

Methods for Reducing Intraoperative Breast Radiation Exposure of Orthopaedic Surgeons

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Background: Standard lead aprons and vests do not adequately shield the most common breast cancer site, the upper outer quadrant (UOQ), from intraoperative radiation. The purpose of the present study was to determine if lead sleeves, wings, and/or axillary supplements decreased intraoperative radiation exposure of the UOQ of the breast.

Methods: An anthropomorphic torso phantom (simulating the female surgeon) was placed adjacent to a standard operating room table. Dosimeters were placed bilaterally over the UOQ of the breast. Scatter radiation dose equivalent rates (mrem/hr) were measured during continuous fluoroscopy of a pelvic phantom (simulating the patient). Five protection configurations (no lead; lead vest; and vest with sleeves, wings, and axillary supplements), 2 surgeon positions (facing the table and perpendicular to the table), and 2 C-arm positions (anteroposterior and cross-table lateral projection) were tested. The t test was utilized with a Bonferroni correction for multiple t tests.

Results: Lead sleeves and axillary supplements decreased intraoperative radiation exposure to the UOQ of the breast when compared with a well-fitted standard lead vest alone ($p < 0.01$) across all surgeon and C-arm positions. The addition of wings decreased radiation exposure to a lesser extent than sleeves or axillary supplements, and the difference when compared with the lead vest alone did not reach significance ($p = 0.29$). Breast radiation exposure in the C-arm cross-table lateral projection was highest across all testing.

Conclusions: The UOQ of the breast is not adequately protected by standard lead vests alone or vests with the addition of wings. Axillary supplements and sleeves improved protection of the breast.

Clinical Relevance: Modifications of lead protective vests may improve intraoperative breast radiation protection.

Intraoperative C-arm fluoroscopy is widely used by orthopaedic surgeons to aid in fracture reduction and implant placement. Lead vests, aprons, and thyroid shields as well as leaded glasses are utilized to decrease intraoperative radiation exposure^{1,2}. A recent study by Valone et al. demonstrated that lead vests and aprons do not adequately protect the upper outer quadrant (UOQ) of the breast, the most common site of breast cancer^{3,4}. The UOQ of the breast often extends into the axilla⁵. Breast tissue is at particularly high risk of exposure with the C-arm in a cross-table lateral position³.

Lead wing and sleeve attachments are currently available for lead aprons and vests. Whether or not these additions decrease radiation exposure of the breast intraoperatively has yet to be established. An underarm axillary attachment is, to our knowledge, not a currently available lead garment configuration but may provide improved protection of the breast tissue while allowing the surgeon to move the arms with more agility intraoperatively compared with what is comfortable

with lead sleeves. The axillary attachment is a novel lead configuration but utilizes currently available lead wings.

The aim of this study was to report the efficacy of lead vest supplements in reducing breast radiation exposure. We hypothesized that lead vests with wings, sleeves, and axillary supplements would reduce radiation exposure of the UOQ of the breast compared with lead vests alone. Additionally, we hypothesized that reductions in radiation exposure with vest modifications would be greatest during cross-table lateral image acquisition.

Materials and Methods

A standard operating room setting was simulated using anthropomorphic phantoms to represent the surgeon and patient. Both phantoms scatter ionizing radiation in an amount and direction comparable with human tissue. The pelvic phantom was male-specific and the torso phantom used to simulate the surgeon was female-specific with 2 breast attachments (400 cc; size-C cup) (ATOM Dosimetry Phantom; CIRS). A standard C-arm

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fluoroscope (BV Pulsera; Philips) was used in continuous mode without magnification for 10 seconds at a setting determined by the automatic brightness control of the C-arm (85 kVp and 4.2 mAs). Dosimeters (SOR/RF; Mirion Technologies) were attached to the UOQ of each breast, equidistant from the center of the breast. Lead was applied over the dosimeters for testing. Data were recorded in radiation dose-equivalent rates (mrem/hr).

