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RADIOLOGY PHYSICS

ORIGINAL ARTICLE

The effect of breast shielding outside the field of view on breast entrance surface dose in axial X-ray examinations: a phantom study

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PURPOSE

The purpose of this study was to evaluate the effect of outside-field-of-view (FOV) lead shielding on the entrance surface dose (ESD) of the breast on an anthropomorphic X-ray phantom for a variety of axial skeleton X-ray examinations.

METHODS

Using an anthropomorphic phantom and radiation dosimeter, the ESD of the breast was measured with and without outside-FOV shielding in anterior-posterior (AP) abdomen, AP cervical spine, occipitomental 30° (OM30) facial bones, AP lumbar spine, and lateral lumbar spine radiography. The effect of several exposure parameters, including a low milliampere-seconds technique, grid use, automatic exposure control use, wraparound lead (WAL) use, trolley use, and X-ray table use, on the ESD of the breast with and without outside-FOV shielding was investigated. The mean ESD (μSv) and standard deviation for each radiographic protocol were calculated. A one-tailed Student's t-test was carried out to evaluate whether ESD to the breast was reduced with the use of outside-FOV shielding.

RESULTS

A total of 920 breast ESD measurements were recorded across the different protocol parameters. The largest decrease in mean ESD of the breast with outside-FOV shielding was 0.002 μSv ($P = 0.084$), recorded in the AP abdomen on the table with a grid, OM30 on the table with a grid, OM30 standard protocol on the trolley, and OM30 on the trolley with WAL protocols. This decrease was found to be statistically non-significant.

CONCLUSION

This study found no significant decrease in the ESD of the breast with the use of outside-FOV shielding for the AP abdomen, AP cervical spine, OM30 facial bones, AP lumbar spine, or lateral lumbar spine radiography across a range of protocols.

KEYWORDS

Field of view, shielding, entrance surface dose, anthropomorphic phantom, wraparound lead, radiography

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Protection and optimization of patient radiation doses are key principles in the safe practice of diagnostic radiography.[1] Ionizing radiation can result in deterministic or stochastic effects on biological tissue,[2] and radiation protection serves to eliminate or reduce deterministic effects and render the probability of stochastic effects as low as possible.[3] Lead shielding has been used as a radiation protection tool since low levels of diagnostic radiation became implicated in late radiation responses approximately 80 years ago.[4] Lead (or equivalent) shielding is a radiation protection apparatus that can be directly applied to the patient either inside the field of view (FOV) to reduce the radiation dose to radiosensitive organs, or outside the FOV to protect the patient against scattered radiation. Despite this, several radiation advisory bodies have recently published position statements advocating the curtailment

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of the practice of using lead protection in diagnostic imaging.[5-7]

The "as low as reasonably practical (ALARP)" principle is based on the optimization of patient radiation dose by balancing the benefit with the risk of the dose applied to obtain a diagnostically acceptable image.[8] Factors that can be considered when applying the ALARP principle include decreasing exposure time, increasing the distance between the source and object, and the use of shielding.[8] The ALARP principle can be applied to both primary and secondary radiation. The radiation dose in the primary beam is relatively high, 2% of which is directly absorbed by the patient.[9] It has been suggested that lead shielding within the primary beam may increase the patient radiation dose in some instances by interfering with the automatic exposure control (AEC) and by misplacement or movement that may obscure pathology, potentially leading to overexposure and repeat exposures.[5,10-12] However, this current study focuses on secondary radiation and so these factors were not of concern.

