

Breast Radiation Exposure in Female Orthopaedic Surgeons

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Background: Breast cancer prevalence is higher among female orthopaedic surgeons compared with U.S. women. The most common breast cancer site, the upper outer quadrant (UOQ), may not be adequately shielded from intraoperative radiation. Factors associated with higher breast radiation exposure (protective apron size and type, surgeon position, and C-arm position) have yet to be established.

Methods: An anthropomorphic torso phantom, simulating the female surgeon, was placed adjacent to a standard operating table. Dosimeters were placed over the UOQ and lower inner quadrant (LIQ) of the breast, bilaterally. Scatter radiation dose-equivalent rates were measured during continuous fluoroscopy to a pelvic phantom (simulating the patient). Four apron sizes (small, medium, large, and extra-large), 2 apron types (cross-back and vest), 2 surgeon positions (facing the table and 90° to the table), and 2 C-arm positions (anteroposterior and cross-table lateral projection) were tested.

Results: The median dose-equivalent rate of scatter radiation to the UOQ (0.40 mrem/hr) was higher than that to the LIQ of the breast (0.06 mrem/hr) across all testing, although this was not statistically significant ($p = 0.05$). The cross-back aprons provided higher protection to the LIQ compared with the vests ($p < 0.05$). Lead protection in sizes that were too small or too large for the torso had higher breast radiation dose-equivalent rates. C-arm cross-table lateral projection was associated with higher breast radiation exposure (0.98 mrem/hr) compared with anteroposterior projection (0.13 mrem/hr) ($p < 0.001$).

Conclusions: Breast radiation exposure is higher in a C-arm lateral projection compared with an anteroposterior projection. Higher dose-equivalent rates were observed for the UOQ compared with the LIQ of the breast and for aprons that were too small or too large, although these differences did not reach significance. Factors that may reduce radiation exposure include lead protection of appropriate size and distancing the axilla from the patient and x-ray tube.

Clinical Relevance: Increased breast cancer prevalence has been reported for female orthopaedic surgeons. The UOQ of the breast may be at risk for intraoperative radiation exposure. Methods of reducing exposure are warranted.

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Intraoperative fluoroscopy is a valuable tool to the orthopaedic surgeon. The utility of C-arm fluoroscopy in confirming fracture reduction, guiding implant placement, and performing minimally invasive procedures has led to its widespread use in orthopaedics. Occupational radiation exposure of the orthopaedic surgeon has been well-studied, with reports of scatter radiation to the head, neck, and eyes, leading to the development of radiation-shielding aprons, thyroid shields, and

leaded-glass eyeshields¹⁻⁵. The occupational exposure risk of breast radiation has yet to be established, and the efficacy of protective shielding has, to our knowledge, yet to be studied.

In a recent study by Chou et al., a 2.9-fold increase in the prevalence of breast cancer was reported for a population of 505 female orthopaedic surgeons compared with U.S. women of similar age and race⁶. Female radiographic technologists who experience long-term, low-dose radiation exposure have a

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TABLE I Median Scatter Radiation to the Breast

Parameter	N	Median Radiation Dose-Equivalent Rate (mrem/hr)	P Value
Dosimeter location			0.05
UOQ	104	0.40	
LIQ	104	0.06	
Lead shielding			0.0001
No lead	16	16.0	
Vest	128	0.19	
Apron	64	0.20	
Lead shield size			0.70
Small	48	0.18	
Medium	48	0.14	
Large	48	0.13	
Extra-large	48	0.37	
Shield fit			0.39
Female	64	0.17	
Male	64	0.20	
Unisex apron	80	0.40	
C-arm projection			0.0002
Anteroposterior	104	0.13	
Cross-table lateral	104	0.98	
Torso position			0.13
Facing table	104	0.19	
90°	104	0.40	

similar 3-fold increased risk of breast cancer^{7,8}. These findings do not prove that radiation causes breast cancer but do suggest that it may be a risk factor for breast cancer in these populations.

