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Assessment of the impact of chest radiography on the breast of female patients in a medical facility in Asaba, Delta State: An evaluation of the lifetime cancer risk

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ABSTRACT

Objectives: Posteroanterior (PA) Chest radiography is the most common medical investigation worldwide. This study is aimed at determining the mean and median entrance surface dose (ESD), 75th percentile ESD, dose to right (RT) and left (LT) breast, absorbed dose (D_T) and organ dose from PA chest radiography for female patients between the ages of 20-79 years. It is also aimed at determining the effective dose (E) and estimating the lifetime cancer risk.

Methods: This prospective study was carried out with 121 female subjects who came for routine PA chest radiography. Digital radiography (DR) unit was used for all patients. Thermoluminescent dosimeters (TLDs) was positioned at the centre of the collimated beam of each patient and transparent nylon was attached to the skin. The TLDs were also attached to both breasts with the patient facing the erect bucky to estimate the exit dose (ED).

Results: The mean, median and 75th percentile ESD for the 6 age groups were 0.96 ±0.15 mGy, 0.95 (0.71-

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1.23) mGy and 1.07mGy respectively. The mean dose to the RT, LT breast and the D_T were 0.35 ±0.12, 0.40 ±0.13 and 0.58 ±0.12 mGy respectively. The mean *E* for the age groups was 0.029 mSv, while the mean organ doses to the lungs, breast and thyroid were 0.290, 0.059 and 0.022 mGy respectively. The estimated lifetime cancer risk among the age groups ranged from 1.0-2.8 per million. **Conclusion:** The mean ESD and *E* were above recommended guidelines. ESD and D_T were primarily affected by focus film distance (FFD) and field size for all age groups. An evaluation of the lifetime cancer risk from this study shows that the risk was twice as high as the United Kingdom (UK) Health Protection Agency (HPA) report. Though the risk was minimal, there may be need to review the current protocol to meet up with the reported values in the HPA published guidelines.

KEY WORDS

Entrance Surface Dose (ESD); thermoluminescent dosimeter (TLD); Digital Radiography (DR); Effective Dose (E); Exit Dose (ED); Absorbed Dose (DT)

Introduction

Medical imaging is an essential aspect of modern medicine [1]. Until the advent of the use of ionizing radiation for the diagnosis and treatment of diseases, access to quality care was a serious challenge [2, 3]. As of today, medical exposure accounts for the highest man-made use of ionizing radiation and conventional X-ray imaging accounts for the most frequently used and most readily available imaging modality worldwide [4, 5].

The protection of patient, staff and the public from ionizing radiation has raised serious concern, due to better understanding of the damages it can cause, this has brought about the recommendation from notable bodies like the International Atomic Energy Agency (IAEA), the International Commission on Radiological Protection (ICRP), the National Radiological Protection Board (NRPB) and the International Commission on Radiation Units and Measurements (ICRU) and other national/regional guidelines on the effective use of radiation [6-9].

Chest radiography remains the most commonly performed diagnostic imaging examination, especially for the diagnosis of many pulmonary diseases/conditions. The advantages of chest radiography include high accessibility, low cost, and minimal radiation dose to lungs and breasts [10-12].

It is, however, necessary that radiation dose be properly optimized with emphasis on proper collimation, adequate focus to film distance (FFD) and the appropriate selection of kVp and mAs. The latter has been shown to have a significant effect on the patient dose outcome [13, 14].

Although the use of phantoms and mathematical algorithms can be helpful in assessing dose, they are recommended not to replace surveys of actual patient examinations. Data from patient examinations provide the only definitive method for determining values of dose reference levels (DRLs) during clinical use [15].

DRLs and ADs are essential parts of protocol optimization. It is essential to ensure that appropriate image quality for the diagnostic purpose is achieved when changing patient doses. Optimization must balance image quality and patient dose, that is, image quality must be maintained at an appropriate level as radiation doses are decreased [16].

To this end, this study is aimed at determining the mean, median and 75th percentile ESD (local DRL) for a total of 121 female patients from 20-79 years for PA chest radiography, and to determine the dose to right (RT) and left (LT) breast, absorbed dose (D_T), organ dose, effective dose (*E*) and to estimation lifetime cancer risk. A comparison of the above quantities was made with relevant studies.