Secondary radiation originates from the attenuation of primary radiation, including scatter and extra-focal radiation.[13] Lead shielding outside the FOV has been advocated by many studies, with scatter radiation reduced by more than 20% when lead shielding was used in mobile pediatric chest radiographs and breast dose reduced up to 80% by breast shielding in anterior-posterior (AP) and lateral lumbar spine X-ray projections.[14,15] While the later study included 100 patients and 40 phantom measurements, only five pediatric patients were included in the former study, possibly limiting its generalizability. The International Commission of Radiological Protection (ICRP) is of the consensus that shielding more than 5 cm from the primary beam has a negligible effect on additional patient dose from secondary radiation.[16] Furthermore, for the anatomy outside the FOV, radiation exposure results largely from internal scattering, which lead shielding cannot protect against.[16] The British Institute of Radiology has reported that scattered radiation in projection radiography often amounts to no more than 0.2% of overall patient radiation dose.[5] This has led to the argument that radiographers should focus on the main source of patient radiation dose–the primary beam–by improving collimation, increasing the distance, and individualizing doses by using the AEC.

Main points

- The largest decrease in mean entrance surface dose (ESD) of the breast with outside-field of view (FOV) shielding was 0.002 μSv ($P = 0.084$).
- This phantom-based study suggests that outside-FOV lead shielding of the breast does not significantly reduce ESD to the breast in anterior-posterior (AP) abdomen, AP cervical spine, occipitomental 30° facial bone, AP lumbar spine, and lateral lumbar spine radiography.
- Further studies are required to support the complete discontinuation of this radiation protection tool.

Breast tissue and the gonads have a tissue weighting (wT) factor of 0.12 and 0.08, respectively, meaning that the relative risk of stochastic effects occurring in the breast is relatively high.[17] The linear threshold model is used to estimate the risk from low-dose radiation exposure, which is endorsed by the United States National Academy of Sciences and the ICRP. According to this model, even the smallest dose of radiation can increase the risk of harmful effects proportionally, and there is no safe level of exposure.[18] In a laboratory setting, it was found that the number of double-strand breaks increased linearly with doses ranging from 1 mGy to 1 Gy in cultured cells.[18] Another investigation reported that exposure to a chest X-ray increases the risk of breast cancer by a factor of two, irrespective of age, at first exposure and by up to five times when carrying three or more rare variants in a deoxyribonucleic acid (DNA) repair gene.[19] However, it is probable that the tissue and cellular response to radiation, including damage and repair, is influenced by specific trigger thresholds, hormesis, and hypersensitivity of a particular tissue.[18] Both studies indicated that further research is required to identify subpopulations that are vulnerable to ionizing radiation, which in turn would be useful in a clinical setting.

When considering the radiosensitivity of breast tissue, the well-known breast cancer-carrying gene (BRCA1) and breast cancer gene 2 (BRCA2) mutations put some individuals, particularly those exposed before the age of 30 years, at an increased risk of breast cancer development from diagnostic levels of radiation.[20] Due to the generation of an abnormal protein in individuals carrying a *BRCA1* or *BRCA2* gene mutation, they may not be able to fix this DNA damage, with 72% of BRCA1 and 50% of BRCA2 healthy mutation carriers displaying a radiosensitive phenotype.[21,22] A cohort study of 1.601 women carrying BRCA1 and BRCA2 mutations reported an association between increased risk of breast cancer and exposure to chest X-rays [hazard ratio (HR): 1.54; $P = 0.007$]. This risk was higher in women aged 40 years and younger (HR: 1.97; $P < 0.001$).[23]

Although the cancer risk of any tissue reduces significantly with increased age, it should be noted that a single dose of 0.1 Gy results in approximately 914 cases and 70 cases of breast cancer per 100,000 when exposed at 5 years and 50 years, respectively.[24] Outside-FOV breast shielding in AP cervical spine radiography was shown to reduce breast dose by 99.9% in a phantom study.[25] Additionally, Foley et al.[26] demonstrated that breast displacement combined with lead shielding outside the FOV in computed tomography (CT) angiography reduced breast dose by 36%. However, a 23% reduction may be a result of displacement alone, with no data reported for shielding alone.[26] It has been suggested that with the advancement in radiographic technology in the past 70 years, fixed exposure systems have turned into modern, efficient direct digital systems that can use the AEC to control exposure level.[27,28] This has resulted in a substantial decrease in entrance doses, from 12 mGy in the 1950s to now below 1 mGy.[5] Therefore, it has been questioned whether other mechanisms of dose optimization such as primary beam collimation and AEC use are more important.[5,6]

