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# Investigating the adjacent patient radiation dose received during a simulated ward chest X-ray examination

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## Abstract

**Introduction:** A patient having a chest X-ray will inevitably be exposed to radiation from the primary beam. Using a light beam diaphragm (LBD) on the X-ray tube reduces scattered radiation at the X-ray tube through longitudinal and horizontal collimation. But not scattered secondary radiation resulting from interactions of the primary beam. This study aimed to investigate whether lead protection on simulated hospital ward inpatients (opposite and adjacent to a simulated chest X-ray examination) would change the secondary scattered radiation dose received.

**Materials and methods:** Three phantoms (simulated patients) were used, phantom A received the primary beam, and the other two received scattered radiation (positioned at different distances from the simulated patient receiving the chest X-ray). Phantom B was positioned one metre adjacent (to the side of phantom A being X-rayed), and phantom C was two metres opposite phantom A. The scattered radiation dose to radiosensitive organs (thyroid, breast, and gonads) was recorded using Thermoluminescent Dosimeters (TLDs). Six exposures were conducted, three with lead protection and three without. The mean radiation dose and standard deviation were compared using a paired two-sample t-test for statistical significance ($p>0.05$).

**Results:** The lead protection reduced the radiation dose to the radiosensitive organs by 64%-100% ($p$=0.51-0.18) one metre adjacent and 65%-100% ($p$=0.65-0.18) two metres opposite. Noticeably the phantom two metres opposite had substantial individual organ dose reductions due to the distance from the primary beam.

**Conclusion:** Lead aprons, thyroid collars, and distance reduced the radiation dose to the radiosensitive organs of the surrounding phantoms (simulated patients) from an adjacent chest X-ray examination and present opportunities for dose reduction techniques during ward chest X-ray examinations.

# Introduction

Patients receive radiation doses in the radiology department from direct medical imaging examinations emitting ionising radiation and indirectly through scattered radiation from adjacent medical imaging examinations in inpatient ward environments.

The United Kingdom (UK) Ionising Radiation (Medical Exposure) Regulation (IR(ME)R),[1] advises everybody but the patient should vacate the exposure area during an X-ray examination. This includes doctors, nurses, and patients' families to avoid unnecessary radiation exposure. Often during inpatient ward chest X-ray examinations, the surrounding or adjacent hospital beds have patients that are unable to leave the area due to their medical conditions; in this scenario, the radiographer has to Justify the examination and optimise and limit radiation to reduce the stochastic risk of ionising radiation to patients.[2]

Both forward and back scattered secondary radiation[3] can significantly contribute to patient dose[4] (skin tissue and internal organ). However, the transmission of scattered secondary radiation is omnidirectional, with diagnostic X-ray imaging photons scattering at large angles,[5] with significant doses recorded from the back, forward, and 45-degree oblique directions from chest X-ray energies.[6,7]

Most X-ray transmission studies have concentrated on how the exposures from chest X-rays affect the image quality,[8–11] with few studies on the transmission of secondary radiation at adult chest X-ray doses. Burrage, Rampart, and Beeson[12] previously measured secondary scattered radiation from newborn infant chest X-rays using an anthropomorphic phantom and found the scatter at 1 metre (m) from the patient being X-rayed to be low (0.1 micrograys (µGy), with similar results by Trinh, Schoenfeld, and Levin[13] of scattered radiation at 90 degrees and 135 degrees from newborn infants.

The study aimed to measure the radiation dose received by immobile adult inpatients on beds adjacent and opposite to an adult patient having a ward-simulated Anterior-Posterior (AP) chest X-ray examination at set distances with and without lead protection. The study will test the null hypothesis of no change in radiation dose between wearing and not wearing lead protection in adjacent and opposite inpatients. The alternative hypothesis is a change in adjacent and opposite inpatient radiation dose between wearing lead protection and not wearing lead protection.

