Hand Surgery and Fluoroscopic Eye Radiation Dosage: A Prospective Pilot Comparison of Large Versus Mini C-Arm Fluoroscopy Use

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Abstract

Background: The purpose of this study is to (1) perform a prospective pilot comparison of the impact of large versus mini C-arm fluoroscopy on resultant eye radiation exposure and (2) test the hypothesis that the use of either modality during routine hand surgery does not exceed the current recommended limits to critical eye radiation dosage. **Methods:** Over a 12-month period, eye radiation exposure was prospectively measured by a board-certified hand surgeon using both large and mini C-arm fluoroscopy. For each modality, accumulated eye radiation dosage was measured monthly, while fluoroscopic radiation output was recorded, including total exposure time and dose rate. **Results:** A total of 58 cases were recorded using large C-arm and 25 cases using mini C-arm. Between the 2 groups, there was not a significant difference with total exposure time ($P = .88$) and average dose rate per case ($P = .10$). With the use of either modality, average monthly eye radiation exposure fell within the undetectable range (<30 mrem), significantly less than the current recommended limit of critical eye radiation (167 mrem/month). **Conclusions:** The impact of various fluoroscopic sources on eye radiation exposure remains relatively unexplored. In this study, the minimal detectable eye radiation dosages observed in both groups were reliably consistent. Our findings suggest that accumulated eye radiation dosage, from the use of either fluoroscopic modality, does not approach previously reported levels of critical radiation loads.

Keywords: radiation, fluoroscopy, mini C-arm, eye radiation, radiation exposure, cataracts

Introduction

The World Health Organization has recognized cataract as the most prevalent eye disease in the world, and the association of excessive eye radiation exposure and the premature development of cataracts has been previously reported.^{2,7,12,14,21} The current concept on the pathogenesis of radiation-induced cataract formation suggests that oxidative stress generated by elevated radiation levels results in the generation of reactive oxygen species and increased DNA damage at the lens epithelium. Such cumulative eye damage may result in cataracts and diminished visual acuity.^{2,7,12,14}

The intensive use of fluoroscopy among unprotected interventional cardiologists and nurses, compared with a matched control group, has been associated with statistically significant dose-dependent increased risk of posterior lens opacities.^{2,7,9,14} Moreover, a 20-year prospective cohort study, among over 35 000 radiological technologists, has reported that exposure to fluoroscopic radiation doses, lower than recommended by the International Commission on Radiological Protection (ICRP), may increase the long-term

risk of cataract formation.⁶ Similar studies have proposed a correlation linking excessive radiation to the eye lens with the increased prevalence of early onset cataracts.^{2,7,9,15,21} While future long-term radiation safety studies are indicated, these authors suggested that, as a precaution, ocular radioprotection should be mandatory in the interventional radiology suite.⁷ Similarly, Jacob et al⁹ found that protective lead glasses lowered the risk of developing posterior subcapsular cataracts in interventional cardiologists.

Whether the practicing orthopedic surgeon assumes similar risks of developing early onset cataracts is unclear, as the overall safety of intraoperative fluoroscopy remains controversial.^{5,8,17,18,20} Previous studies have suggested that fluoroscopic radiation exposure is a potential occupational health hazard for the practicing hand surgeon, given operator

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Figure 1. Eye dosimeters were secured to surgical loupes and positioned at the level of the orbit behind the nonleaded glass eyewear (A). Mini C-arm configuration consisted of the vertical position at head level of the operator and the image intensifier situated below the radiolucent table (B).

proximity and the relative lack of protective shielding.¹⁶ Such concerns are compounded by the reality that the consistent use of lead-lined protective eyewear among hand surgeons remains uncommon. As a result, the question of whether mandatory protective eyewear is necessary with the use of intraoperative fluoroscopy remains insufficiently addressed.

The use of mini C-arm fluoroscopy, frequently for fracture management and arthritis treatment, has become commonplace in hand surgery. In contrast to the traditional large C-arm, the mini C-arm is less expensive, yields potentially less scatter of ionizing radiation, and, given its size and maneuverability does not require a radiology technologist to operate.^{4,5,8,17,18,20} These advantages over the traditional C-arm have contributed to its increased application during hand surgery, particularly during outpatient procedures performed at ambulatory surgical centers.

Presently, the amount of radiation exposure to the eye, associated with the routine use of either large or mini C-arm fluoroscopy, is unexplored and merits further investigation. The purpose of this study is to (1) perform a prospective pilot comparison of large versus mini C-arm fluoroscopy and resultant eye radiation exposure and (2) test the hypothesis that the routine use of either fluoroscopic modality does not exceed the current ICRP-recommended limits to critical eye radiation dosage.