It has been reported that overall patient radiation dose for a standard AP pelvis radiograph has reduced by a factor of 60 between 1900 and 2012.[5,29-31] However, the number of diagnostic imaging examinations patients undergo has increased, leading to an increased cumulative dose with two patients per 1.000 receiving a cumulative effective dose greater than 100 mSv in a 5-year period being reported in an international study on CT examinations.[32] Therefore, despite the dose reduction for individual examinations, cumulative doses are increasing. As a result, low doses of scattered radiation outside the FOV are also increasing, contributing to the argument that outside-FOV lead shielding should still be considered in radiographic examinations, particularly for those known to be sensitive to radiation such as children and those with BRCA1/2 mutations. Currently, the state of practice concerning the use of lead shielding differs throughout Europe, individual countries, and local departments. Due to recent publications, many radiographers are opting to use or not use lead shielding in X-ray examinations,[5,6] and this inconsistency has the potential to create confusion and patient fear in a radiographer's practice. It is generally agreed that a united,

definitive statement from regulatory bodies throughout Europe regarding the use of lead shielding would be useful to limit confusion and differing practices by radiographers.[33]

The current study aimed to investigate whether there is a reduction in the entrance surface dose (ESD) of the breast with the use of outside-FOV shielding for AP abdomen, AP cervical spine, occipitomental 30° (OM30) facial bones, AP lumbar spine, and lateral lumbar spine radiography across a range of parameters.

Methods

Experimental design

This study was conducted in the X-ray laboratory in the Assert Building at University College Cork (UCC). The approval of the UCC Ethics Committee was not required for this research. All experiments were conducted using the Carestream Health Inc. DRX-Evolution Plus X-ray unit and the DRX Plus 3543C detector. A dosimeter (Quarta, RADEX ONE) was used to obtain the ESD of the breast on a whole-body anthropomorphic X-ray phantom (PBU-50., Kyoto Kagaku) with dimensions of 165 cm and 50 kg. Detailed phantom information can be found in the reference section.[34] In the current experiment, the X-ray energy used in abdominal radiography was 75 kVp, lumbar spine and facial bone was 80 kVp, cervical spine was 70 kVp, and lateral lumbar spine was 90 kVp.

Quality control

Quality control tests on the lead shielding, X-ray tube output, and X-ray equipment were carried out before the study. The entire surface area of the lead shielding apron (0.35 mm Pb/150 kV) and the WAL (0.25 mm Pb/150 kV) were placed on the detector and screened, and no defects were detected. Tube output variability was assessed by securing the dosimeter to the breast region of the phantom 5 cm from the FOV, setting a fixed exposure, and irradiating the phantom 10 times. All QA tests fell within expected tolerances.

Pilot study

A pilot study was conducted to assess dosimeter placement stability, parameter selection, dosimeter reading variability, and phantom positioning issues. It was found that the dosimeter required fixation to the phantom. Dosimeter reading variability fell within acceptable tolerances. It was established that the variable parameters would include a low milliampere-seconds (mAs) technique and the use of a grid, AEC, WAL, a trolley, and an X-ray table. The phantom could not be supported when erect or on its side; therefore, all projections were conducted in the supine position.

Entrance surface dose measurements

The dosimeter was secured to the breast of the phantom in the midline. Outside-FOV shielding was placed on top of the dosimeter, or, in the case of WAL, wrapped around the phantom and dosimeter 5 cm or more from the FOV in all projections, as shown in Figure 1. The phantom underwent AP abdominal, AP cervical spine, OM30 facial bone, AP lumbar spine, and lateral lumbar spine radiography. A standard set of exposure parameters, adapted from Bontrager's Handbook of Radiographic Positioning and Techniques, were set for each projection.[35] Based on the standard, a low mAs technique and the use of a grid, AEC, combined grid and AEC, WAL, a trolley, and an X-ray table were explored for each projection. The phantom was exposed 10 times under each protocol, and the ESD of the breast and deviation index (DI) with and without outside-FOV shielding was recorded for each exposure.

