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An Investigation of Exposure to the Eyes and Thyroid of Personnel Near to Patient in Abdominal Radiography: A Phantom Study

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Abstract

Abdominal radiography is beneficial in a variety of clinical situations. Prior to the introduction of multiplanar imaging, it was considered as the main examination for gastrointestinal pathology. However, the radiation dose received is considered high since it is equivalent to the dose of at least 75 chest radiographs. Personnel including staff or relatives may be required to assist patients in many conditions, increasing unnecessary radiation and the likelihood of radiation-induced cancer. The purpose of this study was to determine the radiation dose received by personnel when eyes and thyroid are exposed during abdominal radiography. The Rando and body phantoms were used to represent personnel and patients in this experimental approach. The dose was measured as entrance surface dose (ESD) by using TLD-100, which was positioned at the Rando phantom's eyes and thyroid. The study included a total of twenty exposures, five times at each of four distinct sites. The mean doses (eyes/thyroid in mGy) were 0.083/0.081, 0.090/0.087, 0.093/0.092, and 0.092/0.089, respectively, at locations 1, 2, 3, and 4. The results indicated that there was no correlation between organ and location affecting ESD measurement (p=0.960). There was no significant difference in dose between the two organs (p=0.355), with the mean difference in the eyes being 0.002 more than in the thyroid. The proximity of the eyes to the tube source contributed for the increased dose observed at the eyes. Though ESD was substantial for location pairings 1 vs. 3 (p=0.001) and 1 vs. 4 (p=0.015) owing to the anode-cathode phenomena. In conclusion, personnel should avoid the tube source and cathode region, since they give a greater dose of radiation, particularly when the personnel are closest to the patient and does not have eyes or thyroid protection.

Keywords: Abdominal X-ray; Entrance Surface Dose; Radiosensitive Organs; Scatter Radiation; Thermoluminescent Dosimeter.

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Introduction

Abdominal radiography continues to be a routinely performed diagnostic examination for imaging investigation [1]. It serves as the first imaging test used to identify the cause of many acute abdominal pain and lower back pain, as well as unexplained nausea and vomiting, which are often present in the radiology department [2]. A plain abdominal radiograph offers sufficient information for physicians to continue treatment without requiring further imaging workup [1], [3]. In other words, the plain film reassures the physician and expedites empiric treatment and patient discharge especially when combined with a mild history and physical examination.

Despite its simplicity, many patients, including paediatric, geriatric, and traumatised [4], [5] patients, are mostly unable to perform and maintain the postures required for radiographic examination. As a result, personnel will need to assist such patients in achieving and maintaining the appropriate posture. In a previous study, at least six cases were reported the required personnel during the abdominal radiography examination during a four-week period [4]. Abdominal radiography delivers a high dose of radiation owing to the abdominal region's thickness and tissue type. According to a previous research, the dose in an abdominal radiography is equivalent to the dose in seventy-five chest radiographs [6]. Another study [7] also confirmed that abdominal radiography do indeed provide a high dose of radiation, at 1.0 mSv, compared to 0.1 mSv for chest radiography. As a result, personnel's radiosensitive organs may be exposed to high amounts of scatter radiation from patients and, upon occasion, incident X-rays.

The purpose for wearing lead protection equipment is to protect against scatter radiation. Despite the widespread use of lead aprons, personnel are not always required to wear lead glasses and thyroid shields while performing radiography examinations. The percentage of use of eye and thyroid shields was much lower at 40% compared to the rate of use of the lead apron, which was at 80% [8]. The limited use of protective glasses and thyroid shields was owing to their expensive cost, hefty weight, and discomfort associated with shielding equipment while performing duties [9]. This negligent practise exposes the lens and thyroid to scattered radiation, which may result in radiation injury. As a result, the radiation impact on personnel health has been extensively studied, particularly with regard to cataracts, lens damage, and thyroid cancer [4], [10].

The dose to the eyes and thyroid has been measured previously, but at progressively long distances from the primary beam [11]. The concept of distance and the inverse square law are already well-known, particularly among radiology personnel. Increased distance reduces the scatter radiation dose by a factor of four and even to a negligible level [12]. It is, however, inapplicable in some circumstances when personnel must be closest to the patient, such as when restraining or holding the patient into the appropriate position is required. For abdominal radiography, personnel may be required in the examination room especially when the patients are unable to cooperate and have difficulty to understand the instructions. As a result, the closest position increases the likelihood of scatter radiation reaching the personnel. Studies showed an increase in scatter radiation intensity of 80% when staff were staying closer to the patient rather than two steps away from the main beam [13].

