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RESEARCH ARTICLE

The effectiveness of breast lead shielding on scattered radiation in lumbar spine radiography: a phantom study

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Abstract:

This study evaluates the effectiveness of breast lead shielding in reducing scattered radiation in lumbar spine radiography. Using an anthropomorphic phantom model, an experimental study simulating anteroposterior (AP) and lateral lumbar spine radiography was performed with and without breast shielding. The scattered radiation doses were measured using Radcal ACCU-PRO dosimeter. Significant reductions in scattered radiation dose (42%- 49% reduction) were observed in both AP and lateral projections with the use of breast lead shielding as compared to without shielding ($p < 0.001$). These findings suggest that breast lead shielding effectively reduces radiation exposure in lumbar spine radiography. The study highlights the importance of using breast shielding to protect patients from scattered radiation. Further research should explore the long-term benefits of shielding, its application in other radiographic procedures and potential advancement in shielding materials and technique.

Keywords: Breast shielding, lumbar spine radiography, scattered radiation

1. INTRODUCTION

X-rays possess intrinsic energy that may be imparted to the matter they interact with. Radiation exposure has three main sources: primary x-rays (the main exposure with the highest dose), scattered radiation, and radiation leakage (Park et al.,2022). Scattered radiation is produced when x-ray photons lose energy due to Compton interactions with objects. This type of radiation primarily arises when ionizing radiation strikes a patient and reflects off the body or tabletop. Scattered x-rays deposit less energy in tissues compared to primary x-rays, as they lose energy during the scattering process Frane et al., 2023).

The amount of scattered radiation exposure increases as the distance from the x-ray source decreases, following the inverse square law (Frane et al., 2023). Higher primary x-ray doses result in greater scattered radiation doses. The intensity of scatter is influenced by factors like x-ray tube voltage (kVp) and patient thickness. Thicker body parts, which are harder to penetrate, require higher radiation doses to produce clear images, leading to more scattered radiation (Shing et al., 2023). For example, obese patients receive higher radiation doses than thinner patients, even when imaging the same region, due to increased primary and scattered radiation (Park et al., 2022).

Lumbar spine radiography is a standard 2D imaging technique that visualizes bone and soft tissue in the spine, aiding in diagnosing and treating spine-related diseases (Chen et al., 2022). This procedure exposes patients to high radiation doses, reaching up to 1.5 mSv, due to the dense anatomical region requiring strong x-rays to penetrate pelvic bones (Lai et al., 2020). A study by Hamid et al. (2020) found that the highest radiation doses were recorded in the pelvis and lumbosacral spine, with average entrance skin doses (ESD) of 7.4 and 6.3 mGy, respectively, compared to other body regions.

High radiation exposure is a significant concern for patients with chronic conditions, such as scoliosis, that require frequent imaging (Lai et al., 2020). Adolescent idiopathic scoliosis (AIS) patients undergo repeated whole-spine radiographs throughout their diagnosis and treatment, resulting in cumulative radiation exposure. A study by Luan et al. (2021) found that AIS patients received an average of 16 whole-spine radiographs, with each radiograph delivering a dose of 0.8–1.4 mSv, leading to an annual dose of 2.4–5.6 mSv.

Ionizing radiation in medical imaging can cause deterministic and stochastic effects, which are harmful side effects (Sidi et al., 2020). Lumbar spine x-rays are particularly concerning due to the high radiation dose and exposure of nearby radiosensitive organs, like the breast (Park et al., 2022). Breast shielding is crucial in lumbar spine imaging to reduce the risks posed by scattered radiation. This research investigates the effectiveness of breast lead shielding in reducing scattered radiation during lumbar spine radiography. Scattered radiation from lumbar spine radiography poses a risk to radiosensitive organs like breast tissue, potentially increasing radiation-induced damage (Shing et al., 2023). This study uses a phantom model to simulate human tissue and measure the effects of breast shielding on scattered radiation in lumbar spine radiography. The study provides quantitative data on the effectiveness of breast lead shielding, offering insights into its practical application in clinical settings and contributing to the ongoing debate on radiation protection. Scattered radiation in lumbar spine radiography is particularly concerning due to the thick body region involved. Studies have shown that the breast, a radiosensitive organ, receives significant doses from scattered radiation during lumbar spine radiography (Eyisi et al., 2021). The use of breast shielding can mitigate these doses, as evidenced by research indicating substantial dose reductions with shielding (Davies et al., 2020). Moreover, systematic reviews have highlighted the long-term health risks of cumulative radiation exposure, further justifying the need for effective shielding practices (Luan et al., 2021).

