Radiation Exposure with Use of the Mini-C-Arm for Routine Orthopaedic Imaging Procedures

Brian L. Badman, Lynn Rill, Bradley Butkovich, Manuel Arreola and Robert A. Vander Griend

This information is current as of April 12, 2011

Supplementary Material	http://www.ejbjs.org/cgi/content/full/87/1/13/DC1
Reprints and Permissions	Click here to **order reprints or request permission** to use material from this article, or locate the article citation on jbjs.org and click on the [Reprints and Permissions] link.
Publisher Information	The Journal of Bone and Joint Surgery 20 Pickering Street, Needham, MA 02492-3157 **www.jbjs.org**

Radiation Exposure with Use of the Mini-C-Arm for Routine Orthopaedic Imaging Procedures

By Brian L. Badman, MD, Lynn Rill, PhD,
Bradley Butkovich, MD, Manuel Arreola, PhD, DABR, and Robert A. Vander Griend, MD

Investigation performed at the Departments of Orthopedics and Radiology, University of Florida—Shands Teaching Hospital, Gainesville, Florida

Background: The use of mobile fluoroscopic devices during orthopaedic procedures is associated with substantial concern with regard to the radiation exposure to surgeons and support staff. The perceived increased risks associated with large c-arm devices have been well documented. However, no study to date has documented the relative radiation risk associated with the use of a mini-c-arm device. The purpose of the current study was to determine the amount of radiation received by the surgeon during the use of a mini-c-arm device and to compare this amount with documented measurements associated with the large c-arm device.

Methods: With use of a radiation dosimeter, measurements were carried out with tissue-equivalent anthropomorphic phantoms to quantitatively determine exposure rates at various locations and distances from the mini-c-arm for two common upper and lower extremity procedures.

Results: Regardless of position, distance, or relative duration of exposure, exposure rates resulting from the use of the mini-c-arm device were one to two orders of magnitude lower than those reported in the literature in association with the use of the large c-arm device.

Conclusions: The mini-c-arm device should be utilized whenever feasible in order to eliminate many of the concerns associated with use of the large c-arm device, specifically those related to cumulative radiation hazards, positioning considerations, relative distance from the beam, and the need for protective shielding.

Over the past several decades, mobile fluoroscopy has greatly contributed to the field of orthopaedic surgery. While this technique was initially employed for only select operative procedures such as intramedullary femoral nailing, modern uses of the mobile fluoroscope have been vastly expanded to include any surgical procedure requiring visualization of the skeletal anatomy. Several previous reports have documented the radiation exposure and associated risks resulting from the use of large c-arm devices and have outlined the necessary radiation-protection measures that the surgeon and his or her staff must follow in order to minimize these risks. Radiation exposure to surgical personnel depends on the orientation of the fluoroscopic beam relative to the patient, the total exposure time, the distance from the beam to the surgeon, the position of the surgeon within the operative field, and the use of protective lead garments and shields[1-10].

During fluoroscopy, the distance to the radiation source (the patient in the case of scattered radiation) determines the amount of radiation exposure according to the inverse square law, which states that the exposure decreases proportionately to the square of the distance between the source and the object of concern. Giachino and Cheng[3] first commented on this principle in a cadaveric hip-pinning study in which a 750-fold reduction in radiation was noted when the measuring equipment was moved 18 in (45.7 cm) from the fluoroscope. Several subsequent authors have documented similar findings[2-5]. Increasing the distance from the source in order to decrease radiation exposure is a beneficial guideline for operative personnel; however, the dilemma for surgeons is that close proximity to the beam is routinely required for such procedures as maintenance of a difficult reduction or freehand placement of interlocking screws. In addition, other dose-reduction techniques based on geometric considerations, such as positioning the patient adjacent to the image intensifier, may be limited by the practical demands of the procedure.

With the introduction of smaller c-arm devices, fluoroscopic imaging is now routinely used for fracture treatment in the emergency room and for outpatient orthopaedic proce-

Fig. 1

Photograph showing the forearm-examination setup.

extremities at low entrance exposure and scattered radiation levels. The x-ray generator has a maximum output power of 7.5 W at 75 kV and 100 µA. The image intensifier has a diameter of 6 in (15.2 cm) rather than 3 in (7.6 cm) as initially used for mini-c-arm devices.

