used (3912 mrem [39.12 mSv]) (Table II). At the 10-in position (positioning of the specimen midway between the x-ray source and the image intensifier), patient exposure decreased considerably, to 1453 mrem (14.53 mSv) during use of the standard c-arm and to 994 mrem (9.94 mSv) during use of the mini c-arm. Finally, in the best-case configuration, with the specimen positioned directly on top of the image intensifier, there was a further diminution in exposure, to 850 mrem (8.50 mSv) with use of the large c-arm and to 305 mrem (3.05 mSv) with use of the mini c-arm.

*Surgeon Exposure*

The dosimeters placed circumferentially 1 in outside the collimated beam were meant to provide an estimate of the potential dose to which the surgeon was exposed. We found a great degree of variability in the exposure levels recorded by these peripheral dosimeters. Even dosimeters that were placed in the same plane diverged widely in their measured exposure. We reasoned that this was because the distribution of scattered radiation in three dimensions depends on the shape of the specimen. Therefore, the highest individual measurement in any of the planes evaluated should be considered a potential exposure level. In a real procedural scenario, a c-arm operator may be standing at any point around the periphery of the focal point and thus be subject to variable amounts of scatter radiation depending on the anatomical properties of the imaged body area nearest to him or her. We were most interested in the dosimeter that detected the highest level of exposure so that a truly

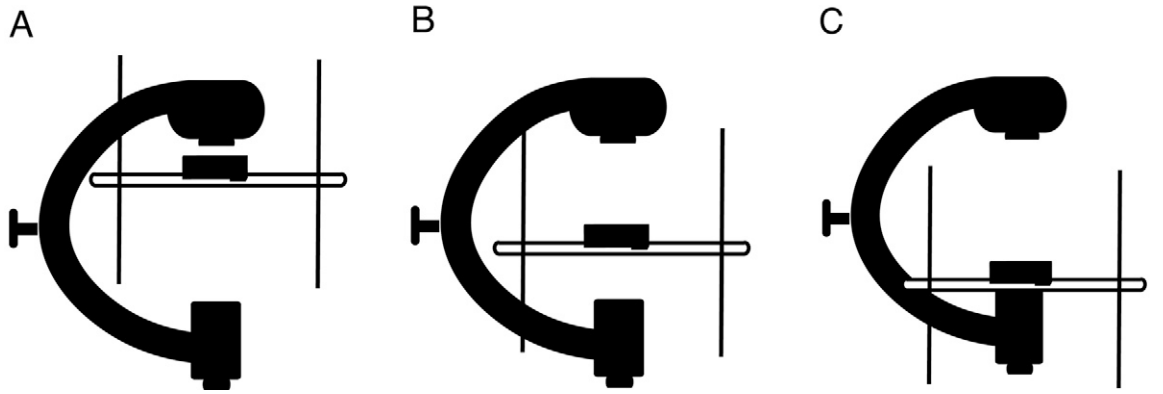


Fig. 3

The three positions tested with the mini-c-arm fluoroscope, including the worst-case scenario with the specimen placed 2 in from the radiation source (A), the midway position with the specimen placed 10 in from the image intensifier (B), and the best-case scenario with the specimen positioned at the image intensifier (C).

**TABLE I Radiation Doses at the Different Specimen and Dosimeter Positions During Use of the Standard C-Arm**

| Specimen*/Dosimeter Position | Dose† *(mrem†)* | |
|---|---|---|
| | Deep | Shallow |
| Worst case (specimen 2 in from x-ray source) | | |
| Dosimeters on x-ray-source side | 0 | 0 |
| | 0 | 0 |
| | 11 | 13 |
| | **12** | **14** |
| Dosimeters on platform | 29 | 34 |
| | 14 | 16 |
| | 13 | 16 |
| | **31** | **38** |
| Dosimeters on intensifier side | 0 | 0 |
| | 14 | 17 |
| | 13 | 15 |
| | **14** | **16** |
| Direct (patient dose) | **8042** | **8988** |
| Midway position (specimen 10 in from intensifier) | | |
| Dosimeters on x-ray-source side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Dosimeters on platform | **13** | **16** |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Dosimeters on intensifier side | 16 | 19 |
| | 15 | 18 |
| | **18** | **20** |
| | 16 | 19 |
| Direct (patient dose) | **1297** | **1453** |
| Best case (specimen at intensifier) | | |
| Dosimeters on x-ray-source side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Dosimeters on platform | **14** | **17** |
| | 0 | 0 |
| | 0 | 0 |
| | 13 | 16 |
| Dosimeters on intensifier side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Direct (patient dose) | **750** | **850** |

*X-ray technique factors: 62 kV and 1.6 mA for the worst case, 57 kV and 1.2 mA for the midway position, and 57 kV and 1.1 mA for the best case. †The shallow dose is the dose measured at a 0.7-mm depth in the skin; the deep dose is measured at a 1-cm depth. Exposure of <10 mrem was reported as 0. The values for the highest dosage recorded by any dosimeter in the testing sequence are in bold. ‡1 mrem = 0.01 mSv.