2. MATERIALS AND METHODS

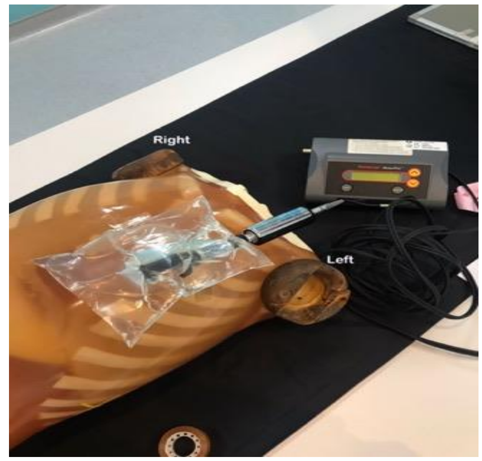
2.1 Ethical clearance

Due to the nature of experimental study, this study was exempted from ethics review by the Faculty Ethics Review Committee (FERC) with reference number FERC/FSK/EM/2024/00006.

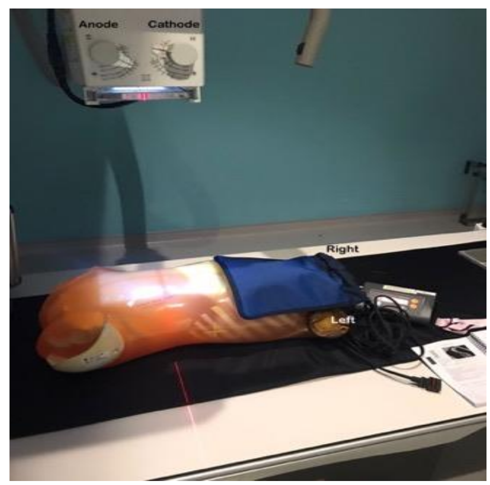
2.2 Experiment procedure

An anthropomorphic phantom is used in this experiment to imitate a human being in a natural clinical setting. The anthropomorphic phantom used was the whole-body phantom PBU-50 which was made from Kyoto, Japan. The phantom material has radiology absorption and Hounsfield number approximate to human body. The soft tissue and organs are made from urethane-based resin while the synthetic bones are made from epoxy resin. The join attachments in the phantom are made of epoxy and urethane with carbon fiber. The phantom is free from metal as the screws were made from polycarbonate. The material consists of water and SZ-50 with density, effective atomic number and electron density of 1.000 and 1.061, 7.417 and 6.14, 3.343 and 3.258, respectively. The phantom size is approximately 165 cm in height and 50 kg in weight. In addition, to mimic breast tissue on the phantom, a pair of breast implants filled with saline water is utilized and placed within the second and sixth ribs with the medial margin parallel to the sternum's edge (Elshami et al. 2020).

An anthropomorphic phantom was positioned for lumbar spine radiography. Dosimeters were placed at the breast region to measure scattered radiation dose accurately. Radiographs of the lumbar spine were taken in both the anteroposterior (AP) and lateral projections, with and without breast shielding. For consistency, the same imaging parameters were used in both scenarios as shown in Figure 1.



(a)



(b)

Figure 1: The anthropomorphic phantom displaying dosimeter placement underneath breastimplant for AP lumbar projection (a) without breast shielding and (b) with shielding

2.3 Dose measurement

The measurement of radiation dose rate was made using Radcal ACCU-PRO dosimeter that with 10x6-6 general purpose ion chamber (Figure 2). The ion chamber has rate specifications of 20 nGy/s – 149 mGy/s with exposure and cine specifications of 100nGy – 516 Gy and 1 nGy/fr – 10 mGy/f, respectively. The auto dose threshold is 19 µGy/s with calibration accuracy of ±4% using x-rays @ 60 kVp & 2.8 mm Al HVL. The ion chamber has exposure rate dependence of ±5%, 0.4 mR/s to 80 R/s, up to 500 R/s for 50 us pulses and energy dependence of ±5%, 30 keV to 1.33 MeV (with build-up material). The ion chamber is a concentric cylinder with polycarbonate walls and electrode constructed with conductive graphite interior coating. The minimum field size is 25x38 mm with 0.05 kg weight and 6cm3 active volume. The dosimeter is positioned at the breast region. The dosimeter provided precise measurements of the scattered radiation dose received by the breasts. Five readings were taken for each condition (with and without shielding), and the mean dose value was calculated to ensure accuracy.