The reported risk of radiogenic breast cancer is based on the high-dose radiation exposure of atomic-bomb survivors, who were exposed to a type, energy, and magnitude of radiation that differed from that used in fluoroscopy^{9,10}. The breast cancer risk of low-dose radiation exposure is unknown, although a higher incidence of breast cancer has been reported for patients exposed to low-dose radiation while undergoing treatment for scoliosis and tuberculosis^{11,12}. The National Council on Radiation Protection and Measurements (NCRP) has recommended annual dose limits for occupational exposure of the whole body (5 rem), lens of the eye (15 rem), skin (50 rem), and fetus (0.5 rem)⁹. The annual dose limit for occupational radiation exposure of breast tissue has yet to be established. The International Commission on Radiological Protection (ICRP) recommends an annual radiation dose limit of 2 rem for the torso, suggesting that radiation exposure limits to the breast may be less than those reported for other organs.

The most common site of all breast cancers is the upper outer quadrant (UOQ) of the breast¹³. While the most common site of radiation-induced breast cancer has yet to be established, in a study of breast cancer in 28 women who underwent irra-

diation for Hodgkin lymphoma, the UOQ was the location of cancer in 59% of the cases¹⁴. Whether or not lead aprons and/or vests adequately protect this region from intraoperative radiation exposure has yet to be determined.

The primary aim of our study was to report the breast radiation exposure of an anthropomorphic female torso in a simulated operating-room setting. We hypothesized that scatter radiation would be higher to the UOQ compared with the lower inner quadrant (LIQ) of the breast and that aprons that were too large would be associated with increased scatter radiation to the breast. Additional factors associated with an increased risk of occupational radiation exposure (apron type, surgeon position, and C-arm position) were also studied.

Materials and Methods

Anthropomorphic phantoms were used to simulate the surgeon and the patient in an operating-room setting. Both phantoms scatter ionizing radiation in an amount and direction comparable with that of human tissue. An anthropomorphic torso phantom (37-inch diameter) with 2 breast attachments (400 cc; size-C cup) (ATOM Dosimetry Phantom; CIRS) was placed adjacent to a standard operating table to simulate the orthopaedic surgeon. A second anthropomorphic phantom of a pelvis (ATOM Dosimetry Phantom) was placed on the operating table to simulate the patient (Fig. 1). The torso phantom was placed 25 cm from the pelvic phantom at a height corresponding to a surgeon height of 165 cm (modeled after the average height of U.S. women 20 to 70 years of age)¹⁵. The torso dimensions corresponded to a medium-sized apron/vest based on the manufacturer's (Infab) sizing chart. A mobile,



Fig. 1
The simulated operating-room configuration with anthropomorphic phantoms of the pelvis (to simulate the patient) and a female torso (to simulate the surgeon).