The experimental setup was determined by positioning anthropomorphic phantoms as a patient might be positioned within the c-arm for a typical forearm or ankle examination. The anthropomorphic phantoms were composed of human bones surrounded by tissue-simulative material. The forearm examination was performed with the c-arm positioned horizontally and the phantom centered between the x-ray tube and the image intensifier. The ankle examination was performed with the c-arm positioned vertically and the ankle phantom resting on the image intensifier. Air kerma measurements were made in the plane parallel to the floor at various radial distances from the phantom. These measurements represent the amount of scattered radiation to which the operating orthopaedic surgeon is exposed. Figures 1 and 2 show the experimental setups that were used to simulate forearm and ankle examinations, respectively.

The fluoroscopic technique factors were set automatically by the brightness-control system in the normal fluoroscopy mode of the mini-c-arm. For the ankle examination,
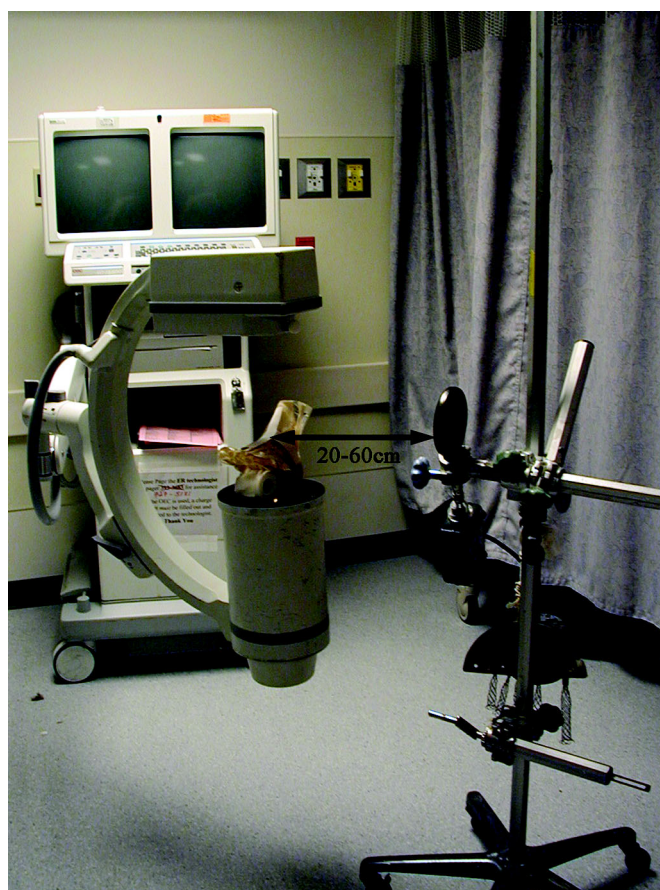
dures because of the portability, convenience, and ease of use of the equipment. On the basis of the initial manufacturer reports of reduced radiation output and the presumed increased safety afforded by the smaller size of these devices, many orthopaedic surgeons have foregone the safety precautions that are used in association with large c-arm fluoroscopy devices[11]. For instance, despite the lack of supportive data, several surgeons at our institution no longer wear protective lead garments when using the mini-c-arm device. This practice has created much debate as to whether fluoroscopic guidelines for the large c-arm device should be applied to the mini-c-arm device. To our knowledge, no previous study has documented the level of radiation exposure associated with the mini-c-arm. As such, the purpose of the present study was to quantify the amount of scattered radiation that is present during a typical mini-c-arm examination in order to determine (1) the relative risk of radiation exposure to the surgeon with extended use, (2) whether surgeon positioning is pertinent, and (3) whether protective shielding should be employed.

Materials and Methods

The OEC Mini 6600 Digital Mobile C-arm (OEC Medical Systems, Salt Lake City, Utah) combines a small c-arm with enhanced fluoroscopic imaging and is used for viewing

Fig. 2

Photograph showing the ankle-examination setup.

TABLE I Scattered-Dose Radiation Levels Associated with the Mini-C-Arm Device During the Ankle Examination as Compared with Reported Levels Associated with the Large C-Arm Device at Similar Distances

Distance from Central Beam	Scattered-Dose Radiation Levels (µGy/min)			
	Mini-C-Arm	Large C-Arm[5]	Large C-Arm[13]	Large C-Arm[12]
20-30 cm	2.4 (at 20 cm)	200 (at 26 cm)	—	—
~40 cm	0.65 (at 40 cm)	—	—	24.3
50-60 cm	0.26 (at 60 cm)	60 (at 53 cm)	33 (at 55 cm)	—
~80 cm	—	0 (at 79 cm)	—	2.8

those technique factors were 54 kVp and 32 µA. The forearm technique factors were higher (58 kVp and 36 µA); this difference was due to the fact that the phantom was positioned midway between the x-ray tube and the image intensifier, resulting in a magnified image. Because of its proximity to the x-ray tube, the radiation incident on the forearm phantom (2.53 mGy/min) was also substantially higher than that on the ankle phantom (0.77 mGy/min).