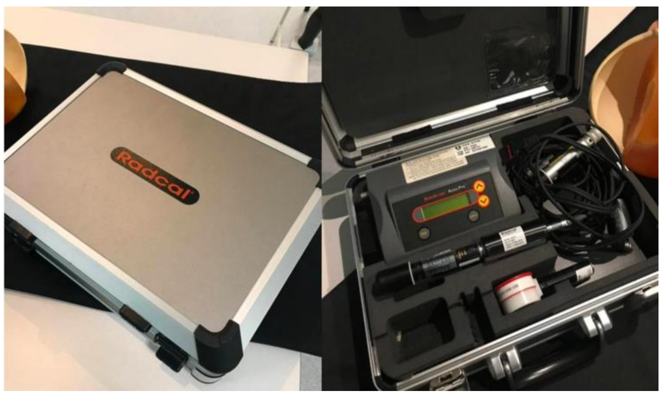


Figure 2: Radcal ACCU-PRO dosimeter

2.4 Statistical analysis

Statistical analysis was conducted to compare the scattered radiation doses between the shielded and unshielded phantoms using SPSS version 28. Paired-sample t-test was employed to compare that scattered radiation dose for the two projections without and with breast shielding with $p < 0.05$ was considered statistically significant.

3. RESULTS AND DISCUSSION

3.1 Scattered radiation dose

The study found that breast lead shielding significantly reduced the scattered radiation dose to the breasts during lumbar spine radiography. For the AP projection, the mean dose rate without shielding was 1.23 mGy/h, while with shielding, it reduced to 0.68 mGy/h. Similarly, for the lateral projection, the dose rate decreased from 2.15 mGy/h without shielding to 1.02 mGy/h with shielding. These results indicate that breast shielding effectively reduces scattered radiation exposure.

Table 1. Dose comparison for both left and right breast with the presence of shielding and without shielding

Projection	Radiosensitive organ	Presence of shielding	Mean dose (mGy/h)	p- value
AP	Left breast	No	17.61 ± 0.52	< 0.001
		Yes	9.55 ± 0.18	
AP	Right breast	No	17.23 ± 0.53	< 0.001
		Yes	9.56 ± 0.15	
Lateral	Left breast	No	16.06 ± 0.32	< 0.001
		Yes	9.34 ± 0.11	
Lateral	Right breast	No	18.93 ± 0.22	< 0.001
		Yes	9.66 ± 0.04	

According to the result obtained from this experimental study on the measurement of dose rate on the breast area, there is indeed scattered radiation dose on the breast during lumbar spine radiography procedure. This could be proven by comparing the value of radiation dose rate on the breast area in both projections (AP and lateral) for both conditions without breast shielding and with breast shielding. There were differences in the dose rate value pattern for both conditions as the radiation dose was reduced after the implementation of lead breast shielding.

This study has demonstrated that there was a significant dose reduction to the left breast and right breast in AP and lateral projection of lumbar spine radiography of the anthropomorphic phantom after the utilization of lead breast shielding, respectively. The significant dose reduction to the left and right breasts observed in this study during lumbar spine radiography using an anthropomorphic phantom can be clearly justified by the statistical analysis conducted. The dose rates were reduced for the left breast and for the right breast in the anteroposterior (AP) and lateral projections following the utilization of lead breast shielding. The finding is consistent with other previous studies. For instance, a study by Elshami et al. (2020) found that the use of breast shielding in cervical x-ray reduce the radiation by 99.9% on the breast. A similar study by Eyisi et al. (2021) showed that there was reduction on scatter radiation to the breast during lumbosacral x-ray which was lowest among the age group of 50-59 years old.