The purpose of this study was to determine the level of radiation exposure received by personnel's eyes and thyroid organs while they were closest to the patient during abdominal radiography by utilising a female Rando phantom.

Materials and Methods

Data Collection

Two phantoms were used in this study to represent personnel and patient: (i) a female Rando anthropomorphic (Alderson Research Laboratories, USA) phantom and (ii) the torso region of the whole-body PBU-50 (Kyoto Kagaku, Japan) phantom. These phantoms were used to represent the interaction of radiation with the personnel skin surface and the attenuation characteristics of the patient during abdominal radiography, thus generating realistic scatter radiation without exposing a real human. In this study, the TLD-100 (LiF; Mg, Ti) was utilised to determine radiation dose which is the entrance surface dose (ESD). TLDs have a high sensitivity to low energy scatter radiation and are composed of many small TLDs, which enable simultaneous dose measurements.

Annealing Process and Calibration of TLDs

TLDs were annealed in a TLD annealing oven that was preheated to 400°C from room temperature and then maintained at that temperature for one hour. Prior to exposure, the TLDs were immediately cooled to room temperature within the oven using force air cooling. TLDs were also calibrated prior to the study's commencement to obtain the calibration factor (CF) value. The calculation of the radiation calibration factor (RCF) was derived from a previous study [14]. The value was used to convert between nanoCoulomb (nC) and miliGray (mGy) units. The CF was generated by immediately exposing the TLDs and Cobia smart metre (RTI Group, Sweden) to 70 kVp at five different mAs values with a source image distance (SID) of 100 cm. The smart metre reading was taken immediately, while TLDs were measured 24 hours after exposure using TLD-3500 (Thermo Scientific, USA). The radiation dose was plotted against the nC unit using a smart metre, and CF was produced.

Radiation Dose Measurements

The female Rando phantom was used to represent personnel at a height of 160 cm, which is around the average height of Malaysians [11]. The dose was determined at four different locations across the X-ray table. First location is 50 cm from the primary beam's centre (Figure 1(a)), which was designated in the anode region. The distance between the primary beam's centre and the Rando phantom's body surface was measured. On the X-ray table, a body phantom was positioned supine to simulate a patient for abdominal radiography (Figure 1(b)). Collimation was opened according to the phantom's area of interest (ROI).

This study used 80 TLDs with a total of 20 exposures. Each pair of annealed TLDs was placed in a capsule and positioned at the Rando phantom's eye (bridge centre between eyes) and thyroid (Adam's apple) (Figure 1(c)). All exposures were performed using a Siemens Polydoros IT 55 general radiography equipment (Model number: 4803388) at a 70 kV and 40 mAs exposure factors. After replacing exposed TLDs with unexposed TLDs, exposure was repeated until the fifth exposure, allowing for the calculation of means. This procedure was performed for the Rando phantom's for other three locations. The second location was also in the anode region, while the third and fourth locations were in the cathode area.

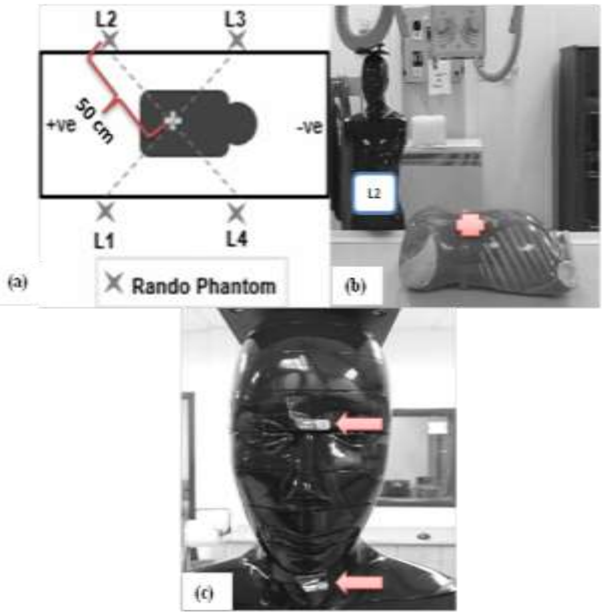

Figure 1. (a) Illustration of Rando phantom (Alderson Research Laboratories, USA) arrangement surrounds the X-ray table; (b) An example of equipment setup during the experiment with PBU-50 body phantom (Kyoto Kagaku, Japan) positioned supine on X-ray table (L2 is the position of Rando phantom); and (c) TLDs (arrows) in a capsule attached to the eyes and thyroid of Rando phantom for dose measurement.