A Radial Industries MDH model 1015C radiation meter (Monrovia, California), with an 180-cc pancake ion chamber, was used to measure exposures in milliroentgen (mR). Thirty-second exposure readings were then obtained at distances of 20, 40, and 60 cm from the center of the phantom. Air kerma rates, in µGy/min, were determined from these exposure measurements, and the average air kerma was estimated with use of an examination time of five minutes[2]. The mini-c-arm is equipped with an alarm that alerts the user after five minutes of fluoroscopy.

Results

Ankle Examination

A table in the Appendix shows the air kerma measurements obtained during a five-minute examination at various distances and angles from the anthropomorphic ankle phantom. The average air kerma value at 20 cm (approximately 8 in) was 12 µGy. As expected, the measured air kerma decreased with increased distance from the phantom. Air kerma values were confirmed to be 77% lower at 40 cm and 90% lower at 60 cm when compared with the values at 20 cm.

The measured air kerma values for this experimental setup correlated well with the published values in the OEC mini-c-arm technical reference manual[11]. The geometry of the manufacturer's setup was similar to that of the ankle-examination setup, with the mini-c-arm positioned vertically in an inverted position and the phantom resting on the image intensifier. Rather than using an anthropomorphic phantom, the manufacturer used the American National Standards Institute extremity phantom, which consists of a 2-mm-thick aluminum plate sandwiched between two 2.54-cm-thick acrylic slabs. The fluoroscopic technique factors used for the manufacturer's measurements were 70 kVp and 96 µA, which were substantially higher than those used for our ankle examination. As a result, the air kerma entering the phantoms was a factor of 4.3 higher when the manufac-

turer's measurements were compared with our ankle-examination measurements. Likewise, the scattered air kerma rate at 0° and 20 cm from the phantom was also 4.5 times higher when the manufacturer's measurements were compared with our ankle-examination measurements (0.39 mGy/hr compared with 0.085 mGy/hr).

Air kerma values for a five-minute ankle examination varied with the angle of measurement. The variation of these measurements is expected because of the nonuniformity of the ankle phantom. The highest values were measured at an angle of 90° from the x-ray tube axis (perpendicular to the position of the foot) because the x-rays traveled through less tissue when scattered from the lateral malleolus. Lower values were measured at 180°, 225°, and 0° because the scattered radiation was further attenuated by the tissues of the foot.

Forearm Examination

A table in the Appendix shows the air kerma measurements obtained during a five-minute examination at various distances and angles from the anthropomorphic forearm phantom. The mini-c-arm was oriented horizontally, with the forearm phantom positioned midway between the x-ray tube and the image intensifier. The entrance air kerma rate to the forearm phantom was 2.53 mGy/min, which was a factor of 3.3 higher than the entrance air kerma rate for the ankle phantom and was similar to the rate for the manufacturer's measurements using the American National Standards Institute extremity phantom[11]. Scattered air kerma values were within 20% of those measured by the manufacturer at all distances.

Because of the orientation of the mini-c-arm, measurements were not performed at 90° (which corresponded to the position of the x-ray tube) or at 270° (which corresponded to the position of the image intensifier). Measurements performed behind these objects, however, showed no detectable radiation during the thirty-second measurement period.

The average scattered air kerma value at 20 cm during a five-minute fluoroscopic examination of the forearm phantom was 31 µGy. Because of the relative symmetry of the forearm phantom with respect to the measurements, air kerma rates were fairly uniform at all angles, with a standard deviation of 4.76 µGy or 15%. Air kerma measurements at backscatter angles (toward the x-ray tube) were approximately

TABLE II Number of Five-Minute Fluoroscopic Procedures Required to Exceed Annual NCRP* Occupational Radiation Exposure Limits with Use of Mini-C-Arm and Large C-Arm Devices			
NCRP Recommended Annual Dose Limits	Total Number of Procedures Allowable Before Limits Met		
	Whole Body (50 mGy)	Hand/Skin (500 mGy)	Eye Lens (150 mGy)
Unshielded surgeon positioned 20 cm from mini-c-arm (8 µGy/min)	1250	12,500	3750
Unshielded surgeon positioned 40 cm from mini-c-arm (2 µGy/min)	5000	50,000	15,000
Unshielded surgeon positioned 26 cm from large c-arm (200 µGy/min)	50	500	150
*NCRP = National Council on Radiation Protection and Measurements.			