**TABLE II Radiation Doses at the Different Specimen and Dosimeter Positions During Use of the Mini C-Arm**

| Specimen*/Dosimeter Position | Dose† *(mrem†)* | |
|---|---|---|
| | Deep | Shallow |
| Worst case (specimen 2 in from x-ray source) | | |
| Dosimeters on x-ray-source side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Dosimeters on platform | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | **15** | **18** |
| Dosimeters on intensifier side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Direct (patient dose) | **3363** | **3912** |
| Midway position (specimen 10 in from intensifier) | | |
| Dosimeters on x-ray-source side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Dosimeters on platform | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Dosimeters on intensifier side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Direct (patient dose) | **848** | **994** |
| Best case (specimen at intensifier) | | |
| Dosimeters on x-ray-source side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Dosimeters on platform | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Dosimeters on intensifier side | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| | 0 | 0 |
| Direct (patient dose) | **320** | **305** |

*X-ray technique factors: 63 kV and 47 μA for the worst case, 58 kV and 36 μA for the midway position, and 53 kV and 32 μA for the best case. †The shallow dose is the dose measured at a 0.7-mm depth in the skin; the deep dose is measured at a 1-cm depth. Exposure of <10 mrem was reported as 0. The values for the highest dosage recorded by any dosimeter in the testing sequence are in bold. ‡1 mrem = 0.01 mSv.

worst-case scenario could be established for that mapping configuration.

*Large C-Arm*

When the specimen was positioned within 2 in of the radiation source (the worst-case configuration), scatter exposure was captured by dosimeters on the platform, on the x-ray-source side, and on the image-intensifier side (Table I). When the specimen was in the 10-in position, scatter radiation was detected by dosimeters positioned on the platform and on the image-intensifier side. When the specimen was positioned in the best-case configuration, scatter was recorded only by dosimeters mounted on the platform (14 and 17 mrem [0.14 and 0.17 mSv]). Less than 10 mrem of exposure was recorded by the dosimeters in the x-ray-source and image-intensifier positions. It is important to note that if a dosimeter measured <10 mrem, a value of 0 mrem was assigned and noted in this manner on the occupational radiation exposure report that was returned to us.

*Mini C-Arm*

Considerably less exposure was detected when the testing configurations were repeated with the mini c-arm. Only when the specimen was brought within 2 in of the x-ray source did the peripheral dosimeters record any measurable radiation. The exposure levels were 15 and 18 mrem (0.15 and 0.18 mSv) at the platform position (Table II). In the best-case and 10-in configurations, <10 mrem of exposure was recorded by the peripheral dosimeters at all mounted positions.

## Discussion

Like many imaging tools that rely on ionizing beam radiation, the mini-c-arm fluoroscope has been the subject of much scrutiny over the years. Both direct and indirect comparisons have shown the radiation exposure levels associated with the mini c-arm to be consistently lower than those associated with its large-c-arm counterpart[17,20,25-27,30]. Nonetheless, authorities on radiation protection maintain that strict adherence to established safety principles is still warranted. Despite the reputed exposure-reduction capabilities of the mini c-arm, many practitioners remain concerned about potentially exposing their patients and themselves to radiation[2,10,31].

Orthopaedic trainees and fluoroscopic operators may be at particular risk for being exposed to high doses of radiation when using mini-c-arm fluoroscopy. In separate reports, Smith et al.[29] and Oddy and Aldam[28] showed that exposure correlates with the level of experience of both the surgeon and the radiographer. Presumably, more practice means less operating time and the need for fewer radiographs to confirm satisfactory anatomical alignment and hardware placement. Jayasekera and Roach expressed concern that orthopaedic trainees lack a thorough working knowledge of radiation physics and safety principles[31]. They postulated that this deficiency may lead to imprudent imaging practices that may predispose them to elevated exposure. This highlights the importance of incorporating radiation safety into the didactic elements of resident education.

Exposure during the use of mini-c-arm fluoroscopy has been evaluated in a host of studies, in which it has been concluded that any measurable exposure is the result of direct contact with the radiation beam and exposure from scatter is universally low[17,18,20,26,30]. The authors of such studies have drawn the conclusion that the risk of exposure during mini-c-arm fluoroscopy is minimal for both the patient and the surgeon, with some even going so far as to suggest that protective lead garments are not needed when using a mini-c-arm fluoroscope[17,18]. However, on the basis of our data, we believe that protective safety measures should be strictly enforced during both large and mini-c-arm fluoroscopy. These measures include the routine use of lead shielding for patients, surgeons, and any adjacent medical staff.

In most studies of radiation exposure during mini-c-arm fluoroscopy, the authors collected data under a best-case scenario (i.e., with the specimen on the image intensifier, the c-arm in an inverted position, a small specimen size, and as large a distance from the radiation source as possible) and extrapolated their conclusions on the basis of this model[10,17,18,20,24-27,29,30]. Many of these same authors focused exclusively on exposure of the operating team or surgeon during the routine use of a mini c-arm for certain hand or wrist procedures[10,26]. Very few studies have involved a body part larger than a hand or wrist[17,18,27].