Based on the torso dimensions and the manufacturer's (Infab's) sizing chart for best fit, a newly manufactured medium-sized, female lead vest with 0.50-mm protection was used. The vest was lined with snaps to attach wings, sleeves, and axillary supplements. Standard wings and sleeves from the manufacturer were used. The axillary supplement consisted of a wing placed on the inferior aspect of the axillary opening (Fig. 1).

Five lead configurations, 2 surgeon positions, and 2 C-arm positions were tested, for a total of 20 permutations. The 5 lead protection configurations were (1) no lead, (2) lead vest, (3) vest with wings, (4) vest with sleeves, and (5) vest with axillary supplements (Fig. 1). The 2 surgeon positions were (1) facing the table and (2) at 90° to the table with the left axilla facing the operating table. The 2 C-arm positions were (1)

anteroposterior and (2) cross-table lateral. The source was beneath the operating room table and on the side of the surgeon for each projection (Fig. 2).

Statistical Analysis

Each permutation (lead configuration, surgeon position, and C-arm position) was tested 3 times, and the average dose-equivalent rate (mrem/hr) for each dosimeter was calculated. The t test was used to compare the regular vest with the vest with wings, with sleeves, and with axillary supplements for each scenario separately. A Bonferroni correction was used to adjust for multiple t tests, and a significance level of 0.0167 was used. A power analysis was not performed.

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There was no outside funding for this study.

Results

The mean scatter radiation to the UOQ of the breast with a regular lead vest alone (97.4 mrem/hr) was higher than that with the addition of lead sleeves (0.8 mrem/hr) and axillary supplements (1.3 mrem/hr) ($p < 0.01$) across all testing. Wing