Statistical analysis

The collected data underwent statistical analysis using Microsoft Excel 2019 (Microsoft Corp., Redmond, WA). The mean ESD of the breast with and without outside-FOV shielding for each projection was calculated. The standard deviation (SD) for each data set was also computed. A one-tailed Student's t-test was conducted to determine whether a statistically significant difference was present between the ESD of the breast with and without outside-FOV shielding for each projection. Statistical significance was defined as $P < 0.05$.

Results

The ESD of the breast for each protocol with and without outside-FOV shielding was collected and expressed as the mean and SD. A paired one-tailed t-test revealed that the use of outside-FOV shielding was not found to significantly reduce the ESD of the breast when compared with no shielding for any X-ray projection or parameter ($P < 0.05$). The SD of the mean ESD was considered low for all protocols, at between 0–0.006 µSv. Many of the deviation indices indicated overexposure of the phantom. A summary of the mean ESD data can be found in Table 1. For AP abdominal radiography, the largest decrease (0.002 µSv) in mean ESD of the breast was observed in the grid X-ray table protocol ($P = 0.084$). In AP cervical spine radiography, the greatest reduction in mean ESD was reported in the AEC X-ray table, WAL X-ray table, and grid trolley protocols, with a decrease of 0.001 µSv ($P = 0.172$). For OM30 facial bone radiography, a 0.002 µSv decrease in mean ESD with the use of outside-FOV shielding was recorded in the grid X-ray table, standard trolley, and the WAL trolley protocols ($P = 0.084$). For the AP lumbar spine, the greatest reduction in mean ESD was 0.001 µSv, observed in the grid X-ray table, standard trolley, low mAs trolley, grid trolley, and WAL

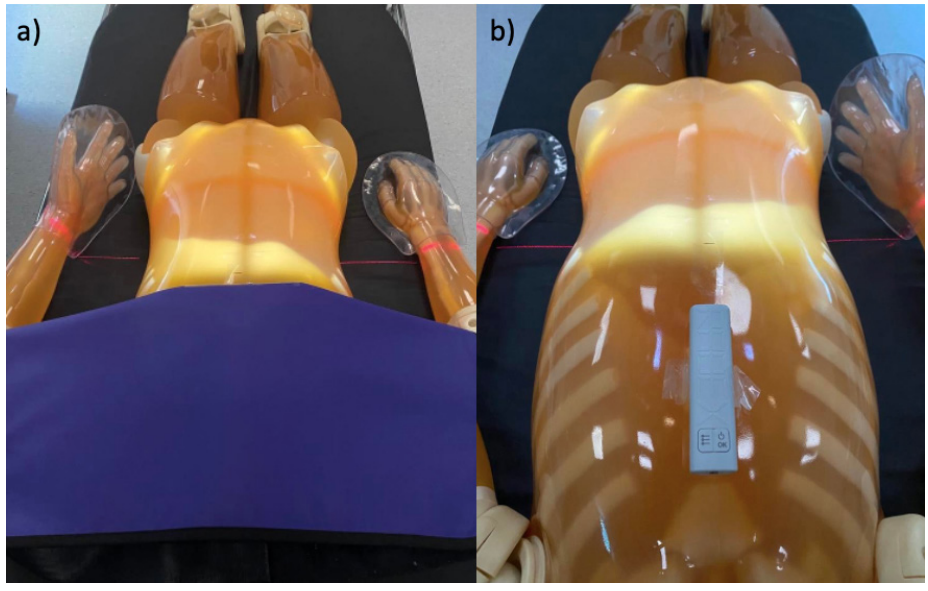

Figure 1. The anthropomorphic phantom displaying the dosimeter placement and collimation for anterior-posterior abdominal imaging **(a)** with the gonadal shield placed outside the field of view and **(b)** with no shielding.