TLDs were read 24 hours after exposure to determine the ESD values at the respective organs and locations. To accommodate for any differences between different TLDs, each was labelled with its assigned organ and location. The TLDs readings were converted to nC and subsequently to the radiation dose unit mGy using the estimated CF during the pilot phase. The gathered data were then case-insensitively entered into the table.

Data Analysis

The Statistical Package for the Social Sciences was used to analyse the data (SPSS, version 21; IBM Corp., New York, NY, USA). We obtained descriptive statistics, such as the mean and standard deviation. The independent t-test and the two-way ANOVA test were employed to analyse the parametric dose data. An independent t-test was used to determine the mean ESD at the Rando phantom's eyes and thyroid organs. Meanwhile, the mean ESD values for four distinct locations were compared using a two-way ANOVA test. The variance for the tests considered statistically significant at a 95% confidence interval and a p value 0.05 as a level of significance.

Results

Analysis of ESD at eyes and thyroid organs

Table 1 summarises the independent t-test results in terms of mean and standard deviation (SD). The analysed data revealed no statistically significant changes (p>0.05) in ESD measurements between personnel's eyes (0.089±0.006 mGy) and thyroid (0.087±0.007 mGy). However, the results indicate that ESD measurements at the eyes were greater than that at the thyroid by 0.002 of the mean difference.

Table 1. Results of analysis of ESD between eyes and thyroid level (n = 40).

Group organ (n)	Mean (SD) of ESD (mGy)	Mean difference (95% CI)	T-statistic (df)	*p* value*
Eyes (20)	0.089 (0.006)	0.002 (-0.002,0.006)	0.937 (38)	0.355
Thyroid (20)	0.087 (0.007)			

* Independent t-test; significant at p>0.05 (2-tailed).

ESD analysis in four Rando phantom locations

The line graph in Figure 2 depicts the distribution of ESD over four distinct Rando phantom locations. The graph indicates that location 3 (0.092±0.003 mGy) has the greatest ESD measurements, followed by location 4 (0.090±0.003 mGy), 2 (0.089±0.003 mGy), and 1 (0.082±0.009 mGy), respectively. Simultaneously with the two-way ANOVA analysis, a test between individuals was conducted (see Table 2). There is no significant correlation between location and organ (p>0.05). This indicates that the ESD measurements are independent of the organs at each location.

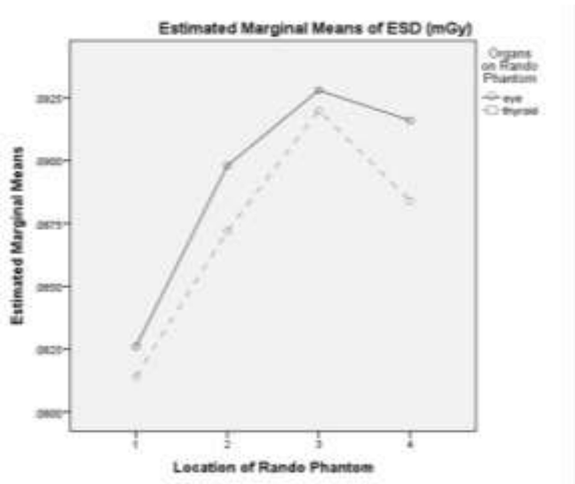

Figure 2. Line graph of ESD distribution among locations 1, 2, 3, and 4 of Rando phantom.

Table 2. Results of test of between-subject (individuals) effects.

Source	df	F	*p* value
Location	3	6.086	.002
Organs	1	1.169	.288
Location * Organs	3	.099	.960

Post-hoc Examination Bonferroni's method was performed to ascertain the significance of the difference between multiple locations. All location changes are placed within a 50 cm radius of the main beam's centre. The test result is summarised in Table 3. ESD was found to be significantly different across location pairs 1 and 3 (p=0.001) and 1 and 4 (p=0.015). The test revealed that independent of the organ variables, the dose at location 3 was folded 1.12 and at position 4 was folded 1.09 greater than at location 1. Meanwhile, other location pairings (1 vs. 2, 2 vs. 3, 2 vs. 4, and 3 vs. 4) have no significant difference in ESD values.

Table 3. Results of analysis of ESD among four different locations.