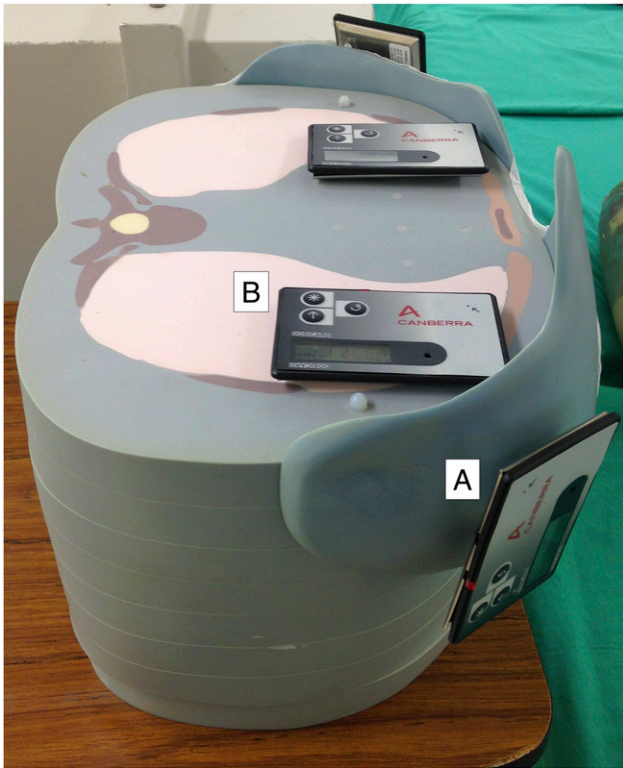


Fig. 2
Dosimeter placement on the upper outer quadrant (A) and lower inner quadrant (B) of the breast, bilaterally.

standard C-arm fluoroscope (BV Pulsera; Philips) was used in continuous mode without magnification, at a setting determined by the automatic brightness control of the C-arm with the pelvic phantom centered in the field of view with a 30 frame-per-second display (70 kVP; 6.58 mA). Dosimeters (DOSICARD; Canberra Industries) were placed on the UOQ and LIQ of the breast, bilaterally (Fig. 2). To test the effect of the orientation of the silicon diode detector on radiation recordings, median dose-equivalent rates were recorded with the detector facing the x-ray source (12.1 mrem/hr) and at 90° to the source (11.3 mrem/hr). The difference was not significant.

Cross-back lead aprons (0.5-mm lead equivalence) (Fig. 3) and vests (0.25-mm lead equivalence for the back panel; 0.25-mm lead equivalence for each front panel) (Fig. 4) were placed on the torso phantom. The lead protection was newly manufactured for this study. Four sizes were tested: small, medium, large, and extra-large. “Male” and “female” vests were tested. The male vests were broader with larger arm holes compared with the female vests. The cross-back aprons were unisex. Two C-arm positions were tested: standard anteroposterior projection and cross-table lateral projection. The distance from the x-ray tube to the pelvic phantom was 50 cm for both the anteroposterior and cross-table lateral projections. Two surgeon positions were tested: 1 with the torso phantom facing the pelvic phantom (Fig. 5) and 1 with the torso at 90° (right axilla facing the pelvic phantom) (Fig. 6).

Statistical Analysis

Each parameter (apron type and size, surgeon position, and C-arm projection) was tested 3 times, and the median radiation dose-equivalent rate (mrem/hr) for each dosimeter was calculated. A Wilcoxon rank-sum test was used to compare the median radiation dose-equivalent rate between pairs of groups (LIQ and UOQ, left and right breast, anteroposterior and lateral projection, torso facing the table and axilla facing the table, and male and female vests) and

a Kruskal-Wallis test was used to compare the difference in radiation exposure according to apron size. A univariate linear regression analysis was used to evaluate the difference in radiation exposure to the LIQ and UOQ of the breast based on apron type, with a significance criterion of $p < 0.05$.

Results

The median dose-equivalent rate of scatter radiation to the UOQ of the breast (0.40 mrem/hr) was higher than that to the LIQ of the breast (0.06 mrem/hr) ($p = 0.05$) across all testing (Table I). When comparing lead shielding to no lead shielding across all testing (both C-arm positions, surgeon positions, and all lead apron sizes), protective lead equipment resulted in lower median dose-equivalent rates for both cross-back apron use (0.20 mrem/hr) and vest use (0.19 mrem/hr) compared with no lead shielding (16.0 mrem/hr) ($p = 0.0001$). The vests and cross-back aprons provided no statistically significant difference in shielding of the UOQ ($p = 0.86$); the cross-back aprons were more effective than the vests at shielding the LIQ ($p < 0.05$) across all testing.