50% higher than the corresponding forward angles. As was the case for the ankle examination, the air kerma values decreased by 83% and 95% as the distance from the phantom increased to 40 cm and 60 cm, respectively.

Discussion

The results of the current study indicate that the exposure levels from the miniature c-arm are substantially less at much closer distances than described in previous reports on the large c-arm[1,3-5,7-10,12,13]. The skin-entrance exposure rates as measured with the forearm and ankle phantoms were 2.53 mGy/min and 0.77 mGy/min, respectively. The patient exposure rates reported for the large c-arm typically have been one to two orders of magnitude higher[12,13]. Similarly, the measured scattered radiation exposure rates for the mini-c-arm were also substantially lower than previously published data for the large c-arm at comparable distances (Table I). At 20 cm, the average scattered radiation exposures for the ankle and forearm examinations were 2.4 and 6.2 µGy/min, respectively, with rates diminishing further by 77% and 83%, respectively, at 40 cm and by >90% at 60 cm. Assuming an average exposure of 40 µGy per five-minute procedure, an unshielded surgeon operating approximately 20 cm from the mini-c-arm beam could perform approximately 12,500 procedures before reaching established annual occupational extremity limits, 3750 procedures before reaching established annual occupational eye limits, and 1250 procedures before reaching established annual occupational whole-body deep radiation limits (Table II). Furthermore, direct hand exposure at the greatest rate measured (2.53 mGy/min) would cause hand limits to be exceeded after approximately 198 minutes[6].

With regard to the orientation of the mini-c-arm, radiation levels generally were lower when the phantom was closest to the image intensifier with the unit positioned in an inverted manner, resulting in exposure rates that averaged 58% less for the ankle examination as compared with the forearm examination (Fig. 3). Although the levels measured around the beam in each orientation were relatively uniform, the highest exposure to the surgeon was noted at the angle of greatest backscatter, determined to be at 90° to the foot during the ankle examination, as radiation was scattered off the lateral malleolus. The lowest exposure was noted between 180° and 360°; this finding was thought to be a result of the larger soft-tissue envelope on the medial side of the foot, which allowed for greater radiation absorption. For the forearm examination, the greatest exposure was noted at the backscatter angles of 45° and 135° and the lowest was found behind the x-ray tube or image intensifier, where no radiation was detectable.

On the basis of these data, it is clear that the mini-c-arm is safer than the large c-arm and is associated with substantially lower occupational exposures as measured both within the beam and at all distances from the beam. Given these findings, we believe that some of the indispensable precautions required for use of the large c-arm are not applicable to the mini-c-arm. More specifically, we believe that a surgeon using the mini-c-arm and positioned at a working distance of >20 cm from the beam will not be exposed to substantially high radiation levels. This recommended working distance is typically required for
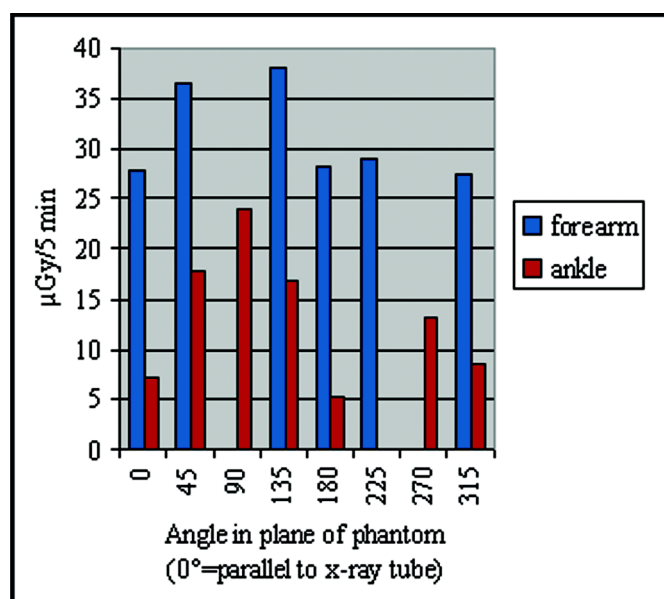

Fig. 3
Illustration depicting the relationship between the radiation level and the position of the mini-c-arm.