Materials and Methods

Institutional review board approval was sought and not required by our institution for this study. Over a 12-month period, eye radiation exposure was prospectively measured

by a board-certified hand surgeon (C.F.L.) utilizing both large (OEC 9900 Elite fluoroscopy unit; OEC Medical Systems, Salt Lake City, Utah) and mini C-arm fluoroscopy (OrthoScan, Scottsdale, Arizona) during routine surgical procedures. Eye dosimeters were secured to surgical loupes and positioned at the level of the orbit behind the nonleaded glass eyewear (Figure 1A). Control dosimeters monitoring background dosage were located about 50 feet away from the test mini C-arm. Total accumulated radiation dosage was analyzed and compared with control dosimeters on a monthly basis, and background radiation exposure was eliminated (Landauer, Glenwood, Illinois). Mini C-arm configuration consisted of the vertical position, with the source emitter located above the operative extremity, at head level of the operator, and the image intensifier situated below the extremity and radiolucent table (Figure 1B). Large C-arm was utilized in the standard vertical configuration and operated by a certified radiology technologist. Fluoroscopic units were utilized in the default setting of automatic brightness mode. At the completion of each procedure, mini C-arm radiation output was recorded, including the average dose rate (mGy/s) and total exposure time (seconds). For each procedure, operative anatomic location, case type, and indication for procedure were documented.

Data Analysis

All values are expressed as the mean monthly values $\pm$ the standard error of the mean. Statistical significance between the experimental groups was determined by a pairwise Student *t* test.

Table 1. Most Common Current Procedural Terminology (CPT) Codes Performed.

Description	CPT code(s)	No. of cases
ORIF distal radius fracture	25607, 25608, 25609	43
Closed reduction pinning	25606, 25660, 26608, 26676, 26725, 26727, 26776	9
ORIF metacarpal fracture	26615	7
Removal of hardware	20680	5
Arthrodesis	25805, 26841, 26862	4
ORIF scaphoid fracture	25628	3
Others	25230, 25390, 25545, 26210, 26540, 26735, 26785	12

Table 2. Average Output of Mini C-Arm Versus Large C-Arm.

	Mini C-arm (n = 25)	Large C-arm (n = 58)
Dose rate (mGy/s)	4.87 ± 2.50	1.52 ± 0.85
Total exposure time (s)	37.48 ± 7.31	39.80 ± 2.92
Average monthly eye radiation exposure	<30 mrem	<30 mrem

Results

Over the 12-month collection period, 58 cases were recorded using large C-arm fluoroscopy, and 25 cases were performed using mini C-arm. The most commonly recorded procedures included open reduction internal fixation (ORIF) distal radius fractures, removal of hardware, closed reduction, and percutaneous pinning of metacarpal and phalangeal fractures (Table 1). Average mini C-arm radiation output per case included an average dose rate of 4.87 ± 2.50 mGy/s and total exposure time of 37.48 ± 7.31 seconds. Respectively, average large C-arm output yielded 1.52 ± 0.85 and 39.80 ± 2.92 seconds (Table 2). There was no statistical difference with total exposure time ($P = .88$) and average dose rate ($P = .10$) between the 2 groups. With both large and mini C-Arm utilization, average monthly eye radiation exposure values were less than 30 mrem. These values were less than the current ICRP-recommended limits for eye radiation exposure of 167 mrem per month (or 2000 mrem per year).¹

Discussion

Ultraviolet radiation and the accumulation of oxidative stress have been established as critical parameters in the pathogenesis of age-related cataract development.^{3,19} The presence of single-strand DNA breakage has been isolated from the

human cataractous lens, and the accumulation of DNA damage within the lens epithelium is postulated to result in the progression of irreversible lens opacity formation.^{3,11} Ionizing radiation exposure has also been recognized as a source of DNA damage, contributing to the opacification of the posterior subcapsular region of the lens.^{7,13} Such accumulation of ionizing radiation damage may result in small imperfections within the lens epithelium that can, over time, aggregate to form larger opacities, which may ultimately compromise visual acuity.^{7,13} Previously, Kleiman et al¹⁰ have demonstrated that, in a rodent model, 0.5 Gy of ionizing radiation dosage is sufficient to induce posterior lens opacities consistent with that of human cataract.

