Radiation Exposure and Hand Dominance Using Mini C-Arm Fluoroscopy in Hand Surgery

HAND
2016, Vol. 11(2) 188–191
© American Association for
Hand Surgery 2016
DOI: 10.1177/1558944715627224
hand.sagepub.com

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Abstract

Background: The mini C-arm is popular with hand surgeons, and they are particularly at risk for radiation exposure, as they cannot easily distance themselves from the radiation beam. We hypothesized that the nondominant hand receives more radiation exposure than the dominant hand as it is generally closer to the radiation source. This study seeks to determine whether a hand surgeon receives a different amount of radiation exposure to their hands based on hand dominance and then accounting for this, provide a more accurate assessment of hand radiation exposure from mini C-arm fluoroscopy. **Methods:** Two fellowship-trained hand surgeons wore ring dosimeters on both hands during surgeries with mini C-arm fluoroscopy involving bony work of the forearm and hand. Radiation exposure to the hands was measured from ring dosimeters. **Results:** Six-ring dosimeter pairs were worn during 64 cases, averaging 10.7 cases per ring. No ring met the minimal dose threshold of 30 mrem to record a numerical value. Each ring experienced an average of 413 seconds of fluoroscopy time and 66.3509 cGy*cm² of radiation output from the mini C-arm. **Conclusions:** The results do not allow comparison of radiation exposure related to hand dominance. Assuming worst-case scenario: each ring measured 29 mrem (just below the threshold), the surgeon's hands experienced 2.7 mrem per case. This would allow a hand surgeon to perform 18 391 cases per year before exceeding the allowable annual hand exposure limit of 50 000 mrem set by the National Council of Radiation Protection and Measurements and International Commission on Radiological Protection.

Keywords: fluoroscopy, mini c-arm, radiation, hand surgery

Introduction

Since Röntgen's landmark discovery of x-rays in 1895, fluoroscopy has become an integral surgical tool as well as significant source of radiation. Over the past 30 years, fluoroscopy use has grown, putting the surgeon at increased risk for radiation exposure. The effects of ionizing radiation exposure in humans are well documented and include skin burns, dermatitis, cataracts, and malignancy.^{4,8,14,18} With such dependence on fluoroscopy, orthopedic surgeons have been identified as being at higher risk for developing cancer than other hospital employees who routinely work with radiation.^{1,9}

The mini C-arm is a relatively new advancement that has become popular in hand surgery, as it has sought to increase portability as well as decrease radiation exposure in the intraoperative setting. There have been many studies in the past 10 years that have found a decreased risk of radiation exposure to the surgeon from mini C-arm compared with large C-arm.^{1,2,5,7,10,13,14,17,21} However, several recent studies have shown that the mini C-arm is still capable of generating considerable radiation exposure to the surgeon, especially if used with disregard to safety practices.^{6,16}

Several studies have sought to quantify how much radiation exposure a surgeon's hands are exposed to during hand surgery using the mini C-arm.^{15,19,20} These studies were done with intraoperative dosimeters and vary considerably in the amount of radiation exposure reported to the hand surgeon's hands. Despite many similarities in study design, they differ on which hand the ring dosimeter was worn. All hand surgeons at our institution consistently use their nondominant hand to maintain bone reduction and positioning, leaving their dominant hand free to use the wire driver. This places their nondominant hand much closer to, and occasionally directly in the radiation beam, putting their nondominant hand at risk for significant radiation exposure.

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Table 1. Ring Groups.

Ring groups	Number rings (pairs)	Number cases	Cases per ring
Set No. 1	8 (4 pairs)	32	8
Set No. 2	4 (2 pairs)	32	16
Combined	12 (6 pairs)	64	10.7

We hypothesized that in hand surgery, the nondominant hand receives more radiation exposure than the dominant hand. The main purpose of this study is first to determine whether hand surgeons receive a different amount of radiation exposure to their hands based on hand dominance and second to provide a more accurate assessment of hand radiation exposure to the hand surgeon from mini C-arm fluoroscopy accounting for hand dominance.