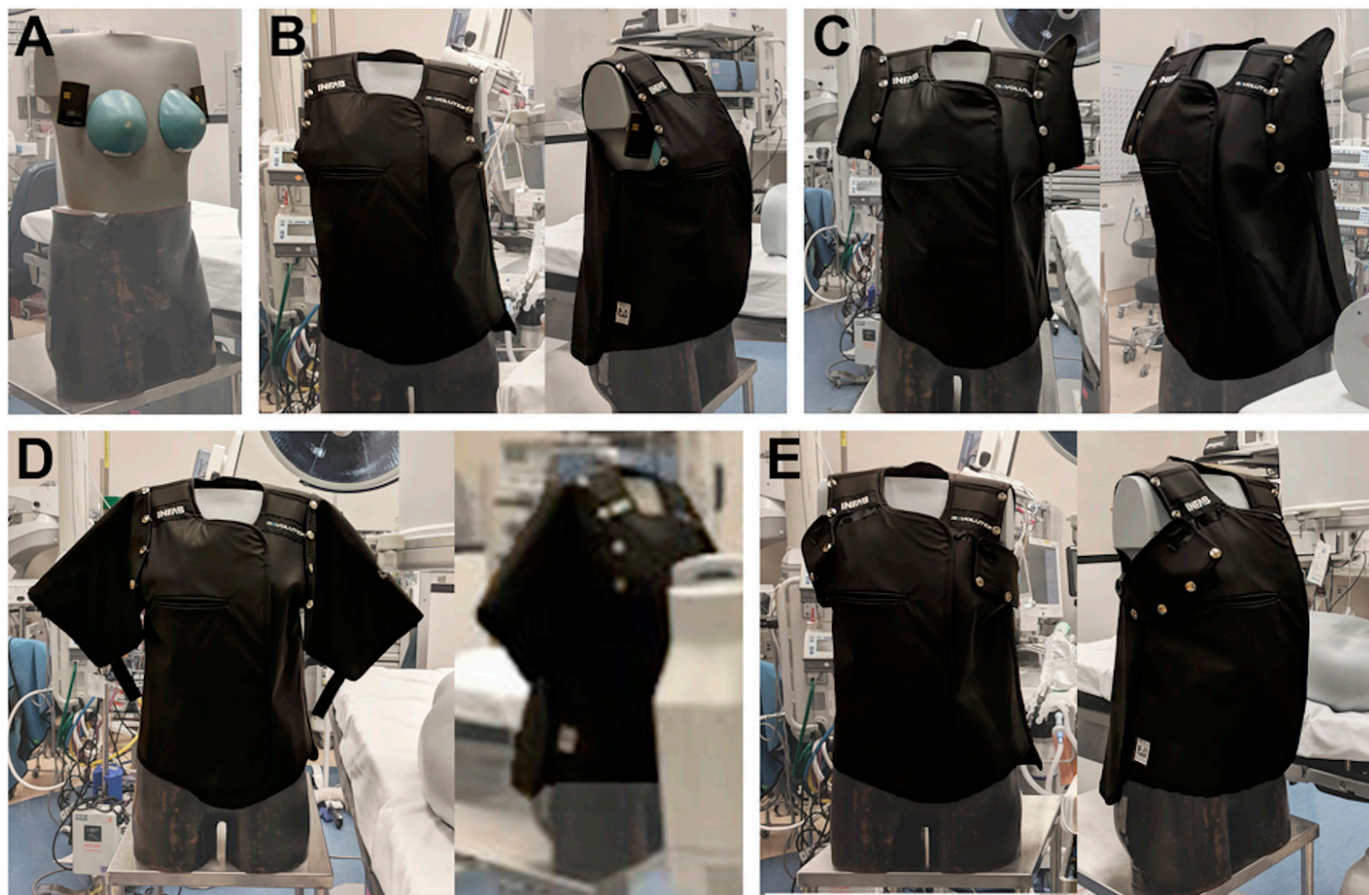


Fig. 1

Five configurations were tested, including the phantom without lead protection (Fig. 1-A) and with a regular lead vest (Fig. 1-B), lead vest with wings (Fig. 1-C), lead vest with sleeves (Fig. 1-D), and lead vest with axillary supplements (Fig. 1-E).

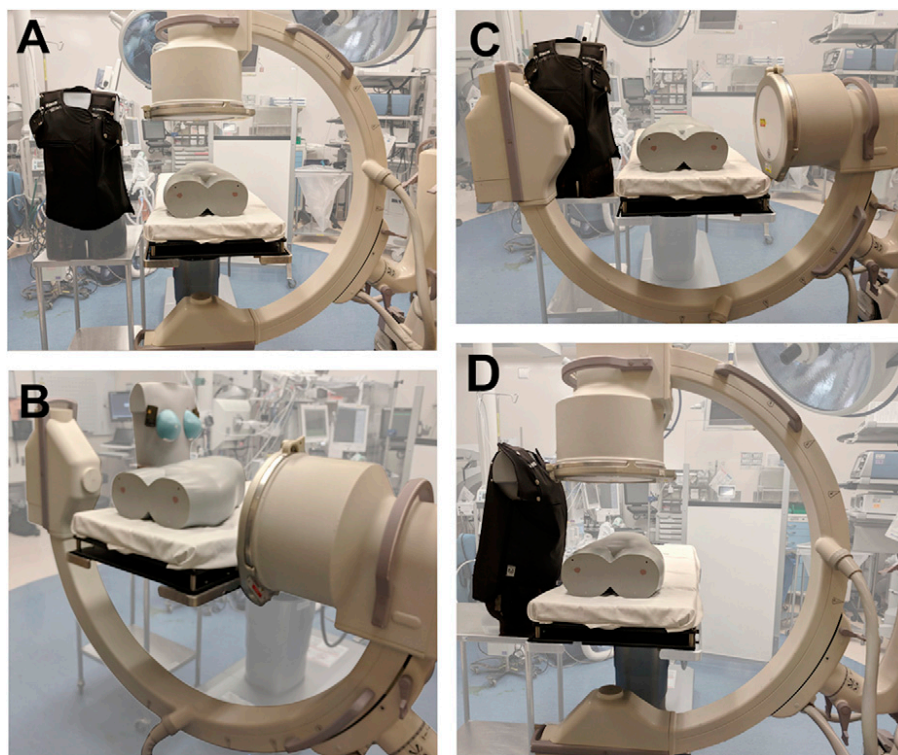


Fig. 2

Simulated scenarios. **Fig. 2-A** Scenario 1: Surgeon perpendicular to table, C-arm in anteroposterior position. **Fig. 2-B** Scenario 2: Surgeon facing table, C-arm in cross-table lateral position. **Fig. 2-C** Scenario 3: Surgeon perpendicular to table, C-arm in cross-table lateral position. **Fig. 2-D** Scenario 4: Surgeon facing table, C-arm in anteroposterior position.