# Methods

An ethical application and risk assessment were approved by the University Ethics Panel (ETH21-22/S19RPR). The study was completed in a university X-ray laboratory. Local radiation rules were followed and approved by the university's radiation protection supervisor. Quality assurance[14] was conducted on all X-ray equipment before commencing to ensure no radiation leakage from the X-ray tube housing, collimators, or Dose Area Product (DAP) meter attached to the X-ray tube housing contributed to the scatter.[15,16]

### Calibration

The study used *n*=30 lithium fluoride Thermoluminescent Dosimeters[17] (TLDs), which were annealed using an electric annealing oven[18] heated to 242 degrees Celsius ($^{o}$C) for 10 minutes, then cooled to 80$^{o}$C for 20 minutes, before step cooling to room temperature; before irradiation to release any previously stored energy.[19] The TLDs were then placed on a tissue equivalent material (to minimise low energy Compton X-ray backscatter[19]) and irradiated using an X-ray tube[20] with an exposure protocol of 125 Kilovoltage (kV), 1.4 milliampere-seconds (mAs), a large focal spot, collimation of 35x43 centimetres (cm), and a Source to Image Detector (SID) of 183 cm. Post irradiation, the TLDs were transported to a TLD nitrogen reader[21,22] and heated to 50$^{o}$C to remove the low-temperature stored energy peaks before rapid heating to 240$^{o}$C to measure the high energy glow peaks[23] recorded in Nanocoulombs units (nC) before annealing to reuse.[24,25] The TLDs were grouped according to sensitivity[26, 27] to compensate for minor manufacturing variations[23, 24]and put into batches of *n*=3 TLDs for each radiosensitive anatomical area being measured on the Alderson anthropomorphic Rando phantoms,[28] and for background room radiation.

### Phantom set-up

An AP chest X-ray simulated the positioning of a ward mobile examination (Patient A) using an X-ray tube[20] and an AGFA Direct Digital Radiography plate[29] shown in figure 1. The exposure parameters used 125 kV, 1.4 mAs, a large focal spot, collimation of 35x43cm, and a SID of 183cm, the same as the TLD calibration. The Alderson Rando anthropomorphic phantoms,[28] constructed for radiation dosimetry studies, were used as patients B and C. Rando anthropomorphic phantoms[28] used to collect dose measurements were patient B phantom (was male, 175cm tall 73.5kg weight; figure 2) and patient C phantom (female without the added breast tissue, 155cm tall, 50kg weight; figure 3) are transected-horizontally (2.5cm slices for insertion of TLDs into specific internal tissue and organ areas) and made from tissue-equivalent (bone, soft tissue, and lung equivalent) material with characteristics that provide a physical representation of normal human biological anatomy.[30] The phantom (Simulated patient) A receiving the chest x-ray (Adam, Rouilly, UK, AR10A[31] adult life size, with surface anatomy and internal representations of bones and organs, figure 4).

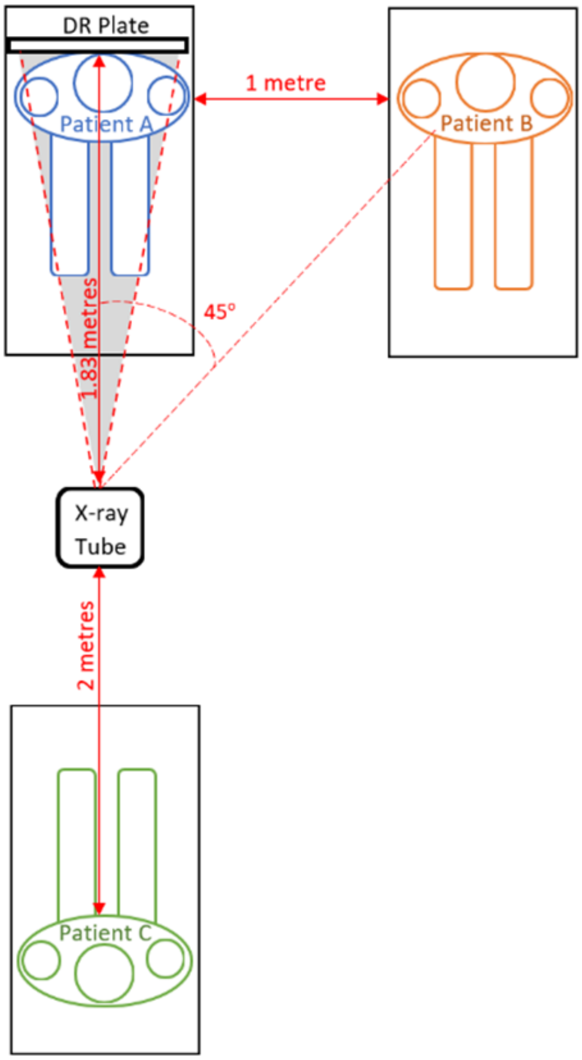


**Figure 1.** Phantom (simulated patients A, B and C) simulated ward bed positioning from the X-ray tube.

Phantom (simulated patient) B was positioned one metre adjacent to the left of phantom (simulated patient) A and 45 degrees from the X-ray source, and phantom (simulated patient) C was positioned two metres opposite phantom (simulated patient) A, imitating a clinical ward setting (figure 1) with and without lead apron (ProtecX Medical, UK. One-Piece Regular Lead Apron[32]) was 0.25 lead equivalence, with thyroid collar (ProtecX Medical, UK. Thyroid Collar[33]) 0.35 lead equivalence.