Materials and Methods

This study is a prospective observational cohort in which the hand radiation exposure of 2 fellowship-trained orthopedic hand surgeons was monitored in a single outpatient surgery center. Each of the 2 surgeons agreed to wear ring dosimeters for consecutive cases, which involved bony work on the hand or forearm in which a mini C-arm was used. Both surgeons used the same setup, placing the mini C-arm horizontally with the patient's extremity against the image intensifier. In each case, the surgeon wore a Ring Thermoluminescent Dosimeter (TLD; Landauer Inc, Glenwood, IL) on the middle finger of both hands. Orthopedic surgery residents were involved in several of these cases as this was done at a teaching institution; however, they did not wear ring dosimeters as they were generally assisting and not performing key parts of the case. These rings require 30 mrem of exposure before they will record numerical data. This is the lowest threshold available in commercially available ring dosimeters. Inclusion criteria included cases involving bony work on the forearm or hand in which the mini C-arm was used.

Institutional review board approval for this study was obtained prior to starting data collection. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Declaration of Helsinki of 1975, as revised in 2008. Informed consent was obtained from both hand surgeons included in the study.

Radiation exposure to the surgeon's hands was recorded from the ring dosimeters worn during the cases. The attending surgeon, type of case, total fluoroscopy time per case, and mini C-arm radiation output per case were recorded. The radiation measurements by the manufacturer only include shallow depth radiation penetration for ring dosimeters.

A priori power study performed before the start of the study suggested a total of 24 ring dosimeters (12 for dominant

and 12 for nondominant hand) would be necessary for a beta of .80 in how hand dominance relates to radiation exposure. It was estimated each ring would need to be used in 8 cases to achieve the minimum recordable radiation threshold of 30 mrem for the ring dosimeters to record a numerical value. Because 2 ring dosimeters would be used per case (1 for the dominant and 1 for the nondominant hand), 96 cases would need to be performed.

Results

After 32 cases between 4-ring dosimeter pairs (8 rings total), no ring met the minimal dose equivalent threshold of 30 mrem to record a numerical value. Each ring was worn in exactly 8 cases. Over the 32 cases, each ring experienced an average of 264 seconds of fluoroscopy time and 46.2928 cGy*cm² of radiation output from the mini C-arm.

The number of cases per ring was then doubled, and a second set of 32 cases were performed between 2-ring dosimeter pairs (4 rings total) again resulting in no ring meeting the minimal dose equivalent threshold. This time, each ring was worn in 16 cases. Over the second set of 32 cases, each ring experienced an average of 711 seconds of fluoroscopy time and 106.4671 cGy*cm² of radiation output from the mini C-arm.

Combining the 2 groups of rings, this represented 6-ring dosimeter pairs worn during 64 cases, averaging 10.7 cases per ring. No ring met the minimal dose threshold of 30 mrem to record a numerical value. Each ring experienced an average of 413 seconds of fluoroscopy time and 66.3509 cGy*cm² of radiation output from the mini C-arm (Table 1).

Of the 64 surgeries performed in this study, 37 were cases of surgery on the hand. This included 10 open reduction, internal fixation (ORIF), 4 osteotomies, 9 percutaneous pinings, 6 arthrodeses, and 8 miscellaneous cases. The remaining 27 cases involved surgery on the forearm and included 11 ORIF, 7 osteotomies, 2 percutaneous pinings, 3 hardware removals, and 4 miscellaneous cases (Table 2).

Discussion

The goal of this study was to determine whether a hand surgeon's hands receive different radiation exposure based on hand dominance while using mini C-arm to provide a more accurate assessment of risks associated with their use in hand surgery. The 2 most significant studies to date that have used

Table 2. Case Type.

Total cases = 64		
Type	Hand = 37	Forearm = 27
ORIF	10	11
Osteotomy	4	7
Percutaneous pinning	9	2
Arthrodesis	6	0
Hardware removal	0	3
Miscellaneous	8	4

Note. ORIF, open reduction, internal fixation.

real-time intraoperative measuring rather than using phantom models to determine hand surgeon's hand radiation exposure are by Singer¹⁵ in 2005 and Tuohy et al²⁰ in 2011. Tuohy et al looked at radiation exposure to the surgeon's dominant hand in 198 cases by 4 different hand surgeons using mini C-arm and found an average of 6.30 mrem per case. Singer looked at radiation exposure to the surgeon's nondominant hand in 81 cases by 5 hand surgeons using mini C-arm and found an average of 20 mrem per case. Despite many similarities in their methods, Singer found a 3-fold higher exposure rate while measuring exposure to the nondominant hand compared with Tuohy et al measuring exposure to the dominant hand. We hypothesized that a hand surgery's nondominant hand receives more radiation exposure than the dominant hand, and this might explain the difference.