attachments reduced scatter radiation to 59.4 mrem/hr, which was not significantly different when compared with a lead vest alone ($p = 0.29$) (Table I). Higher radiation exposure was observed for the C-arm cross-table lateral position (92.7 mrem/hr) compared with the anteroposterior projection (20.5 mrem/hr) across all testing ($p < 0.001$) (Figs. 2-B and 2-C versus Figs. 2-A and 2-D).

The efficacy of protection is reported below for 4 commonly encountered scenarios. “Scenario” refers to the simulated

intraoperative position of the surgeon and C-arm. “Configuration” refers to the lead protection utilized.

Representative Scenarios

Scenario 1: Torso at 90° to Table, C-Arm Anteroposterior Projection (Fig. 2-A, Table II)

Holding a fracture reduction or positioning a drill or Kirschner wire mimics this scenario intraoperatively. The mean radiation dose equivalent rate to the near breast was 99 mrem/hr with no lead, 93 mrem/hr with a lead vest only, 70 mrem/hr with wings, 1.4 mrem/hr with sleeves, and 2.5 mrem/hr with axillary supplements. There was no significant reduction in exposure of the near breast with a lead vest only compared with no lead protection ($p = 0.20$). The reduction in radiation exposure was greater with the addition of lead sleeves ($p < 0.01$) or axillary supplements ($p < 0.01$) than it was with wings ($p = 0.03$) compared with the vest alone. The radiation exposure reduction with wings did not reach significance given the Bonferroni correction. The far breast received minimal radiation exposure irrespective of protection type.

Scenario 2: Torso Facing Table, C-Arm Cross-Table Lateral Projection (Fig. 2-B, Table III)

This reflects the intraoperative scenario of placing screws during perfect circles or positioning an implant. The mean radiation dose equivalent rate to the near breast was 337

TABLE I Average Breast UOQ Radiation Exposure for All Scenarios (Surgeon and C-Arm Positions, N = 20 Trials): Near and Far Breast Data Pooled

	Mean \pm SD (mrem/hr)	P Value
No lead	124.1 \pm 132.5	—
Lead vest		
Regular	97.4 \pm 148.5	0.514*
Wings	59.4 \pm 87.7	0.287†
Sleeves	0.8 \pm 0.2	0.004†
Axillary supplements	1.3 \pm 2.7	0.004†

*P value for regular lead vest versus no lead. †P value for lead vest with augmentation versus regular lead vest.

TABLE II Scenario 1, Surgeon Perpendicular to Table and Anteroposterior Image Acquired (Fig. 2-A)

	Mean ± SD (mrem/hr)		P Value for Near
	Far	Near	
No lead	0.4 ± 0.3	98.7 ± 1.2	—
Lead vest			
Regular	0.0 ± 0.0	92.5 ± 5.8	0.20*
Wings	0.1 ± 0.1	70.0 ± 8.7	0.026†
Sleeves	0.0 ± 0.0	1.4 ± 0.8	0.001†
Axillary supplements	0.0 ± 0.0	2.5 ± 0.9	0.001†

*P value for regular lead vest versus no lead. †P value for lead vest with augmentation versus regular lead vest.