Patient B and C's radiation doses were recorded using batches of *n*=3 TLDs placed into reusable, re-sealable small plastic zip storage bags and positioned on the anterior skin surface of the radiosensitive organs[34] of the thyroid, breast, and testes to record the Entrance Skin Dose (ESD) and internally for the ovaries.

**Figure 2.** Patient B without Lead protection with TLDs attached to the radiosensitive organs.


**Figure 3.** Patient C without lead protection, with TLDs attached to the radiosensitive organs.

**Figure 4**. Patient B and C with lead aprons and lead thyroid collars.

**Dose measurement**

Six exposures were completed; after each exposure, the TLDs were kept in order of anatomical region, read and annealed in the TLD reader[26] with the dose in nC recorded, then replaced in the same order and anatomical region for the subsequent exposure. For the first three exposures, patients B and C were without a lead apron[32] and thyroid collar[33] (figures 2 and 3). For the last three exposures, patients B and C wore a lead apron[32] and thyroid collar[33] (figure 4). The background radiation dose was recorded by a batch of $n$=3 TLDs for each exposure, at the X-ray control panel, and for consistency and comparison, this was recorded at multiple intervals and areas around the X-ray room at positions of phantoms A, B, and C.

The TLD lightcounts (nC) of the absorbed radiation energy, minus the background TLD dose, were converted to absorbed dose units (μGy)[26,35] in Microsoft Excel[36] before calculating the descriptive statistics of mean and standard deviation (SD) of each batch of $n$=3 TLDs for each anatomical organ (with and without lead protection[32,33]). Statistical analysis of the radiation doses calculated the dose difference (with and without lead protection[32,33]) with descriptive statistics of mean and SD, and inferential statistics of a parametric paired two-sample $t$-test to determine statistical significance using a $p$-value[37] ($p > 0.05$) between the mean ESD/absorbed dose (interval data) for phantom organ and tissue TLD measurements with and without lead protection[32,33] (paired sample).[38]

# Results

The radiation dose recorded for Patient B, situated one metre to the left of Patient A, measured significant change when wearing a lead apron[32]/thyroid collar[33] as opposed to no lead protection (figure 5). The thyroid dose was reduced by 64-71% (7.65– 3.34 µGy; $p$=0.51-0.46, table 1), the breast dose was reduced by 85-92% (1.74 - 0.83 µGy; $p$=0.47-0.34), with the ovaries and testes displaying a 100% (0.00 µGy $p$=0.42-0.18) dose reduction (table 1). However, it is accepted that these dose levels are clinically low.