When comparing the C-arm positions across all apron types and sizes and surgeon positions, higher dose-equivalent rates were observed for both the UOQ and the LIQ in a C-arm lateral projection (0.98 mrem/hr) compared with an anteroposterior projection (0.13 mrem/hr) ($p < 0.001$). The median dose-equivalent rate observed with the torso phantom facing the table (0.19 mrem/hr) was lower than that with the torso at 90° (0.40 mrem/hr) ($p = 0.13$). The highest dose-equivalent rate for the left-breast UOQ was observed with the C-arm



Fig. 3
Cross-back lead apron (large size shown here).



Fig. 4
Female vest (small size shown here).

in the lateral position and with the torso facing the table (45.7 mrem/hr for no lead protection, 17.9 mrem/hr for vests, and 10.9 mrem/hr for cross-back aprons) ($p < 0.01$) (Fig. 5). The highest dose-equivalent rate for the right-breast UOQ was observed with the C-arm in the lateral position and with the torso at 90° (32.7 mrem/hr for no lead protection, 27.7 mrem/hr for vests, and 29.4 mrem/hr for cross-back aprons) ($p = 0.67$) (Fig. 6).



Fig. 5
The highest radiation doses to the left breast were observed in the C-arm cross-table lateral projection with the “surgeon” facing the table.

The median dose-equivalent rate of radiation to the UOQ observed for a medium-sized vest or apron, across all surgeon and C-arm positions, was 0.14 mrem/hr. Higher rates were observed for lead protection that was too small (size small, 0.18 mrem/hr) or too large (size extra-large, 0.37 mrem/hr), but these differences were not statistically significant. Larger aprons were more protective than small aprons in the C-arm anteroposterior projection and less protective in the C-arm lateral projection, although this was not statistically significant. The radiation dose-equivalent rates for male and female vests were not statistically significantly different.

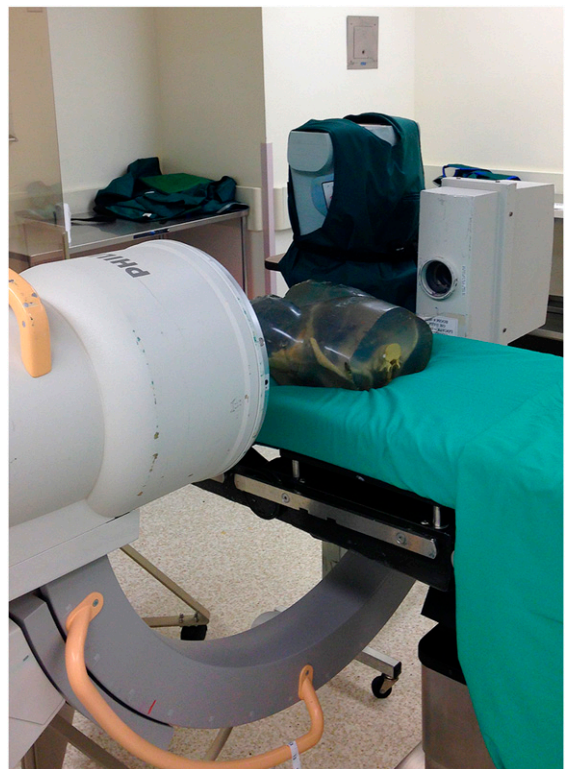


Fig. 6
The highest radiation doses to the right breast were observed in the C-arm cross-table lateral projection with the “surgeon” at 90° to the table.

Discussion

Our study demonstrated that the breast is susceptible to intraoperative ionizing radiation exposure. The UOQ of the breast was exposed to higher scatter radiation doses than the LIQ. In some simulated scenarios, median dose-equivalent rates with lead protection (29.4 mrem/hr in the C-arm lateral projection and the torso at 90° to the table) approached those observed without lead protection (32.7 mrem/hr).

We hypothesized that aprons that were too large would be associated with increased radiation to the breast. Although the median dose-equivalent rate observed for the extra-large apron was higher than that observed for the small, medium, and large aprons, this difference was not statistically significant.