Methods

This prospective study was carried out in a busy medical facility in Asaba, Delta State, located in South-South Nigeria for 3 months. The study involved 2 diagnostic Radiographers and 2 medical physicists. Before the commencement of the study, approval

was gotten through the medical facility ethical committee and patients' informed consent form was duly filled. Female patients from the age of 20-79 years was recruited in the study who were referred mostly through the general out-patient department (GOPD). The patients' age groups were divided into 6 (20-29, 30-39, 40-49, 50-59, 60-69 and 70-79 respectively). The patient-specific parameter used in this study was age (years), height (m), weight (kg) and chest thickness (cm). Other machine parameters were kVp, mAs, film to focus distance (FFD) (cm) and field size (cm^2).

The study used a DR with a grid system for each patient [**Table 1**]. Each patient was positioned by the radiographer in a PA position in front of the erect bucky. Measurement was done using TLD chips. One of the TLD chips was positioned at the back of the patient (posteriorly) after beam collimation was made by the radiographer. It was used to estimate the entrance surface dose (ESD). The other two TLD chips were positioned each on the right (RT) and left (LT) breast to estimate the surface breast dose and to equally estimate the exit dose from which the absorbed dose was determined (D_T) respectively.

In other to effectively use the TLD chips, they were first annealed in a TLD Furnace Type LAB-01/400 at a temperature of 400°C for one (1) hour and was allowed to cool to room temperature. To remove lower peaks, they were heated to a temperature of 100°C for another two (2) hours and were put to use after 48 hours. Parameters like the element correction factors (ECF) (0.9-1.1) and homogeneity of the TLD chips (< ±30%) were found to be within the acceptable range for the patient dose measurements [17].

A RadPro Cube 400 manual TLD Reader (Freiberg Instruments GmbH, Germany) was used to determine the corresponding TLD count for the chips. Average background counts were obtained from three TLD chips that were not exposed to radiation (TL_0). Obtained TL counts (TL_i-TL_0) were multiplied with a pre-determined X-ray calibration factor using the following equation [18]:

$$ESD = (TL_i - TL_0) \times CF_{Cs-137} \left({}^{mGy}/_{count}\right) \quad [1]$$

Where $TL_{i=1, 2, 3...}$ is the count from the selected chips, TL_0 is the background count, CF is the calibration factor of the TL chips, which were calibrated with Cesium-137 (Cs-137) source between 0.2-2mGy.

Table 1. Digital Radiography machine specifications

Manufacturer	**RADIOLOGIA**
Type	Ceiling Mounted Unit (DR System)
Serial Number	19030007
Machine Model	POLYRAD PREMIUM CS
Power Capacity	50kW
kVp Range	40-150kVp
mAs Range	0.1-630mAs
Maximum Current	3.5-1.6A
Minimum Filtration	2mmAl @75kVp
Focal Spot	1.2/0.6
Grid	Removable (14×17 inches)
Total Filtration	3.3mmAl
Line Voltage	115-240V
Phase	3, 50/60Hz
Target	Tungsten
Manufactured Date	February 2019

The ESD was calculated using equation [1]. The mean ESD was determined from the mean of all the age groups. In addition, the median was determined from the middle number(s) of the ESD for all age groups, after which the 75th percentile ESD (local DRL) was determined.

The patient effective dose (E) was calculated using the mathematical relation:

Effective dose (E) = Σ [Tissue weighting factor (W_T) ×Equivalent dose (H_T)] [2]

The tissue weighting factor (W_T) was determined using the International Commission on Radiological Protection (ICRP) report 103 and the equivalent dose (H_T) was determined from the product of the absorbed

Table 2. Mean patient and machine parameters

N	Age (yrs)	Weight (kg)	Height (m)	kVp	mAs	FFD (cm)	Field size (cm^2)	Thickness (cm)
27	24.3 (20-29)	64.0 (52-83)	1.66 (1.62-1.72)	67.7 (65-68)	14.1 (12.5-20)	150 (148-157)	1176.8 (704-1369)	16.3 (14-22)
25	33.0 (30-39)	80.5 (63-99)	1.61 (1.53-1.76)	70.7 (65-75)	16.1 (12.5-20)	178 (170-180)	761.6 (575-928)	25.0 (21-27)
30	43.2 (40-49)	72.3 (53-102)	1.67 (1.56-1.75)	71.3 (65-78)	14.6 (12.5-16)	180 (178-180)	691.4 (500-900)	23.4 (19-27)
17	56.2 (50-59)	75.9 (55-93)	1.61 (1.48-1.76)	73.4 (68-80)	18.7 (16-22)	170 (160-180)	915.8 (675-1120)	25.0(20-30)
12	64.7 (60-69)	69.8 (54-89)	1.57 (1.50-1.78)	75.2 (65-78)	17.2 (16-20)	180 (178-180)	760 (500-1089)	24.6 (18-27)
10	74.7 (70-79)	72.3 (53-87)	1.62 (1.47-1.70)	67.5 (70-80)	15.7 (16-20)	172 (170-180)	682.5 (500-980)	23.7 (21-27)