**Table 1.** Absorbed organ and tissue dose data from simulated patients (phantoms B and C).

| | | No Lead Coat | | | | Lead Coat & Thyroid Shield | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phantom | Position of TLD | Exposure 1 TLD (µGy) | Exposure 2 TLD (µGy) | Exposure 3 TLD (µGy) | Mean TLD (µGy) | Exposure 1 TLD (µGy) | Exposure 2 TLD (µGy) | Exposure 3 TLD (µGy) | Mean TLD (µGy) | Dose difference in µGy | SD | Dose difference as % | *t*-value | *p*-value |
| B | Right Thyroid | 43.36 | 9.25 | 11.31 | 21.31 | 0.00 | 8.39 | 14.58 | 7.65 | 13.66 | 25.8 | 64.1% | -0.92 | *p*=0.46 |
| B | Left Thyroid | 28.87 | 0.00 | 5.89 | 11.58 | 0.00 | 0.00 | 10.02 | 3.34 | 8.24 | 17.9 | 71.2% | -0.79 | *p*=0.51 |
| B | Right Breast | 32.73 | 0.00 | 0.00 | 10.90 | 0.00 | 0.00 | 2.51 | 0.83 | 10.07 | 19.6 | 92.4% | -0.89 | *p*=0.47 |
| B | Left Breast | 26.93 | 0.59 | 8.75 | 12.09 | 0.00 | 0.00 | 5.24 | 1.74 | 10.35 | 14.4 | 85.6% | -1.24 | *p*=0.34 |
| B | Right Ovaries | 40.78 | 7.51 | 20.64 | 22.98 | 0.00 | 3.22 | 1.26 | 1.49 | 21.49 | 18.3 | 93.5% | -2.03 | *p*=0.18 |
| B | Left Ovaries | 7.05 | 0.00 | 0.00 | 2.34 | 0.00 | 0.00 | 0.00 | 0.00 | 2.34 | 4.0 | 100% | -1 | *p*=0.42 |
| B | Right Testes | 24.98 | 0.00 | 2.81 | 9.26 | 0.00 | 0.00 | 0.00 | 0.00 | 9.26 | 13.6 | 100% | -1.17 | *p*=0.36 |
| B | Left Testes | 31.38 | 0.00 | 0.00 | 10.46 | 0.00 | 0.00 | 0.00 | 0.00 | 10.46 | 18.1 | 100% | -1 | *p*=0.42 |
| C | Right Thyroid | 22.96 | 0.00 | 0.00 | 7.65 | 0.00 | 0.00 | 0.00 | 0.00 | 7.65 | 13.2 | 100% | -1 | *p*=0.42 |
| C | Left Thyroid | 13.02 | 0.00 | 2.28 | 5.10 | 0.00 | 0.00 | 0.00 | 0.00 | 5.10 | 6.9 | 100% | -1.27 | *p*=0.33 |
| C | Right Breast | 12.95 | 11.98 | 0.00 | 8.31 | 0.00 | 0.00 | 0.00 | 0.00 | 8.31 | 7.2 | 100% | -1.99 | *p*=0.18 |
| C | Left Breast | 32.69 | 0.00 | 0.00 | 10.90 | 0.00 | 0.00 | 0.00 | 0.00 | 10.90 | 18.8 | 100% | -1 | *p*=0.42 |
| C | Right Ovaries | 14.66 | 0.00 | 3.77 | 6.14 | 0.00 | 0.00 | 0.00 | 0.00 | 6.14 | 7.6 | 100% | -1.40 | *p*=0.29 |
| C | Left Ovaries | 9.96 | 0.00 | 0.00 | 3.32 | 0.00 | 0.00 | 0.00 | 0.00 | 3.32 | 5.7 | 100% | -1 | *p*=0.42 |
| C | Right Testes | 10.62 | 0.00 | 0.00 | 3.54 | 0.00 | 3.73 | 0.00 | 1.24 | 2.3 | 7.4 | 65% | -0.53 | *p*=0.65 |
| C | Left Testes | 15.97 | 0.00 | 0.00 | 5.32 | 0.00 | 0.00 | 0.00 | 0.00 | 5.32 | 9.2 | 100% | -1 | *p*=0.42 |