We are aware of a limited number of studies involving direct examination of the amount of radiation to which a patient is exposed during mini-c-arm imaging. We previously demonstrated that imaging of a phantom hand during a simulated procedure resulted in 181 and 272 mrem (1.81 and 2.72 mSv) of deep and shallow exposure over a 300-second imaging period[20]. Athwal et al. found that the exposure rate associated with a mini-c-arm unit was nearly half that associated with its large-c-arm counterpart during a simulated wrist procedure[26]. However, they did not comment on exposure of the patient in their scenario. In a recent article, Shoaib et al. indirectly calculated exposure of the surgeon and patient to radiation during both mini and large-c-arm imaging[27]. They demonstrated that, while use of the mini c-arm minimized the surgeon's exposure, its use did not alter the exposure sustained by the patient. On the basis of these investigations, it seems that the body of knowledge concerning exposure during c-arm fluoroscopy is growing. However, it is also clear that a more thorough analysis of exposure dose mapping during regular working conditions is warranted.

In our study, we quantified radiation exposure sustained by the patient and surgeon during use of standard and mini-c-arm fluoroscopes to image a body part larger than a hand or wrist. We performed our testing with a variety of imaging configurations, as may be encountered in a realistic procedural setting. In addition, we systematically mapped direct and scattered radiation both above and below the point of focus, and we compared these values with measurements obtained during use of a large c-arm.

This study demonstrated that, as the imaged extremity increases in cross-sectional area and tissue density, or approaches the radiation source (i.e., when it is imaged under less-

than-ideal conditions), there is a precipitous amplification in the radiation to which the patient is exposed. For example, when the large c-arm was used and the ankle specimen was brought from a best-case to a worst-case configuration, there was a tenfold increase in direct exposure of the patient. Exposure of the surgeon to scatter radiation also increases considerably (twofold in our study) when the extremity is imaged with the large c-arm under suboptimal conditions. When our testing configuration was repeated with use of the mini c-arm, the exposure sustained by the patient again increased more than tenfold from the best-case to the worst-case configuration. Exposure of the surgeon (scatter radiation) measured 15 and 18 mrem (0.15 and 0.18 mSv) at the platform position when the specimen was in the worst-case configuration. This finding highlights the fact that, even when one is out of the direct path of the radiation beam, radiation exposure is still not negligible.

As previously mentioned, a portable pressurized ion chamber with a high sensitivity for detecting radiation exposure was set in the doorway approximately 20 ft (6 m) from our imaging setup to act as a control. Normal background radiation readings on the ion chamber range from 5 to 7 μrem/hr. Surprisingly, although the portable sensor was 20 ft from the testing zone, it still recorded 200 μrem/hr during mini-c-arm imaging. While this dose is seemingly inconsequential, it highlights the fact that scatter radiation is present even at great distances from the radiation source and is not zero as some believe. Furthermore, the dosimeters that were recorded as measuring 0 mrem in the occupational radiation exposure report actually detected a cumulative dose of <10 mrem. The long-term stochastic effects of prolonged radiation exposure are unclear. However, a review of epidemiological data suggests that the lowest dose of x-rays that has reliably been shown to increase cancer risk is 5 to 10 rem (0.05 to 0.1 Sv) during a protracted exposure[32]. Data extracted from the dermatology literature suggest that observable effects of acute radiation exposure, such as skin changes, become evident within hours and can be present after a threshold dose of 200 rad (2 Gy)[33]. Permanent skin changes can occur after years of chronic radiation injury and have a threshold dose of 1000 rad (10 Gy). While levels produced in our study did not approach such threshold doses, both the short and long-term effects of radiation exposure and the risks that they impose must be carefully weighed against the advantages of using mobile fluoroscopes.

We found that, with all of the configurations that were tested, patient exposure during use of the large c-arm was approximately double that during use of the mini c-arm. Surgeon exposure was also much greater with use of the large c-arm. Because the dosimeters used in the present study were unable to detect exposure of <10 mrem, it was not possible to obtain a true measure of the scatter radiation to which a surgeon is exposed. One other interesting finding was that patient exposure during use of the mini c-arm in the worst-case configuration was approximately five times greater than patient exposure during use of the large c-arm in the best-case configuration, and exposure of the surgeon to scatter radiation was equivalent under those two scenarios. In plain terms, if the mini c-arm is being used in an injudicious manner (with the imaged extremity improperly positioned close to the radiation source), the patient may be at undue risk for sustaining excessive radiation exposure. This again underscores the importance of maintaining ideal imaging conditions when using either fluoroscopy unit under real working conditions.

In summary, this study has shown that, contrary to the belief of some, the mini c-arm is capable of producing considerable radiation exposure, especially if it is used in an injudicious manner. Exposure of the patient and surgeon can be minimized by following known dose-reducing recommendations and strictly adhering to all protective measures, including use of a lead garment. While the mini c-arm can and should be used to image larger body areas, the surgeon must be conscientious to limit the number of exposures, as radiation can be expected to be much higher under such conditions. ■

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