kVp = Peak kilovoltage, mAs = Milliampere-seconds, FFD = Focus-film distance

Table 3. Mean, ESD, dose to the RT and LT breast and Absorbed dose (DT)

Mean age/ range (years)	ESD±SD (mGy)	RT Breast ±SD (mGy)	LT Breast ± SD (mGy)	Absorbed dose (mGy)
24.3 (20-29)	0.89 ± 0.40	0.26 ± 0.19	0.56 ± 0.35	0.48± 0.27
33.0 (30-39)	0.88 ± 0.29	0.34 ± 0.20	0.39 ± 0.25	0.51± 0.27
43.2 (40-49)	1.22 ± 0.17	0.54 ± 0.27	0.27 ± 0.11	0.82± 0.14
56.2 (50-59)	0.97 ± 0.28	0.36 ± 0.21	0.42 ± 0.22	0.58± 0.17
64.7 (60-69)	1.02 ± 0.33	0.41 ± 0.24	0.52 ± 0.13	0.56± 0.23
74.7 (70-79)	0.77 ± 0.43	0.21 ± 0.11	0.24 ± 0.17	0.55± 0.12

ESD = Entrance surface dose, SD = Standard deviation, RT = Right, LT = Left

dose and radiation quality factor for X-ray [19].

Similarly, the Equivalent dose (H_T) = Quality factor (Q) × Absorbed dose (D_T) [3]

In this case the radiation quality factor (Q) for X-ray ≡ 1.

The ICRP publication report 79 and Health Protection Agency (HPA-CRCE-028) report by Wall et *al*, was used to determine the cancer risk coefficients (% per Sv) for chest radiography for the female patients, where 20-29, 30-39, 40-49, 50-59, 60-69 and 70-79 was 9.6, 8.8, 8.6, 7.5, 5.7 and 3.5 (% per Sv) respectively [20, 21].

The organ dose was extrapolated from the variation of organ dose conversion coefficients for lung, breast and thyroid at 70kVp for PA chest examination from the IAEA Technical Reports Series No 457 [**Figure 1**], which is given as [22, 23]:

$$C_{D_T K_i} = \frac{D_T}{K_i} \quad [4]$$

A tube voltage of 70kV was used based on the mean kVp from the 6 age groups. From the above equation, C is the conversion coefficient, D_T is the organ dose and K_i is the incident air kerma. The incident air kerma (K_i) is given as:

$$K_i = K_e \times B \quad [5]$$

Table 4. Comparison of organ dose with other studies

	Organ Dose (mGy)		
	lungs	**breast**	**Thyroid**
This study	0.290	0.0588	0.0220
*UK [21]	0.0460	-	-
*Chaparian et al [45]	0.0400	-	0.122
*Ladia et al [46]	0.0584	0.010	0.0061
*Toroi et al [47]	0.03-0.06	0.01-0.02	-
*De Oliveira et al [48]	0.0342a	0.0095[a]	0.0037[a]
*Zarghani & Toossi [49]	-	0.10- 0.20	1.30

**PCXMC software was used, [a]Mean value was from 3 measurements, UK = United Kingdom*

Where K_e is the entrance surface dose, and *B* is the backscatter factor respectively.

The incident air kerma (K_i) was determined by multiplying the mean entrance surface dose (K_e) by the pre-determined backscatter factor (*B*) from the X-ray unit, which was 1.07 for a field size of 250 mm ×250 mm.

Statistical analysis

The data analysis was performed using SPSS for Windows, Version 22.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics, a One-Way analysis of variance (ANOVA) and Pearson correlation coefficient test were used at a 95% level of significance. P< 0.05 was considered statistically significant.