Larger aprons demonstrated better protection in the C-arm anteroposterior projection than in the lateral projection, suggesting that the wider dimension provided better protection of the torso anteriorly but the larger arm holes exposed the axilla laterally (Fig. 3). Interestingly, the small apron also had a higher median dose-equivalent rate than that of the medium-sized apron. One explanation is that the small apron was too narrow for the medium-sized torso, leaving the axilla exposed. A second explanation is that the 2 panels of the small vest (each of 0.25-mm lead equivalence) did not completely overlap on a medium-sized torso, resulting in <0.5 mm of lead protection (Fig. 4). This is further supported by our finding that the LIQ was exposed to higher doses of radiation when protected by vests compared with cross-back aprons. Vests with a 0.5-mm lead equivalence for each front panel may better protect the LIQ of the breast from radiation exposure. Although not tested in our study, pregnancy aprons (1.0-mm lead equivalence), custom aprons, and aprons with sleeves may provide better protection to both the UOQ and LIQ of the breast.

Similar to the findings of other studies, our results suggest that the C-arm lateral projection increases scatter radiation doses to the surgeon^{1,3,4}. When possible, the surgeon should be positioned next to the image intensifier; however, there are scenarios in which the surgeon is positioned next to the x-ray tube, such as for lateral hip imaging during placement of a cephalomedullary nail and lateral imaging of the knee and ankle. This position places the UOQ of the breast closer to the x-ray source and at a higher risk of scatter radiation exposure. Distancing the axilla from the C-arm and placing the x-ray source beneath the operating table or on the contralateral side of the table is recommended to reduce radiation exposure to the UOQ of the breast.

There are limitations to applying our data from a simulated setting using anthropomorphic phantoms to a clinical setting with orthopaedic surgeons. However, as an illustrative example, if we take the highest rate recorded in our study for a scenario in which the phantom was shielded by lead protection (29.4 mrem/hr, with the C-arm in a cross-table lateral position and the torso at 90°) and assume an average of 5 minutes of fluoroscopy for a femoral intramedullary nailing case as previously reported¹⁶, this would allow a surgeon to perform 800 such cases per year before reaching the annual dose limit for torso exposure. Our data suggest that an orthopaedic surgeon could use 4,000 minutes of fluoroscopy per year before reaching annual dose limits. Although this is more fluoroscopy than most orthopaedic surgeons perform in 1 year, it is shorter than that previously reported for the lens of the eye (4,949 to 11,459 minutes) or the thyroid (6,406 to 19,194 minutes), and is based on the annual dose limit to the torso (not the breast), since annual occupational dose limits to the breast have not yet been established¹. This example does not illustrate the stochastic effects of cancer, where long-term radiation exposure may increase malignancy risk without a threshold dose. In 2007, the ICRP estimated an increased risk of radiation-induced breast cancer death that was twice as high as its 1977 and 1991 estimates, suggesting that the risks of ionizing radiation to the breast may be higher than previously perceived¹⁷. The orthopaedic surgeon exposed to intraoperative fluoroscopy over a career has a cumulative risk of ionizing radiation exposure and may be at higher risk of radiation-induced breast

cancer^{9,18}. Until the cumulative risk of breast cancer due to low-dose radiation is better understood, we recommend lead protection to reduce intraoperative radiation exposure and distancing oneself from the x-ray source when obtaining lateral images.

With an increasing number of women in orthopaedic surgery resident training programs (6.9% in 1997, 13.1% in 2009, and 14% in 2013), studies that evaluate sex-specific occupational risks in orthopaedic surgery are warranted^{19,20}. The cause of breast cancer is multifactorial. Chou et al. reported that, compared with the U.S. female population, female orthopaedic surgeons had both more protective factors (lower body mass index, less smoking, and lower postmenopausal hormone use) and more predisposing factors (increased age at first childbirth and nulliparity)⁶. A follow-up study comparing female orthopaedic surgeons with plastic surgeons and urologists with similar predisposing factors found no difference between the observed and expected prevalence of breast cancer among plastic surgeons and urologists. More urologists in that study (54%) reported using standard fluoroscopy >1 time per week compared with orthopaedic surgeons (37%); however, more orthopaedic surgeons (31%) reported using mini-fluoroscopy >1 time per week compared with urologists (4%), suggesting that mini-fluoroscope use may be associated with increased breast cancer prevalence²¹.