This study did not allow comparison of hand dominance's role in hand radiation exposure as no ring met the minimum threshold of 30 mrem to record a numerical value. There is little orthopedic literature on the role of hand dominance and radiation exposure. Saunders et al¹¹ in 1993 looked at radiation exposure in 65 live orthopedic trauma cases, mostly lower extremity, where participants wore ring dosimeters on both wrists, and found no correlation to surgeon's hand dominance. However, Bahara et al³ pointed out that in hand surgery, one cannot distance themselves from the radiation beam as easily. They noted that hand surgeons frequently have to maintain fracture reduction and position during surgery with their hand, especially during percutaneous pinning procedures in the hand and wrist. Perhaps in future studies, ring dosimeters with lower minimum thresholds will be available to determine whether hand dominance plays a role in radiation exposure.

This study does suggest that use of the mini C-arm in hand surgery is safe, exposing the hand surgeon to minimal radiation. Assuming worst-case scenario, that each ring measured 29 mrem (just below the threshold), the surgeon's hands experienced at most 2.7 mrem per case. This would allow a hand surgeon to perform 18 391 cases per year before exceeding the allowable annual hand exposure limit of 50 000 mrem set by the National Council of Radiation Protection (NCRP) and International Commission on

Radiological Protection (ICRP).⁸ The worst-case scenario from this study suggests a lower hand radiation exposure rate than previously suggested by Singer and Tuohy et al. There are several limitations in this study that may explain this difference.

First, several studies have suggested that although the mini C-arm can generate significant radiation exposure, it is only when the surgeon's hand is directly in the field that the surgeon is exposed to recordable radiation.^{2,5,7} Although it is difficult to distance the hands from the fluoroscopy beam in hand surgery, it is generally possible to avoid putting one's hand directly in the beam if caution is used. The most difficult type of case to distance one's hand from the radiation source is percutaneous pinnings, which only accounted for 17% (11 of 64) of the cases in this study. As well hardware removals are generally easier cases to avoid radiation exposure with many cases only requiring 1 confirmatory shot with the fluoroscope at the end of the case. Hardware removals were excluded in Singer's study, and neither study gives the exact breakdown of case type. It was our intention to give a real life glimpse into radiation exposure in a hand surgeon's practice; hence, all cases in which mini C-arm was used were included, regardless of case type. It is possible that fewer high-risk cases like percutaneous pinnings or including low-risk cases like hardware removals may have led to lower radiation exposure in this study. Second, attention bias may have artificially lowered ring radiation exposure in this study. It was impossible to blind the surgeons, and the awareness that they were being studied may have changed their behavior to be uncharacteristically careful to avoid radiation exposure to their hands.¹² Finally, this study was done at a teaching institution with orthopedic residents, and it is possible some radiation exposure was going unrecorded as only the attending hand surgeons wore ring dosimeters. At a teaching institution, it is impractical to exclude residents from these cases for purposes of the study. However, as the hand surgeons were not blinded and both were aware of the objective of the study, they were proactive about performing the key portions of the case instead of the residents while fluoroscopy was used.

This study indicates that with adherence to basic principles of radiation exposure safety, use of the mini C-arm in hand surgery is a safe, exposing the hand surgeon to minimal risk. The worst-case scenario in our study suggests that more than 18 000 cases per year can be performed before reaching the annual limit. To reach this annual limit, one would have to perform 50 cases per day for an entire year, which for all practical purposes is impossible.

Authors' Note

This article was selected for presentation at the American Association for Hand Surgery meeting in The Bahamas, January 21-24, 2015, and it was also invited for consideration as a finalist for the Resident Award Competition.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This article does not contain any studies with animal subjects.

Statement of Informed Consent

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

Declaration of Conflicting Interests

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

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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