Results

The mean age, weight, height, kVp, mAs, FFD, field size, thickness, ESD, dose to the RT breast, dose to the LT breast and AD was 49.35 ± 19.28 years, 72.47 ± 5.57 kg, 1.62 ± 0.37 m, 70.97 ± 3.06 kV, 16.07 ± 1.70 mAs, 173.17 ± 8.11 cm, 831.35 ± 188.77 cm^2, 23.00 ± 3.35 cm, 0.96 ± 0.15 mGy, 0.35 ± 0.12 mGy, 0.40 ± 0.13 mGy and 0.58 ± 0.12 mGy respectively [**Table 2**].

A One-Way ANOVA for 20-79 years show that there was no statistically significant difference in kVp and age (P = 1.000), weight (P = 1.000), height (P = 0.564), mAs (P = 0.846), FFD (P = 0.078) and patient thickness (P = 0.931), except for the patient field size [Table 2]. Statistically significant difference was seen between mAs and FFD/field size (P < 0.001). The field size statistically affected all parameters. The patient thickness showed statistically significant difference with the FFD (P = 0.001) and field size (P < 0.001) respectively [Table 2]. Likewise, there was correlation between FFD and field size (P = 0.019) and patient thickness (P = 0.047) respectively [**Table 2**]

There was no statistically significant difference between the mean ESD and the RT breast (P = 1.000), LT breast (P = 1.000) and D_T (P = 1.000) respectively [**Table 3**]

A Pearson correlation shows that there was relationship between ESD and dose to the RT breast (P = 0.001) and D_T (P = 0.032) but there was no relationship between patient thickness against ESD (P = 0.772), dose to the RT (P = 0.499) and LT breast (P = 0.342) and D_T (P = 0.589). There was correlation between dose to the RT breast and D_T (P = 0.043) [**Table 3**].

Comparison of the 75th percentile ESD for 20-79 years was made with EC, IAEA, NRPB and NCRP 172 guidelines [**Figure 2**].

Furthermore, a comparison was made between this study and other studies, who mostly used the PCXMC dose software to estimate organ doses [**Table 4**].

Lastly, the lifetime cancer risk as a function of age was determined and was compared with the UK (HPA-CRCF-028) report [**Figure 3**].

Discussion

Estimation of surface breast dose, effective dose and cancer risk coefficient from routine PA chest radiog-

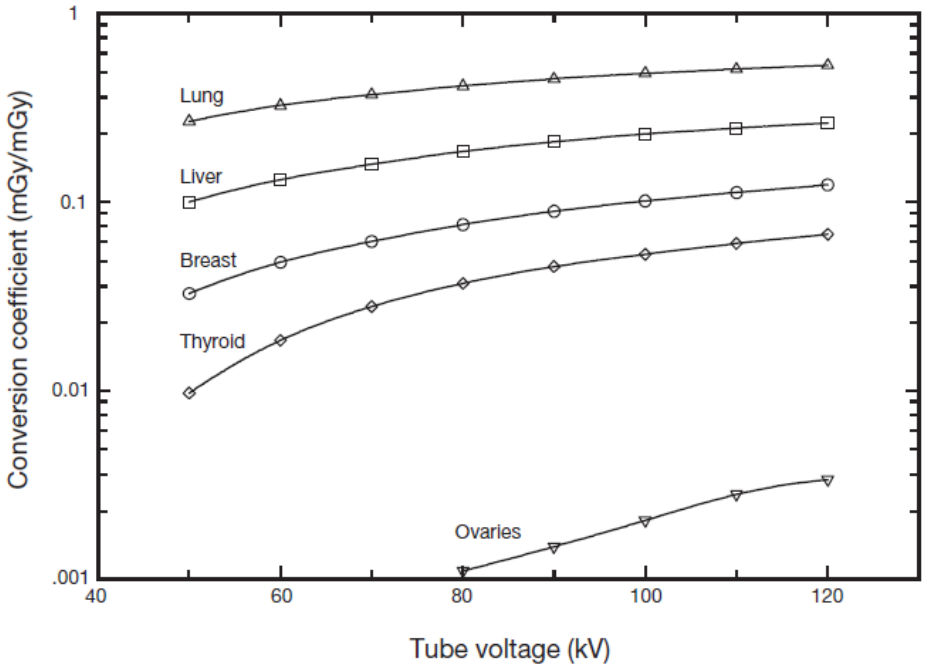

Fig. 1. *Variation of organ dose conversion coefficients with tube voltage for lung, liver, breast, thyroid and ovaries. Chest postero-anterior (PA) examination. X ray spectra have total filtration of 3 mm Al. (Adapted from IAEA TRS no. 457).*