Factor		Mean (95% CI)	Adjusted MD (95% CI)[a]	*p* value
Location of Rando Phantom	1	0.082 (0.078, 0.086)	1 vs. 2: -0.007 (-0.013, -0.000)	0.072
	2	0.089 (0.085, 0.092)	1 vs. 3: -0.010 (-0.017, -0.004	0.001
	3	0.092 (0.089, 0.096)	1 vs. 4: -0.008 (-0.015, -0.001)	0.015
	4	0.090 (0.086, 0.094)	2 vs. 3: -0.004 (-0.011, 0.003)	0.723
			2 vs. 4: -0.002 (-0.008, 0.005)	1.000
			3 vs. 4: 0.002 (-0.004,0.009)	1.000

Discussion

This study focused on the radiation dose to personnel's eyes and thyroid organs while they were in the X-ray room for abdominal radiography. The radiation dose to both organs was comparable statistically. This could be explained by the near proximity of the organs' levels. As a result, minimal ESD variation was observed between the eyes and thyroid organs. The amount of ESD obtained at the eye's organ was found to be 2% more than that received at the thyroid organ. This study corroborates earlier research [4], [15], which found 3% and 5% increase in radiation doses collected at the eye's organ, respectively. These findings indicating high doses to the eye lenses are most likely linked to the difference in radiation intensity between the X-ray tube and the patient entrance surface.

The intensity of scatter radiation was strongly impacted by the position of the subject being radiographed. This implies that scatter radiation is more intense on the X-ray tube side and gradually decreases when the photon interacts with and is attenuated by the body region being radiographed. This is corroborated by a previous study [16] which discovered that scatter radiation was higher in the area adjacent to the X-ray tube than in the area close to the patient. The ESD values of personnel's eyes were reported to be higher than those of the thyroid region in this study. This explains the obtained result, as the eye lens level of this Rando phantom was perpendicular to and closest to the primary beam's primary source, whereas the thyroid region level is lower than the eye level and lies closer to the patient's side.

Due to the proximity of the phantom to the patient in this study, the doses collected were more than in the previous study [15], with reported doses of 0.0038 and 0.0037 mGy for eyes and thyroid organs respectively. This inconsistent result is also attributed to the reason that the actual personnel such as staff are familiar with the radiography settings. As a result, when exposure is made, they tended to increase the distance between themselves and the patient or turned their faces away from the irradiation field. These factors make a convincing case for the lower value obtained in the preceding study. Nonetheless, in other instances, personnel were still unable to turn their faces away from the irradiation field in order to watch the patient's movement and respiration or to move away from the primary source in order to hold the patient. Thus, it is critical to emphasise the need of eye and thyroid shielding to personnel who are in close proximity to the patient on a regular basis.

The scatter radiation intensity variation along the location variant of the Rando phantom around the patient was shown in Table 3. The finding explains why ESD is not different across the four locations, but only exists between locations 1 vs. 3 and 1 vs. 4, due to the anode-cathode factor on the X-ray tube. Locations 1 and 2 are on both sides of the anode, while locations 3 and 4 are on the cathode. As a result, significant ESD variation exists between opposing sides of the tube. Due to the greater attenuation of the X-ray intensity on the anode target material, the cathode aspect emits more radiation than the anode. This result was quite consistent with previously published data. They found a wide range of scatter dose values between the anode and cathode, with dose received 57% [17] and 28% [11] higher towards the end of the cathode bound region than at the edge of the anode bound area.

The percentage difference between this study and previous studies varies considerably. In this study, the small percentage discrepancy of 11% and 9% is explained by the distance between each Rando phantom location, which is relatively close to each other and to the main beam's centre. The separation distance of 50 cm was utilised in the study to determine the patient's nearest location. Thus, personnel positioned closer to the non-collimated radiation field are more likely to benefit from the anode heel effect [18]. In comparison, when personnel are situated closer to the centre of beam, the heel effect is reduced, resulting in less intensity variation. Given that the phantom was positioned closest to the centre rays in this study, it apparently does not benefit from the anode heel effect, as seen by the minimal difference in scatter radiation measured between the anode and cathode bound areas.

This study is not without limitations. To begin, this study examined only an abdominal radiograph using a Female Rando phantom. A similar study should be conducted on other common radiographic examinations to allow for comparison of the obtained results. Following that, only 40 mean of ESD measurements were made. Thus, additional TLDs should be used to improve the results' accuracy. Finally, other factors may influence the dose received by examination personnel. As a result, additional research should be conducted in the future to include other factors that may directly or indirectly affect the measurement of ESD.

Conclusion

This study demonstrated that personnel could reduce their scatter radiation exposure by positioning radiosensitive organs toward the patient side rather than the tube side and choosing a suitable tube aspect to remain in. These are based on the high intensity of scatter radiation facing the X-ray tube and on the cathode side. These two findings are critical in reducing radiation exposure to personnel's radiosensitive organs, especially when working near to a patient without wearing any protective shielding.

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