To date, the amount of radiation exposure to the eye, associated with the routine utilization of either large or mini C-Arm fluoroscopy, is unknown. Our findings here demonstrate that accumulated eye radiation dosage, resulting from either fluoroscopic modality, yields radiation loads in the low detection range (less than 30 mrem per month). In addition, these eye dosages do not approach previously reported levels of critical eye radiation. These values were below the most current 2011 ICRP recommendations for eye radiation exposure of 167 mrem per month (or 2000 mrem per year, averaged over 5 years).

The eye radiation dosages found in this study are significantly lower than previously reported hand radiation loads resultant from C-arm fluoroscopy. In a recent prospective comparative study between large and mini C-arm fluoroscopy, Vosbikian et al²² reported that mini C-arm utilization during routine hand surgery was associated with approximately double the hand radiation exposure compared with use of the traditional C-arm, and these findings were consistent with previous phantom model studies comparing both fluoroscopic modalities.^{8,18,20} The differences between eye and hand radiation absorption levels may be partially explained by the proximity of the radiation source to the exposed body part (ie, inverse-square law). During the surgical procedure, in an effort to manipulate the operative extremity or maintain reduction, the surgeon's hands can be directly under the beam of the radiation source, whereas in the vertical mini C-arm alignment, the operator's head may be away and above the emitting source.

We observed no significant differences in resultant eye radiation exposure between large and mini C-arm use, as both modalities yielded the minimal detectable eye radiation levels. Although mini C-arm fluoroscopy has been reported to yield less radiation scatter compared with the traditional larger C-arm,^{5,8,17,20} comparative studies have reported the association of mini C-arm utilization with higher radiation exposure; however, these data are limited specifically to the hand. These findings may be partially explained by the fact that, despite lower energy output (lower kVp) and yielding less radiation scatter, the emitting source of the mini C-arm is above the operating table and

within closer proximity to the surgeon. Previously, Singer et al¹⁸ demonstrated that the large C-arm is associated with less radiation exposure than the mini C-arm, concluding that direct radiation exposure to the patient and scatter to the surgeon are minimized when the C-arm is positioned with the intensifier below the extremity and arm board.

Although our data suggest that surgeon eye radiation exposure from fluoroscopy does not approach the current ICRP-recommended critical limits, we recommend interpreting these findings with caution. The health risks of prolonged low-dose eye radiation exposure are poorly quantified. In its 2007 report, the ICRP¹ conceded that “further information is needed and revised judgments may be required particularly in respect of the eye.” In 2011, the commission revised its initial recommendation of 15 000 mrem annual eye exposure to 2000 mrem, averaged over 5 years. *The ICRP Statement on Tissue Reactions* states that average single year exposure should not exceed that of 5000 mrem.¹ The primary concern is the development of posterior subcapsular cataracts, which are associated with ionizing radiation exposure. Interventional cardiologists have been reported to have an increased risk of developing these cataracts, with an odds ratio of 3.9 when compared with nonmedical workers.⁹ Moreover, a 20-year study of 35 000 radiological technologists suggested that the lifetime exposure threshold for developing cataracts might occur at levels as low as 6000 mrem, which is far lower than the ICRP recommendation.⁶ Similarly, a study of cataracts among Chernobyl cleanup workers found a lifetime, dose-effect threshold less than 1 Gy (100 rem).²³ Together, these data suggest that the “safe” limit of eye radiation exposure may be lower than that of the currently accepted levels.

The strengths of this study include the prospective comparative nature of this investigation over a continuous 12-month period, as well as the collection of eye absorption data by a single board-certified hand surgeon, to control for technical differences and fluoroscopic utilization between individual surgeons. In addition, with regard to total exposure time and average dose rate, we did not find a statistical difference between the outputs of the 2 fluoroscopic sources. Limitations to this study include the relative low sample size and unequal distribution between the 2 study arms. Nevertheless, the minimal detectable eye radiation dosages observed in both groups were reliably consistent throughout this study. These findings suggest that, during routine hand surgery, utilization of either fluoroscopic modality does not approach critical eye radiation levels, as defined by the ICRP. Although the voluntary use of radioprotective eyewear, as a precaution during intraoperative fluoroscopy, should certainly not be discouraged, the findings in this study do not provide supporting evidence for establishing mandatory ocular radioprotective gear as a standard of radiation safety. Future longer term

study of intraoperative fluoroscopic exposure, in both surgeons and operating room personnel, warrants further investigation and may continue to validate the safety associated with its routine use during hand surgery.

Ethical Approval

Institutional review board approval was sought and not required by our institution for this study.

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 when necessary.