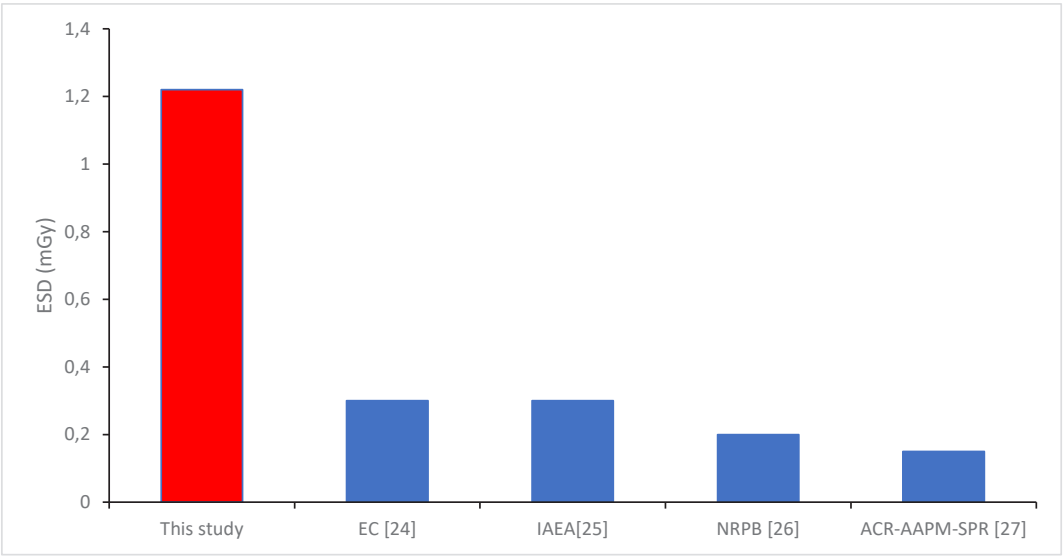

Fig. 2. *Comparison of 75th percentile ESD with established reference levels.*

raphy has been carried out in a busy medical facility in Asaba, Delta State, located in the South-South region of Nigeria.

The mean/75th percentile ESD from the 3 age groups was above the European Commission (EC), IAEA, NRPB and NCRP 172 guideline [24-27] and the mean ESD (0.96 mGy) was above most international studies [28-33]. The study used Cesium-137 source for calibration between 0.2-2 mGy. The choice was because of its uniform energy, compared to the use of

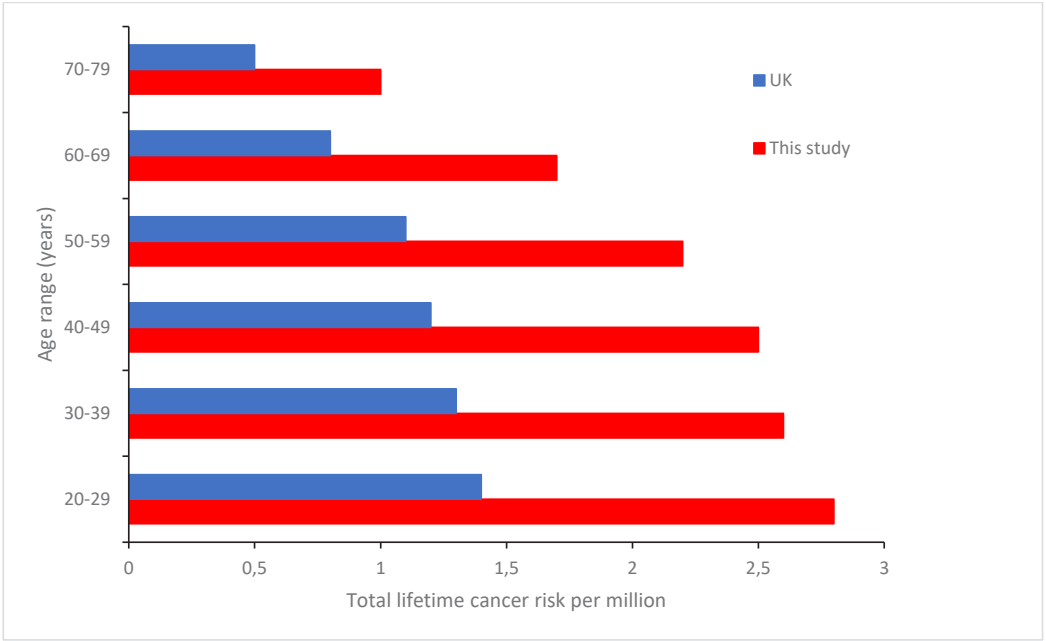

Fig. 3. *Comparison of total lifetime cancer risk as function of age at exposure and sex between this study and UK report.*