Table 1. Summary of the data for each projection protocol

Protocol	Lead	AP abdomen	Cervical spine	OM30 facial bones	AP lumbar spine	Lateral lumbar spine
Standard table	No	0.031	0.021	0.031	0.030	
	Yes	0.030	0.021	0.030	0.031	
Low mAs table	No	0.022	0.016	0.021	0.021	
	Yes	0.021	0.016	0.020	0.021	
Grid table	No	0.032	0.021	0.032	0.031	
	Yes	0.030	0.021	0.030	0.030	
AEC table	No	0.004	0.006	0.009	0.003	0.010*
	Yes	0.004	0.005	0.009	0.004	0.010*
Grid and AEC table	No	0.012	0.009	0.029	0.010	0.024*
	Yes	0.012	0.009	0.028	0.010	0.022*
Wraparound lead table	No	0.031	0.021	0.031	0.030	
	Yes	0.030	0.020	0.030	0.031	
Standard trolley	No	0.032	0.021	0.032	0.032	0.056
	Yes	0.031	0.022	0.030	0.031	0.055
Low mAs trolley	No	0.022	0.016	0.021	0.023	0.046
	Yes	0.022	0.016	0.020	0.022	0.046
Grid trolley	No	0.031	0.022	0.031	0.032	0.055
	Yes	0.031	0.021	0.030	0.031	0.056
Wraparound lead trolley	No	0.032	0.021	0.032	0.032	0.056
	Yes	0.031	0.021	0.030	0.031	0.056

*Measurements were conducted on the trolley using the upright bucky. No data were found to be statistically significant ($P < 0.05$). AP, anterior-posterior; OM30, occipitomental 30°; mAs, milliampere-seconds; AEC, automatic exposure control.

trolley protocols ($P = 0.172$). The trolley grid and AEC protocol demonstrated the greatest decrease in mean ESD of 0.002 μSv for lateral lumbar spine radiography ($P = 0.222$).

Discussion

The use of outside-FOV shielding has long been employed as a radiation protection tool in diagnostic radiography.[5,36] Numerous regulatory bodies have recently advocated the curtailment of its use, citing issues with efficacy, efficiency, patient comfort, and infection control.[5-7] This phantom-based study set out to examine whether breast shielding outside the FOV for AP abdomen, AP cervical spine, OM30 facial bones, AP lumbar spine, and lateral lumbar spine radiography reduced the ESD of the breast.

In 2017, it was reported that radiology services in Ireland and internationally experience an annual 8%–10% increase in demand.[37] Although radiation doses for individual examinations have decreased dramatically in the last century due to the advent of modern technology, the population as a whole undergo more radiological examinations, thereby increasing an individual's cumulative radiation dose.[38,39] Children are particularly at an increased risk of radiation-induced cancer development due to the increased rate at which their cells divide and their life expectancy post-exposure when compared to the adult population.[40,41] Breast tissue is considered the most radiosensitive organ of the human body, with a wT of 0.12 reported by the ICRP 103.[16,42] Ionizing radiation can lead to breaks in DNA, leading to cancer, thereby imposing an additional risk, on top of the intrinsic risk, of breast cancer development in individuals carrying *BRCA1/2* gene mutations.[43] Therefore, the importance of radiation protection and dose reduction to the breast in all patients, especially in children and BRCA1/2 carriers, cannot be ignored.

However, the present study reports no significant reduction in the ESD of the breast with the use of outside-FOV shielding for AP abdomen, AP cervical spine, OM30 facial bones, AP lumbar spine, or lateral lumbar spine radiography across all examined protocols. The SD calculated for the protocols was considered acceptably low. Although the mean DI recorded in most protocols indicated overexposure, it must be considered that a 55 kg phantom may not accurately represent the DI recorded for a standard-sized adult patient under the same parameters. Multiple studies and radiation advisory boards report that the dose to organs outside the FOV is almost entirely from internal scatter generated within the patient, which lead shielding cannot protect against.[5,6,16,44-47] This research supports the view that shielding anatomy outside the primary beam provides negligible additional radiation protection in terms of breast ESD to the patient. Therefore, this study recommends alternative methods of reducing patient radiation doses, such as primary beam collimation, increasing distance, and the use of the AEC or patient-adapted exposure factors.