Declaration of Conflicting Interests

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

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References

1. The 2007 recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP*. 2007;37:1-332.
2. Abe T, Furui S, Sasaki H, et al. Quantitative evaluation of light scattering intensities of the crystalline lens for radiation related minimal change in interventional radiologists: a cross-sectional pilot study. *J Radiat Res*. 2012;54:315-321.
3. Ates O, Alp HH, Kocer I, Baykal O, Salman IA. Oxidative DNA damage in patients with cataract. *Acta Ophthalmol*. 2010;88:891-895.
4. Athwal GS, Bueno RA Jr, Wolfe SW. Radiation exposure in hand surgery: mini versus standard C-arm. *J Hand Surg Am*. 2005;30:1310-1316.
5. Badman BL, Rill L, Butkovich B, Arreola M, Griend RA. Radiation exposure with use of the mini-C-arm for routine orthopaedic imaging procedures. *J Bone Joint Surg Am*. 2005;87:13-17.
6. Chodick G, Bekiroglu N, Hauptmann M, et al. Risk of cataract after exposure to low doses of ionizing radiation: a 20-year prospective cohort study among US radiologic technologists. *Am J Epidemiol*. 2008;168:620-631.
7. Ciraj-Bjelac O, Rehani MM, Sim KH, Liew HB, Vano E, Kleiman NJ. Risk for radiation-induced cataract for staff in interventional cardiology: is there reason for concern? *Catheter Cardiovasc Interv*. 2010;76:826-834.
8. Giordano BD, Ryder S, Baumhauer JF, DiGiovanni BF. Exposure to direct and scatter radiation with use of mini-c-arm fluoroscopy. *J Bone Joint Surg Am*. 2007;89:948-952.

9. Jacob S, Boveda S, Bar O, et al. Interventional cardiologists and risk of radiation-induced cataract: results of a French multi-center observational study. *Int J Cardiol*. 2013;167:1843-1847.
10. Kleiman NJ, David J, Elliston CD, et al. Mrad9 and atm haploinsufficiency enhance spontaneous and X-ray-induced cataractogenesis in mice. *Radiat Res*. 2007;168:567-573.
11. Kleiman NJ, Spector A. DNA single strand breaks in human lens epithelial cells from patients with cataract. *Curr Eye Res*. 1993;12:423-431.
12. Klein BE, Klein R, Linton KL, Franke T. Diagnostic x-ray exposure and lens opacities: the Beaver Dam Eye Study. *Am J Public Health*. 1993;83:588-590.
13. Merriam GR Jr, Worgul BV. Experimental radiation cataract—its clinical relevance. *Bull NY Acad Med*. 1983;59:372-392.
14. Osnes-Ringen O, Azqueta AO, Moe MC, et al. DNA damage in lens epithelium of cataract patients in vivo and ex vivo. *Acta Ophthalmol*. 2012;91:652-656.
15. Rehani MM, Vano E, Ciraj-Bjelac O, Kleiman NJ. Radiation and cataract. *Radiat Prot Dosimetry*. 2011;147:300-304.
16. Singer G. Radiation exposure in hand surgery. *J Hand Surg Am*. 2005;30:1317.
17. Singer G. Radiation exposure to the hands from mini C-arm fluoroscopy. *J Hand Surg Am*. 2005;30:795-797.
18. Singer G, Herron B, Herron D. Exposure from the large C-arm versus the mini C-arm using hand/wrist and elbow phantoms. *J Hand Surg Am*. 2011;36:628-631.
19. Soderberg PG. Development of light dissemination in the rat lens after in vivo exposure to radiation in the 300-nm wavelength region. *Ophthalmic Res*. 1990;22:271-279.
20. Tuohy CJ, Weikert DR, Watson JT, Lee DH. Hand and body radiation exposure with the use of mini C-arm fluoroscopy. *J Hand Surg Am*. 2011;36:632-638.
21. Vano E, Kleiman NJ, Duran A, Rehani MM, Echeverri D, Cabrera M. Radiation cataract risk in interventional cardiology personnel. *Radiat Res*. 2010;174:490-495.
22. Vosbikian MM, Ilyas AM, Watson DD, Leinberry CF. Radiation exposure to hand surgeons' hands: a practical comparison of large and mini C-arm fluoroscopy. *J Hand Surg Am*. 2014;39:1805-1809.
23. Worgul BV, Kundiyevev YI, Sergiyenko NM, et al. Cataracts among Chernobyl clean-up workers: implications regarding permissible eye exposures. *Radiat Res*. 2007;167:233-243.