X-ray source where energy fluence are not uniform. A possible limitation may be the use of a calibration factor from a radioactive source to estimate dose in X-ray examinations, this may have influenced our results. However, the mean ESD in this study was lower compared to a study by Jibiri and Olowookere in Southwestern Nigeria, where 2 different X-ray facilities were used [34]. Although their study used the tube output approach for the estimation of ESD, however, the variation in dose compared to this study was between 70-94 %. Factors accounting for this variation was the technical parameter used, and it has been found that the indirect approach (tube output) may result in ESD accuracy between 20-30 % and in some cases, it may be higher, and this is because the output varies with voltage waveform, anode angle and filtration based on the ICRP 135 report [15]. The highest mean and median ESD were noticed between ages 40-49 from this study.

Breast dose with an Unfors EDD dosimeter in a study by Jecl et *al* with an anthropomorphic simulated phantom in AP projection was 0.35 mGy for surface dose, following thoracic X-ray. The mean dose to the breast from this study was 0.38 mGy, with a variation of 5.8 % compared to Jecl et *al* [35]. In a similar study by Mekis et *al*, using similar anthropomorphic phantom, surface dose to the RT and LT breast from lumbar spine X-ray was 0.45 and 0.26mGy respectively. The dose to the RT (0.35 mGy) was below Mekis study but the dose to the LT (0.40mGy) was above it. The breast dose from Mekis study was from scatter radiation at higher technical parameters mostly the mAs as compared to our study which was from the primary beam. To buttress this point, the chest radiography from this study was PA view in which attenuation would start from the back of the patient before doses reach the breast at the other end. This could cause differences in the dose that was observed [36].

Besides, breast dose (1.19 mGy) from a study by Fordham et *al* with fluoroscopy was considerably higher than our study. The reason was that fluoroscopy procedures are associated with a higher dose due to multiple exposures involved [37]. The doses from this study were from a single exposure. Also, the estimated breast dose from a study by Elshami et *al* was far lower than this study for the RT (0.00174 mGy) and LT (0.0019 mGy) breast respectively. The large differences in dose could be detector related (TLD versus solid-state detector) [38].

This study reveals a good relationship between mean ESD and D_T. The variation in dose between both quantities was ~35 %. It is wordy to note that ESD is

often a benchmark measurement used to assist in quality control and optimisation in radiography departments. However, it is a poor indication of radiation risk as it does not account for tissue sensitivity, penetration and area of the X-ray beam [39]

The mean effective dose (*E*) in this study (0.029 mSv) was above the UK National Patient Dose Database (NPDD) (0.022 mSv) [40], the ICRP 60 and 103 (0.014 mSv) [19, 41]. The mean *E* from a study by Zhang et *al*, for PA chest radiography in 59 patients was 0.043mSv. This value was above our result by a variation of 27% [42].

Reported *E* in most studies were calculated using the ESD, which we often refer to as the skin dose. This study found the difference between the entrance surface dose (ESD) and the exit dose (ED) as proposed in the ICRP 103 report to estimate the absorbed dose. Another challenge from most study was the variation in the weighting factor for the chest. The factor is thought to influence the outcome of the effective dose.

The study also shows that there was no statistically significant difference in the radiation dose reaching the RT and LT breast respectively. The estimated cancer risk coefficient among the age groups was approximately 2.8, 2.6, 2.5, 2.2, 1.7 and 1.0 per million respectively with 20-29 years having the highest risk. The highest cancer risk band (20-29 years) was twice the HPA report (1.4 per million) [21]. Protocol optimization has been found to be necessary in the studied facility, in order to reduce the cancer risk. The maximum risk from this study was lower (1 in 357, 000) compared to a study in Nigeria (South-West) by Achuka et *al*, where the mean cancer risk was 1 in 20, 000 [43]. Protocol optimization and machine failure may have increased the patient dose.