TABLE III Scenario 2, Surgeon Facing Table and Cross-Table Lateral Image Acquired (Fig. 2-B)

	Mean ± SD (mrem/hr)		P Value for Near
	Far	Near	
No lead	13.0 ± 12.1	337.0 ± 40.8	—
Lead vest			
Regular	0.1 ± 0.1	353.7 ± 6.5	0.55*
Wings	0.1 ± 0.0	212.7 ± 15.5	0.001†
Sleeves	0.0 ± 0.0	3.7 ± 2.3	<0.001†
Axillary supplements	0.1 ± 0.1	4.9 ± 2.2	<0.001†

*P value for regular lead vest versus no lead. †P value for lead vest with augmentation versus regular lead vest.

mrem/hr with no lead, 354 mrem/hr with a lead vest only, 213 mrem/hr with wings, 3.7 mrem/hr with sleeves, and 5 mrem/hr with axillary supplements. There was no significant reduction in exposure of the near breast with a regular lead vest compared with no lead ($p = 0.55$). The near breast was exposed to significantly less radiation when the vest with sleeves ($p < 0.001$) or the vest with axillary supplements ($p < 0.001$) was used compared with the regular vest. The vest with wings improved protection compared with the regular vest in this scenario, but the magnitude of exposure differed greatly from that provided by lead sleeves or axillary supplements ($p = 0.001$). The breast further from the source received minimal radiation exposure in all scenarios.

Scenario 3: Torso at 90° to Table, C-Arm Cross-Table Lateral Projection (Fig. 2-C, Table IV)

This scenario occurs when establishing an entry point, reaming, or checking implant position. The mean values of exposure of the near breast were 345 mrem/hr with no lead, 331 mrem/hr with a regular lead vest, 192 mrem/hr with wings, 0.6 mrem/hr with sleeves, and 1.6 mrem/hr with

axillary supplements. The near breast was exposed to significantly less radiation when the lead sleeves ($p < 0.01$) or axillary supplements ($p < 0.01$) were used compared with when the regular vest was worn. The vest with wings also reduced radiation exposure compared with a regular vest ($p < 0.05$), although this difference did not reach significance. The far breast experienced radiation exposure of 58 mrem/hr with no lead and minimal radiation exposure (<1 mrem/hr) with any lead protection configuration, but these differences did not reach significance ($p > 0.01$).

Scenario 4: Torso Facing Table, C-Arm Anteroposterior Projection (Fig. 2-D, Table V)

This is the ideal position for the surgeon and C-arm to minimize radiation exposure of the surgeon when wearing a regular lead vest without modifications. The mean radiation dose equivalent rate was 70 mrem/hr with no lead and ≤ 1 mrem/hr for a lead vest only, vest with wings, vest with lead sleeves, or vest with axillary supplements. This is the only scenario in which the regular lead vest provides excellent protection to the UOQ of both breasts ($p < 0.01$). There was no statistically significant difference in radiation exposure with the use of wings, lead

TABLE IV Scenario 3, Surgeon Perpendicular to Table and Cross-Table Lateral Image Acquired (Fig. 2-C)

	Mean ± SD (mrem/hr)		P Value for Near
	Far	Near	
No lead	57.9 ± 22.8	345.3 ± 20.4	—
Lead vest			
Regular	0.2 ± 0.2	331.0 ± 50.2	0.68*
Wings	0.3 ± 0.2	192.0 ± 5.3	0.040†
Sleeves	0.0 ± 0.0	0.6 ± 0.6	0.008†
Axillary supplements	0.5 ± 0.6	1.6 ± 1.4	0.008†

*P value for regular lead vest versus no lead. †P value for lead vest with augmentation versus regular lead vest.

TABLE V Surgeon Facing Table and Anteroposterior Image Acquired (Fig. 2-D): Near and Far Breast Data Pooled

	Mean ± SD (mrem/hr)	P Value
No lead	70.3 ± 5.8	—
Lead vest		
Regular	1.0 ± 1.5	<0.001*
Wings	0.1 ± 0.1	0.191†
Sleeves	0.3 ± 0.2	0.349†
Axillary supplements	0.2 ± 0.1	0.246†

*P value for regular lead vest versus no lead. †P value for lead vest with augmentation versus regular lead vest.

sleeves, or axillary supplements compared with a regular vest in this scenario.

Discussion

Standard lead aprons and vests have been shown to provide inadequate protection from intraoperative radiation exposure of the breast³. This study corroborates the findings of Valone et al. in demonstrating that the UOQ of the breast is poorly protected with a standard lead vest in common intraoperative scenarios³. We demonstrated that the addition of lead sleeves or axillary supplements to a standard lead vest significantly decreases scatter radiation doses to the UOQ of the breast compared with the lead vest alone. Lead wings added to a vest provided less protection than lead sleeves or axillary supplements.