A prospective cross-sectional study from Enuka et al. (2021) which intent to quantify the amount of breast scatter radiation that occurs during a lumbosacral x-ray radiography among 60 women in various age and BMI groups indicated that there was evidence of scattered radiation to the breast during lumbosacral radiography as well according to the study with the age group of 50-59 years old had the lowest amount of scattered radiation. However, the study shown that there was no significant distinction in scattered radiation towards the breast in lumbosacral x-ray between different projections of AP and lateral. Correspondingly, A. Peiro et al. (2021) discussed that patient radiation exposure might rise because of improper radiation shielding, particularly when an incorrect radiation field size has been employed and digital system capabilities are exploited. The study compared between conventional digital and clinically used field sizes which shown that the scattered dosage absorbed by the pelvis differed significantly. However, the primary dose differences did not change significantly (Peiro et al., 2021).

3.2 Application of breast shielding for scattered radiation dose reduction

In lumbar spine x-rays, scattered radiation can expose nearby radiosensitive organs like the breast, particularly in females, increasing cancer risk and potential genetic mutations in future generations. Radiation protection measures, like breast shielding, are widely used to minimize these risks. This experimental study demonstrates that using breast shielding effectively reduces scattered radiation exposure to the breast during lumbar spine radiography. The findings provide a practical approach for practitioners to limit radiation exposure to radiosensitive organs, confirming that breast lead shielding significantly lowers radiation doses to the breast area (Sidi et al., 2020).

This experimental study evaluates the effectiveness of breast shielding in reducing scattered radiation to the breast during lumbar spine radiography. The results confirm that using lead breast shielding reduces radiation doses to this radiosensitive organ with a range of 42% - 49% reduction, offering a practical dose-reduction strategy for protecting patients during x-ray exposure as shown in Table 2 and Table 3.

Table 2. Radiation dose rate in right and left breast during AP lumbar spine radiography

Part	**Without Shielding**	**With Shielding**	**% dose reduction**
	Dose rate (mGy/h)	Dose rate (mGy/h)	
Left breast	17.61 ± 0.52	9.55 ± 0.18	46%
Right breast	17.23 ± 0.53	9.56 ± 0.15	45%

Table 3. Radiation dose rate (mGy/h) in right and left breast during lateral lumbar spine radiography

Part	**Without shielding**	**With shielding**	**% dose reduction**
	Dose rate (mGy/h)	Dose rate (mGy/h)	
Left breast	16.06 ± 0.32	9.34 ± 0.11	42%
Right breast	18.93 ± 0.22	9.66 ± 0.04	49%

Elshami et al. (2020) highlighted the importance of shielding radiosensitive organs like the eyes and breast during cervical radiography to protect against scattered radiation. Their study showed that eye and breast shielding reduced radiation exposure by 91% and 89% for the eyes and 99.9% for the breast. Similarly, Sidi et al. (2020) demonstrated that breast shielding in lumbosacral x-rays reduced scattered radiation doses by 32.2%, with exposure ranging from 1.02 to 3.63 mGy. These findings emphasize the effectiveness of shielding in significantly lowering radiation doses to non-target organs.

Contrary to findings by Elshami et al. (2020) and Sidi et al. (2020), a study by Hurley et al. (2023) found that using lead shielding outside the field of view (FOV) did not significantly reduce the breast's entrance surface dose (ESD) in various axial skeleton x-ray procedures. This study suggests that shielding areas outside the main ionizing source offers only minimal additional radiation protection for the breast ESD. The contrasting results from various studies may arise from differences in parameters, methods, and analyses. Specifically, the studies by Sidi et al. (2020) and Hurley et al. (2023) yield opposing findings due to their differing approaches: Sidi et al. conducted evaluations with real patients, while Hurley et al. used a phantom study. This discrepancy is attributed to the distinct scatter properties between real patients and phantoms. The current study aligns with the findings of Elshami et al. (2020) and Sidi et al. (2020), demonstrating that breast shielding in radiography can effectively reduce scattered radiation exposure to nearby radiosensitive organs.