The mean kVp and mAs in this work were below a similar study by Ciraj et *al*, where the indirect method was used. The variation between both parameters were 11 and 31 % respectively, but the mean weight between both studies was comparable. The mean ESD was higher, with a variation of 54% but the *Es* were comparable. This study used a direct method for determining patient dose, while Ciraj's used the tube output approach which is an indirect method for estimating patient dose. It was thoughtful to note that factors like the field size and FFD, may have affected ESD [44].

The estimation of organ dose (breast, lungs and thyroid) was calculated manually using the organ dose conversion coefficient graph with a mean tube voltage of 70kV. Most studies have used the PCXMC software for organ dose calculation. The organ dose for the lungs in this study was the highest compared to Wall et *al* (UK) [21], Chaparian et *al* [45], Ladia et *al* [46], Toroi et *al* [47] and De Oliveira et *al* [48]. The dose to the breast (0.0588 mGy) was within Zarghani & Toossi reported range (0.1-0.2) [49], while the thyroid dose from this study was higher compared to Ladia et *al* and De Oliveira et al but was lower compared to Chaparian et *al* and Zarghani & Toossi. Variation in organ doses may arise based on the methods for calculation.

Conclusion

The mean and 75th percentile ESD, D_T, *E*, organ dose, and lifetime cancer risk to 121 female patients between the ages of 20-79 have been determined using TLDs. The mean and 75th percentile ESD were higher compared to most studies. The dose to the RT and LT breast were comparable with anthropomorphic phantoms. The mean and 75th percentile ESD and the effective dose (*E*) were higher in comparison to other studies guidelines. The lifetime cancer risk in this study was "minimal" but was twice the HPA reported values. Protocol Optimization may be necessary to reduce patient dose to the barest minimum. **R**

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Conflict of interest

The authors declared no conflicts of interest.

REFERENCES

1. Bercovich E, Javitt MC. Medical Imaging: From Roentgen to the Digital Revolution, and Beyond. Rambam Maimonides Med J. 2018; 9:e0034.
2. Sharma S, Traeger AC, Reed B, et al. Clinician and patient beliefs about diagnostic imaging for low back pain: a systematic qualitative evidence synthesis. BMJ Open. 2020; 10:e037820.
3. Pasqual E, Turner MC, Gracia-Lavedan E, et al. Association of ionizing radiation dose from common medical diagnostic procedures and lymphoma risk in the Epilymph case-control study. PLoS ONE. 2020; 15(7): e0235658.
4. Campanella F, Rossi L, Giroletti E, et al. Are physicians aware enough of patient radiation protection? Results from a survey among physicians of Pavia District– Italy. BMC Health Serv Res. 2017; 17:406
5. Do KH. General Principles of Radiation Protection in Fields of Diagnostic Medical Exposure. J Korean Med Sci. 2016; 31 Suppl 1(Suppl 1):S6-S9.
6. IAEA General Safety Guide. Radiation protection of the public and the Environment. IAEA Safety Standards Series No. GSR-8. Vienna: IAEA Safety Series. 2018
7. ICRP. Radiological Protection and Safety, in Medicine, ICRP Publication 73, Annals of the ICRP 26, No. 2, Pergamon Press, Oxford. 1996
8. National Radiologic Protection Board (NRPB). National Protocol for Patient Dose Measurements in Diagnostic Radiology, NRPB, Chilton Didcot, UK: NRPB Publication. 1992.
9. International Commission on Radiation Units & Measurements (ICRU). Patient dosimetry for X-rays used in medical imaging. Bethesda, Maryland: ICRU publications, Report 74, 2005.
10. Pinto LM, Pai M, Dheda K, et al. Scoring systems using chest radiographic features for the diagnosis of pulmonary tuberculosis in adults: a systematic review. Eur Respir J 2013; 42: 480–494
11. Wielpütz MO, Heußel CP, Herth FJ, et al. Radiological diagnosis in lung disease: factoring treatment options into the choice of diagnostic modality. Dtsch Arztebl Int. 2014; 111(11):181-187.
12. Truong K, Bradley S, Baginski B, et al. The effect of well-characterized, very low-dose X-ray radiation on fibroblasts. PLoS One. 2018; 13(1):e0190330.
13. Lai ZH, Sá dos Reis C, Sun Z. Effective dose and image optimisation of lateral lumbar spine radiography: a phantom study. Eur Radiol Exp. 2020; 4 (1):13
14. Brennan PC, McDonnell S, O'Leary D. Increasing film-focus distance (FFD) reduces radiation dose for x-ray examinations. Radiat Prot Dosimetry. 2004; 108(3):263-8.
15. International Commission on Radiological Protection. Diagnostic reference levels in medical imaging. ICRP Publication 135. 2017
16. National Council on Radiation Protection and Measurement. Reference levels and achievable doses in medical and dental imaging: recommendations for the United States. Bethesda, Md. NCRP Report No. 172; 2012.
17. Omojola AD Akpochafor MO, Adeneye SO. Validation of entrance surface air kerma of MTS-N (LiF: Mg, Ti) chips with reference ionization chamber using kilovoltage X-ray machine for patient dosimetry. SAR.2020; 58 (2): 16-21
18. Omojola AD, Akpochafor MO, Adeneye SO. Calibration of MTSN (LiF: Mg, Ti) chips using cesium137 source at low doses for personnel dosimetry in diagnostic radiology. Radiat Prot Environ 2020; 43:108-114.
19. ICRP. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann. ICRP 37. 2007: 1–332
20. ICRP, 1998. Genetic Susceptibility to Cancer. ICRP Publication 79. Ann. ICRP 28, 1998: (1-2).
21. Wall BF, Haylock R, Jensen JTM, et al. Radiation risks from medical X-ray examination as a function of age and sex of the patient. Chilton, Didcot, HPA-CRCE-028, UK. 2011
22. International Atomic Energy Agency (IAEA). Diagnostic Radiology Physics: A Handbook for Teachers and Students. IAEA Publications, Vien-