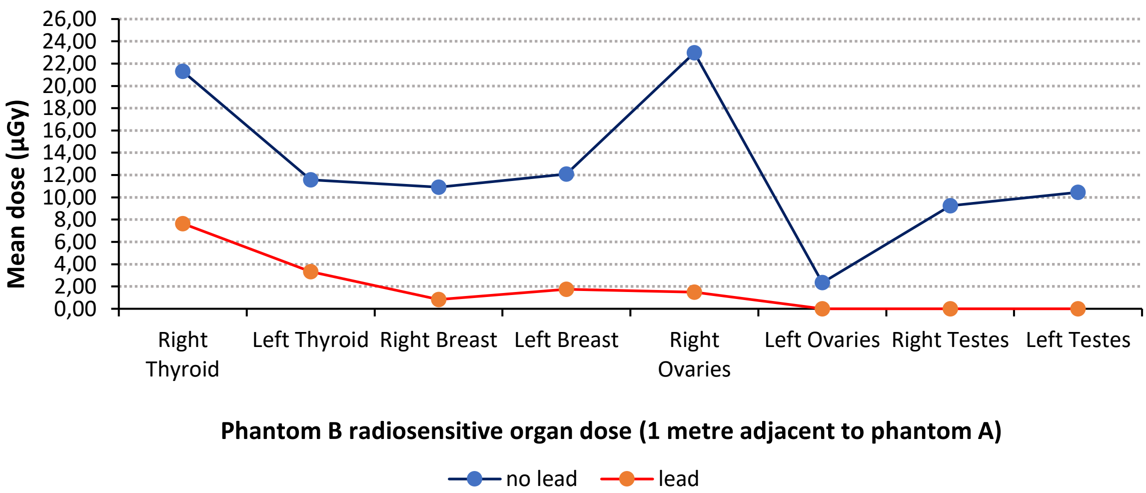


**Figure 5**. Comparison of with and without lead shielding in absorbed dose at 1m adjacent positioning.

The radiation dose recorded for Patient C, situated two metres opposite Patient A, displayed similar changes when wearing a lead apron[32] and thyroid collar[33] as opposed to no lead protection (figure 6).

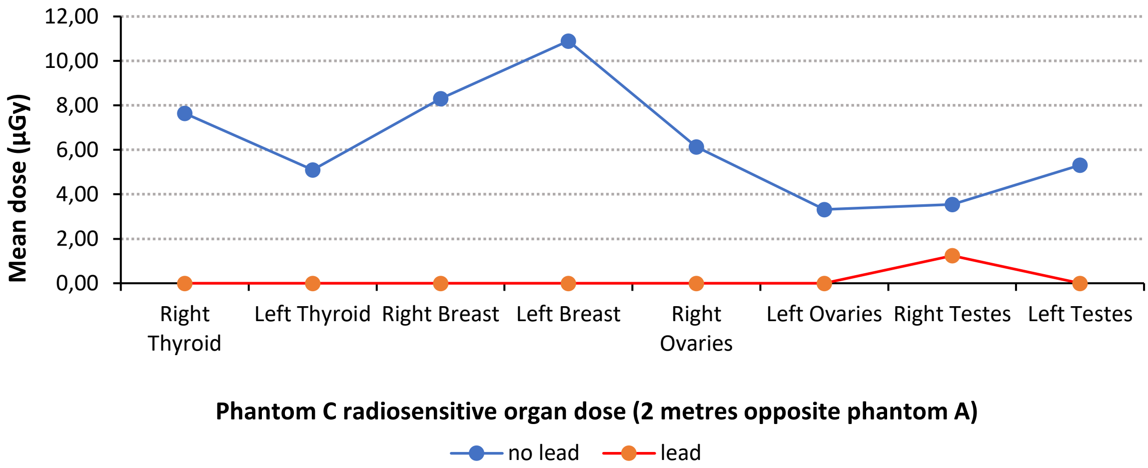


**Figure 6.** Comparison of with and without lead shielding in absorbed dose at 2 m opposite positioning.

The reduction wearing the lead apron[32]/thyroid collar[33] protection measured at the thyroid, breast, and ovaries was 100% (0.00 µGy; $p$=0.42-0.18). The testes were 65-100% (1.24 – 0.00 µGy; $p$=0.65-0.42), which reflected when the distance from the primary beam was over two metres; the sensitivity of the TLDs picked up mostly noise and minimal radiation dose (table 1). This limitation aside, the results reject the null hypothesis of no change between wearing and not wearing lead protection, even at two metres. The paired $t$-test results infer that the two samples (lead apron[32,33]/no-lead apron) are not equal at one and two metres, and there is a change (lower) in the dose received when wearing lead protection.

## Discussion

X-rays have become an integral and indispensable part of diagnosis and intervention within healthcare.[39] Studies have shown that even a low dose exposure to ionising radiation can risk stochastic effects of developing cancer, and no amount of radiation dose can be considered safe.[40] Unnecessary and repeat radiation exposure would therefore be a hazard for inpatients receiving secondary scattered radiation doses in a hospital ward.

Studies have been conducted regarding how much protection radiography staff need from exposure to scattered secondary radiation during working hours.[41–43] Medical ward staff do not require personal dosimeters to monitor radiation exposure or protection if vacating from the radiation area whilst the ward X-ray is being performed.[44] However, there is a paucity of published studies on the amount of radiation exposure inpatients receive during their stay in a hospital. Therefore, this experiment could potentially benefit clinical practice regarding radiation protection for inpatients from portable X-rays conducted in a ward.