normal use of the machine. According to current guidelines, a surgeon working at and beyond such a distance would be capable of performing a minimum of 1250 surgical procedures per year, a number difficult to surpass even in the busiest of orthopaedic practices. Although the long-term effects of low-dose radiation are unknown, the average environmental radiation effective dose equivalent from cosmic rays, external sources, and ingested radioactive materials is approximately 3 millisieverts (mSv) per year[14]. The relative risk of death resulting from exposure to 1 microsievert (μSv) of radiation is equivalent to a one-in-eight-million risk of dying of cancer or a loss in life expectancy of seventy-two seconds, the same risk associated with crossing the street three times[15-17]. As a result, the total cumulative dose associated with the use of the mini-c-arm is relatively small. Despite this knowledge, however, under no circumstance should fluoroscopy be utilized in a cavalier manner, and practices such as live imaging and direct extremity exposure should be avoided. Therefore, because of its comparative safety and ease of use, we strongly advise the use of the mini-c-arm whenever clinically feasible.

Appendix

(*eA*) Tables presenting the raw data from this study are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

Brian L. Badman, MD
Lynn Rill, PhD
Bradley Butkovich, MD
Manuel Arreola, PhD, DABR
Robert A. Vander Griend, MD
Departments of Orthopedics (B.L.B., B.B., R.V.) and Radiology (L.R., M.A.), University of Florida—Shands Teaching Hospital, 1600 S.W. Archer Road, Gainesville, FL 32608. E-mail address for B.L. Badman: blbadman@yahoo.com. E-mail address for L. Rill: rillln@radiology.ufl.edu. E-mail address for B. Butkovich: butkofl@hotmail.com. E-mail address for M. Arreola: arreom@radiology.ufl.edu. E-mail address for R.A. Vander Griend: bob@ortho.ufl.edu

References

1. Barry TP. Radiation exposure to an orthopedic surgeon. Clin Orthop. 1984; 182:160-4.

2. Bushberg JT, Seibert JA, Leidholdt EM Jr, Boone JM. The essential physics of medical imaging. 2nd ed. Philadelphia: Lippincott Williams and Wilkins; 2001. p 52-3.

3. Giachino AA, Cheng M. Irradiation of the surgeon during pinning of femoral fractures. J Bone Joint Surg Br. 1980;62:227-9.

4. Levin PE, Schoen RW Jr, Browner BD. Radiation exposure to the surgeon during closed interlocking intramedullary nailing. J Bone Joint Surg Am. 1987;69:761-6.

5. Mehlman CT, DiPasquale TG. Radiation exposure to the orthopaedic surgical team during fluoroscopy: "how far away is far enough?". J Orthop Trauma. 1997;11:392-8.

6. National Council on Radiation Protection and Measurements. Limitation of exposure to ionizing radiation: recommendations of the National Council on Radiation Protection and Measurements. Bethesda, MD: NCRP Report 116; 1993. www.ncrp.com/ncrprpts.html

7. Riley SA. Radiation exposure from fluoroscopy during orthopedic surgical procedures. Clin Orthop. 1989;248:257-60.

8. Sanders R, Koval KJ, DiPasquale T, Schmelling G, Stenzler S, Ross E. Exposure of the orthopaedic surgeon to radiation. J Bone Joint Surg Am. 1993; 75:326-30.

9. Tremains MR, Georgiadis GM, Dennis MJ. Radiation exposure with use of the inverted-c-arm technique in upper-extremity surgery. J Bone Joint Surg Am. 2001; 83:674-8.

10. Van Staden G, Farrant K, Richards R, Bunker T. Image intensifier position for hand and wrist fractures. Injury. 2000;31:351-2.

11. Scatter Radiation Survey. Mini 6600 digital mobile C-arm operator's manual. OEC Medical Systems; 1996. 10.17-10.19.

12. Dosch JC, Dupuis M, Beck G. [Radiation measurements during interlocking nailing]. Hefte Unfallheilkd. 1983;161:36-8. German.

13. Miller ME, Davis ML, MacClean CR, Davis JG, Smith BL, Humphries JR. Radiation exposure and associated risks to operating-room personnel during use of fluoroscopic guidance for selected orthopaedic surgical procedures. J Bone Joint Surg Am. 1983;65:1-4.

14. National Council on Radiation Protection and Measurements. Exposure of the population in the United States and Canada from natural background radiation. Bethesda, MD: NCRP Report 94; 1988. www.ncrp.com/ncrprpts.html

15. Bushong SC. Radiation exposure in our daily lives. The Physics Teacher. 1977;15:135-44.

16. Cohen BL. Concepts of nuclear physics. New York: McGraw-Hill; 1971.

17. Cohen BL. Before it's too late: a scientist's case for nuclear energy. New York: Plenum Press; 1983.