Our study used a standard fluoroscope. Recent studies have compared the radiation exposure of standard fluoroscopes with that of mini-fluoroscopes. The mini-fluoroscope produces less current than does the standard fluoroscope, but is often used with the x-ray source closer to the patient, which increases the scatter radiation compared with the standard fluoroscope (where the x-ray source is placed beneath the operating table and radiation is scattered toward the floor)^{22,23}. Additional studies are warranted to evaluate radiation exposure to the breast using a mini-fluoroscope, which may place the breast closer to the x-ray source and increase radiation exposure.

Interventional radiologists, vascular surgeons, and gastroenterologists are also at risk of intraoperative radiation exposure²⁴⁻²⁶. A meta-analysis of fluoroscopically guided procedures showed a higher effective dose for orthopaedic procedures (2.5 to 88 μ Sv for extremity nailing and 0.1 to 101 μ Sv for vertebroplasty) compared with urology procedures (1.7 to 56 μ Sv for percutaneous nephrolithotomy), gastrointestinal procedures (2.0 to 46 μ Sv for biliary tract procedures), and vascular procedures (1.8 to 53 μ Sv for head/neck endovascular procedures). The median radiation dose per case to the unshielded operator was highest at the level of the trunk (302 μ Sv) compared with the eye (113 μ Sv) and neck (75 μ Sv)²⁴. No studies, to our knowledge, have evaluated radiation exposure to the breast in these populations.

Our study had limitations. First, the study was performed in a simulated operating-room setting; our findings may not be directly applicable to the orthopaedic surgeon in a setting with different patient and surgeon characteristics and fluoroscopy positioning and settings. The phantom also did not have arms, which may help to shield the breast from radiation exposure. Although we used a female torso phantom in our study, male orthopaedic surgeons may also be at risk of radiation-induced breast cancer. Second, the dosimeters used in our study detected a minimum scatter radiation of 0.1 mrem/hr with an accuracy of \pm 30% below 50 keV. Prior to data

collection, the dosimeters were validated with a first-order air exposure intercomparison test using the C-arm x-ray photon energy for comparison. Scatter radiation dose-equivalent rates of <0.1 mrem/hr were not detected with the dosimeters used in our study, and thus the results may underestimate the total radiation dose-equivalent rate to the breast. The dosimeters were selected for their compact size, which allowed for insertion within the torso phantom to measure radiation exposure to the LIQ of the breast. Although not significant, facing the dosimeters at 90° to the radiation source decreased radiation dose-equivalent rates. Thus, our results may underestimate the exposure of the LIQ of the breast to radiation in an in vivo setting. Finally, our study does not demonstrate causality between radiation exposure and breast cancer. Additional studies are warranted to elucidate the risks of ionizing radiation and to establish annual dose limits for occupational exposure to the breast.

The results of our study suggest that the breast is an area that may not be adequately protected by standard cross-back aprons and vests. Methods of reducing exposure are warranted. To limit intraoperative radiation exposure, we recommend the following: (1) using properly fitted lead aprons and/or vests to protect the breast, (2) increasing the distance between the surgeon and the x-ray source, especially with use of the C-arm in the lateral position,

(3) increasing the distance between the x-ray source and the patient to decrease scatter radiation, (4) positioning the x-ray source beneath the operating table or on the contralateral side of the surgeon when possible, and (5) educating surgeons and trainees about radiation safety. Modifications to lead aprons, new apron designs including axillary wings, or custom lead aprons may provide better protection of the breast tissue in orthopaedic surgeons. ■

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