According to the UK Government,[45] the estimated dose per annum of background radiation a member of the public would receive is around 2.7 millisievert (mSv) (2700 µGy). The recommended UK safe amount of radiation dose received per year resulting from the medical exposure of someone else is 5 mSv (5000 µGy). Equivalent 15 mSv (15000 µGy) to the eye lens, 50 mSv (50000 µGy) to the extremities, and 50 mSv (50000 µGy) to the skin (averaged over an area of 1cm$^2$).[14] It is estimated that nurses in intensive care Unit (ICU) ward with routine chest X-rays would receive a detectable dose of around 0.05mSv (50 µGy) per two-month period,[44] over a year, which would be below dose limits.

Although different manufacturers' portable X-ray machines will emit different levels of scattered radiation and intensity of scatter.[44] It is recommended that radiographers who routinely perform must portable X-rays wear lead shielding, and where safety permits, patients should distance themselves from the source of radiation, a distance of at least two metres,[44] and as this study has evidenced, if available, wear lead shielding. Lead aprons are a widely utilised shielding method for limiting ionising radiation to patients and staff by up to 75% to radiosensitive organs;[46] due to their density and atomic number.

A study by Johansen et al.[47] identified that using alternative lead-free forms of radiographic aprons also offers high X-ray absorption. Conventional lead aprons weigh approximately 7kg making the standard apron heavy. Alternative lead-free aprons are currently being made 20-40% (-4kg) lighter due to the material used (tungsten, tin, barium, and antimony), which are as protective from radiation,[48] lighter and reduce musculoskeletal and back problems. These alternative aprons could benefit inpatients during a portable X-ray due to their lightness.

Likewise, Radiographers should adhere to IR(ME)R[1] policies and procedures of keeping exposure factors 'as low as reasonably practicable' (ALARP[1]) when exposing radiation to a patient in a ward setting and collimating field size to the region of interest.

Other basic protective measures used in radiation safety to achieve an ALARP[1] radiation dose is distance, i.e. how far from the radiation source a patient is. According to the inverse square law[49], exposure at a distance from the point of radiation is inversely proportional to the square of the distance. Doubling the distance between the radiation source (X-ray patient) and inpatients will yield one quarter of the radiation; tripling the distance will achieve one-ninth of the radiation dose.[49]

There are opportunities for future researchers to explore alternative ways to eliminate scattered secondary radiation to an inpatient laying opposite and adjacent to a portable X-ray. Hayre et al.[46] have debated whether patients should rotate their head or body 90 degrees from the primary beam to limit and reduce the effects of secondary scattered ionising radiation.

The study findings within laboratory conditions presented in this study require future research within clinical hospital environments to confirm the findings. Variations of exposure factors used in ward chest X-ray imaging and manufacturer X-ray equipment will vary results. As such, these findings are directly related to the equipment used in this study. However, these findings can assist the radiographer with local decision-making in hospital environments for ALARP x-raying of patients on wards with surrounding patients.

The phantoms used in this study were generic adult samples, therefore a limitation to the study's results is the acknowledgment that the inpatient on hospital wards vary by sex and age, and as such the radiogenic risk of stochastic effects will vary with patients' age-specifics and sex-dependent.[50] Noting that the age-dependent stochastic health effects and radiosensitive organ and tissue-dose-based radiation risk coefficients from X-rays will be higher in children and lower in senior adults,[50] and possibly the cancer mortality risk would vary by ethnicity as well.[50] Recommendations for future studies to assess factors that may contribute to the increased radiogenic risk of stochastic effects should also include the Length of Stay (LOS) of a patient on a hospital ward and the number of ward chest X-ray examinations.[51,52]

## Conclusion

Ionising radiation can lead to stochastic effects on patients through primary and secondary radiation exposure. This study has demonstrated in laboratory settings that using lead protection on surrounding and adjacent inpatients during a chest X-ray examination can reduce the radiation dose to inpatients.

Statistical data analysis demonstrated shielding and distance reduced scattered secondary radiation to the radiosensitive organs by 64%-100% ($p$=0.51-0.18) one metre adjacent and 65%-100% ($p$=0.65-0.18) two metres opposite to a chest X-ray examination. Although the absorbed doses were clinically low (7.65-0 µGy one metre adjacent, and 1.24-0 µGy two metres opposite) within this study, hospital ward inpatients would benefit in clinical practice from lead protection to limit ionising radiation dose to their radiosensitive organs as often these patients require repeat imaging during their hospital ward stay.

Lead aprons and thyroid collars are not the only shielding methods used in radiation protection; future research opportunities exist to investigate alternative lightweight shielding materials for radiation protection.

## Statements and Declarations

**Competing Interest:** All authors declare that there are no conflicts of interest.

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