Interestingly, a study that reported a 99.9% decrease in absorbed dose to the breast using outside-FOV shielding in AP cervical spine radiography utilized 2.5 mm Al filtration and 70 kVp.[25] The present study utilized no additional filtration with 70 kVp, implying that more scatter was generated per exposure in the current study. This suggests that beam filtration was not a contributing factor to breast ESD in the current study. Due to the differing conclusions and no definitive

reasons as to why this current study saw no significant reduction in ESD to the breast using outside-FOV shielding, one must also question if tube housing comes into play. This study utilized a Varex Imaging B-130H housing model type which has a permanent filtration of 0.7 mm Al/77 kV. This modern equipment may not be available due to a lack of resources in many parts of the world. Therefore, the relevance of this study's findings for worldwide consideration is questionable. Furthermore, many of the studies reporting a decrease in radiation dose with the use of outside-FOV shielding are almost a decade old and may not represent the most recent advancements in technology and its effect on patient radiation dose.[14,15,26] One study has proposed that shielding outside the FOV may contribute to increased patient radiation dose as a result of shielding backscatter that reduces with distance from the primary beam.[44] In contrast, additional radiation dose due to the backscatter from lead shielding was not found in this study, as the addition of outside-FOV shielding or WAL did not significantly increase patient breast ESD for any protocol. However, it must be considered that in the present study, all shielding was placed 5 cm or more from the primary beam.

While the present study examined multiple parameters across 920 exposures, further studies could explore the effect of varying kVp, shielding placement 0–5 cm from the primary beam, and the effects of outside-FOV breast shielding on other organs such as the lungs. Furthermore, infection control, patient discomfort, and manual handling issues have been cited as reasons to abandon shielding use. The recent severe acute respiratory syndrome-coronavirus-2 pandemic has increased radiographer awareness and has shown that infection prevention and control measures can be achieved in a busy hospital environment. Despite this, Yu et al.[48] reported that the risk of infection due to outside-FOV lead shielding outweighed the 0.7% dose reduction it provided in pediatric chest CT examinations. Of note, this study only examined one phantom the size of a 5-year-old child, and the potential infection risk due to shielding contamination was not quantified. Additionally, an international survey found that lead shielding led to 25% of patients reporting discomfort due to shielding weight or position.[49] Undoubtedly, more studies are required in these areas. Finally, as breast shielding outside the FOV has the potential to induce a sense of security or imply that radiation doses outside the area of interest are high, the psychological effects of breast shielding should also be explored.

Limitations to this research include sampling bias associated with the use of a 55 kg anthropomorphic phantom rather than human patients. Therefore, the results of this study may not accurately represent the X-ray attenuation and resulting ESD of the breast in patients of different weights (e.g., obese or pediatric patients) and densities (e.g., fibrous and glandular breast tissue). Future work should include a population study to validate or conflict with this study's findings. Furthermore, unlike a similar study, this study did not involve placing radiation dosimeters in the four quadrants of the breast.[26] Rather, the dosimeter was placed in the midline, at the level of the breasts. This may result in a loss of data regarding the ESD received in all regions of the breast. Additionally, only the ESD of the breast was measured. An organ dose measured by thermoluminescent dosimeters inside the phantom may provide greater insight into the effects of outside-FOV shielding of the breasts. Combined, these limitations may limit the generalizability to the human population.

In conclusion, this phantom-based study suggests that outside-FOV lead shielding of the breast does not significantly reduce ESD to the breast in AP abdomen, AP cervical spine, OM30 facial bone, AP lumbar spine, and lateral lumbar spine radiography. Further studies are required to support the complete discontinuation of this radiation protection tool.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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