Similar to other studies, our results demonstrate that the C-arm lateral projection increases scatter radiation doses to the surgeon compared with the anteroposterior projection^{3,6-11}. The UOQ of the breast near the radiation source is poorly protected with a regular lead vest without modification. Sleeves and axillary supplements added to a lead vest minimize radiation exposure in these scenarios.

This study provides 4 representative scenarios of a surgeon operating in a real-life situation. These scenarios highlight the protection provided by lead vest modifications consisting of wings, sleeves, and axillary supplements.

Our study tested the efficacy of axillary supplements placed underneath the arms. The wing currently available from many lead-garment manufacturers was simply attached below the axilla rather than above the shoulder. This is a novel use of currently available wings. Our results suggest that this type of shielding provides improved protection from intraoperative radiation exposure. Although comfort was not evaluated in this study, a protective shield placed under the arm or a custom apron with a smaller arm hole may provide a less cumbersome option to surgeons than arm sleeves. New lead vest supplements and/or modifications may be warranted to better protect the orthopaedic surgeon from intraoperative breast radiation exposure.

Our study had limitations. First, it was performed in a simulated operating room, and as such our results may not be generalizable to a setting in which the patient, surgeon, or operating room parameters differ. Second, the phantom torso used in this study did not have arm attachments, as they were not available from the vendor used. While arms could potentially shield the axilla from scatter radiation, surgeons' arms are frequently flexed or abducted while fluoroscopic images are being obtained, exposing the axilla. An abducted or flexed arm may move the wing attachment further away from the axilla and increase the radiation exposure of the UOQ of the breast in a real-life scenario. For this reason, we tested the axillary supplements, which would not be affected by arm motion intraoperatively. Third, the dosimeters used in this study were selected for their compact size, which allowed for placement beneath the lead vest. They were specifically chosen for their higher sensitivity and accuracy compared with those used in previous studies³, detecting a minimum scatter radiation of 0.01 mrem/hr with an accuracy of $\pm 10\%$. To detect scatter radiation when the dosim-

eters were shielded, 10 seconds of fluoroscopy was used, which may be higher than the total fluoroscopy time for standard orthopaedic cases. Furthermore, although our simulated operating room setup was static, radiation scatter is variable, which led to higher standard deviations (SDs) for testing in which higher radiation doses were detected by the dosimeters.

Although the risk of radiation exposure of the orthopaedic surgeon is of increasing interest, the long-term risk of exposure to low-dose ionizing radiation is not well-established. Chou et al. reported a 2.9-fold higher prevalence of breast cancer in female orthopaedic surgeons compared with the general U.S. population¹². However, female orthopaedic surgeons may be at increased risk for breast cancer because they tend to exhibit reproductive characteristics that are known risk factors for breast cancer, such as having children later in life or having fewer children. Sensitivity analysis assuming that there were no breast cancer cases among nonrespondents indicated that orthopaedic surgeons still had an elevated risk of breast cancer, suggesting that selection bias was not a confounding factor in these results¹².

Similarly, a 3-fold increased prevalence of breast cancer has been reported in female radiographic technologists^{13,14}. It is important to recognize the limitations of population-based studies and the potential for bias. Neither population-based studies nor this study establish causality between radiation exposure and breast cancer.

Until the risks of ionizing radiation are further elucidated and annual dose limits for occupational exposure of the breast are established, the authors recommend that surgeons consider axillary lead shielding to protect the breast tissue from scatter radiation intraoperatively.

Conclusions

This study demonstrates that a lead vest or apron, with or without the addition of wing supplements, does not provide adequate intraoperative protection against radiation to the upper outer quadrant of the breast. Surgeons are encouraged to use lead sleeves or axillary supplements, both of which provide excellent protection of the upper outer quadrant of the breast from scatter radiation doses irrespective of operative scenario. ■

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