These findings corroborate previous research that emphasises the importance of protective measures in radiographic procedures. This aligns with previous research advocating for protective measures to minimise radiation exposure to radiosensitive organs (Bushberg et al., 2012). The study also addresses the gap in literature regarding the application of breast shielding in lumbar spine radiography, providing valuable insights for clinical practice. The significant reduction in radiation dose with breast shielding underscores the importance of incorporating this practice into routine radiographic procedures to enhance patient safety. However, this study has limitations, including the use of a phantom model, which may not fully replicate human tissue characteristics.

4. CONCLUSION

The study confirms that breast lead shielding effectively reduces scattered radiation during lumbar spine radiography. These findings align with the study's objectives, providing strong evidence for the clinical implementation of breast shielding to protect radiosensitive organs during x-ray imaging. Future research should explore the long-term benefits of shielding, its application in other radiographic procedures, and potential advancements in shielding materials and techniques.

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REFERENCES

Adejoh, T., Ezugwu, E.E., Erondu, F.O. *et al.* (2021). A dual-modality quantification of scattered radiation from head to female breasts during radiological investigations in a tertiary hospital in Nigeria. *Egyptian Journal of Radiology and Nuclear Medicine*,52, 240.

Davies B.H., Manning-Stanley A.S., Hughes V.J., Ward A.J. (2020). The impact of gonad shielding in anteroposterior (AP) pelvis projections in an adult: A phantom study utilising digital radiography (DR). *Radiography (Lond)*, 26(3), 240-247.

Elshami W, Abuzaid MM, Tekin HO. (2020). Effectiveness of breast and eye shielding during cervical spine radiography: An experimental study. *Risk Management and Healthcare Policy*, 13, 697-704.

Eyisi-Enuka, C. E., Nzotta , C. C., Robinson, E. D., Omojola, A. D., Adejoh, T., & Agboje, A. A. (2021). Determination of scatter radiation to the breast during lumbosacral x-ray examination using thermoluminescence dosimeter. *Journal of Medical Science and Discovery*, 8(5), 315-328.

Frane N, Megas A., Stapleton Erik, Ganz M., Bitterman AD (2020). Radiation exposure in orthopaedics. *JBJS Reviews*, 8(1), e0060.

Hurley L., Alashban Y., Albeshan S., England A., McEntee M.F. (2023). The effect of breast shielding outside the field of view on breast entrance surface dose in axial x-ray examinations: a phantom study. *Diagnostic and Interventional Radiology*, 29(3), 555-560.

Karami V, Zabihzadeh M, Shams N, Saki Malehi A (2017). Gonad shielding during pelvic radiography: A systematic review and meta-analysis. *Archives of Iranian Medicine*, 20(2), 113-123.

Luan F.J, Zhang J, Mak K.C., Liu Z.H., Wang H.Q. (2021). Low radiation x-rays: Benefiting people globally by reducing cancer risks. *International Journal of Medical Science*, 18(1), 73-80.

Luan, F.J., Wan, Y., Mak, K.C. *et al.* (2020). Cancer and mortality risks of patients with scoliosis from radiation exposure: a systematic review and meta-analysis. *European Spine Journal*, 29, 3123-3134.

Marsh RM, Silosky M (2019). Patient shielding in diagnostic imaging: Discontinuing a legacy practice. *American Journal Roentgenology*, 212(4), 755-757.

Peacock N.E., Steward A.L., Riley P.J. (2020). An evaluation of the effect of tube potential on clinical image quality using direct digital detectors for pelvis and lumbar spine radiographs. An evaluation of the effect of tube potential on clinical image quality using direct digital detectors for pelvis and lumbar spine radiographs. *Journal of Medical Radiation Sciences*, 67(4), 260-268.

Sidi M., Elugwu C.H. (2020). Quantification of scattered raditation to adult female breasts during lumbosacral x-ray and head computed tomography in a negroid population. *Pakistan Journal of Radiology*, 30(4), 252-256.

Tam, S.Y, Fung Y.Y, Lau S.Y, Lam W.N, Wong E.T.H. (2023). Scatter radiation distribution to radiographers, nearby patients and caretakers during portable and pediatric radiography examinations. *Bioengineering*, 10(7),779

Zer Hau Lai, C. S. (2020). Effective dose and image optimisation of lateral lumbar spine radiography: A phantom study. *European Radiology Experimental*, 4(1), 13.