na, Austria. 2014
23. International Atomic Energy Agency (IAEA). Dosimetry in diagnostic radiology: an international code of practice. Technical Reports Series (TRS) No. 457. IAEA Publications, Vienna, Austria. 2007
24. European Committee (EC). European guidelines on quality criteria for diagnostic radiographic images. EUR 16260EN. 1996
25. International Atomic Energy Agency (IAEA). International basic standards for protection against ionizing radiation and for the safety of radiation source. Vienna: IAEA Safety Series. 1996
26. National Radiologic Protection Board (NRPB). National protocol for patient dose measurements in diagnostic radiology. Chilton Didcot, UK: NRPB. Report of the working party of the Institute of Physics Science in Medicine. 2000
27. National Council on Radiation Protection and Measurement. Reference levels and achievable doses in medical and dental imaging: recommendations for the United States. Bethesda, Md. NCRP Report No. 172; 2012.
28. Musa Y, Hashim S, Abdul Karim MK. Direct and indirect entrance surface dose measurement in X-ray diagnostics using nanoDot OSL dosimeters. J Phys Conf Ser. 2019: 1248 012014
29. Nikzad S, Pourkaveh M, Vesal NJ, et al. Cumulative Radiation Dose and Cancer Risk Estimation in Common Diagnostic Radiology Procedures. Iran J Radiol. 2018 15(3):e60955.
30. Akpochafor MO, Omojola AD, Adeneye SO, Aweda MA, Ajayi HB. Determination of reference dose levels among selected X-ray centers in Lagos State, South-West Nigeria. J Clin Sci. 2016; 13:167-72.
31. Ciraj O, Markovic S, Kosutic D. Patient dose from conventional diagnostic radiology procedures in Serbia and Montenegro. J Prev Med. 2004; 12:26–34.
32. Aliasgharzadeh A, Mihandoost E, Masoumbeigi M, et al. Measurement of Entrance Skin Dose and Calculation of Effective Dose for Common Diagnostic X-Ray Examinations in Kashan, Iran. Glob J Health Sci. 2015; 7(5):202-207.
33. Ichikawa T, Ono K, Asada Y. [Evaluation of Entrance Surface Dose in Chest Radiography Using Clinical Images: Estimation of Subject Thickness Using Two-direction Radiography]. Nihon Hoshasen Gijutsu Gakkai Zasshi. 2018; 74 (7):661-666.
34. Jibiri NN, Olowookere CJ. Patient dose audit of the most frequent radiographic examinations and the proposed local diagnostic reference levels in southwestern Nigeria: Imperative for dose optimisation. J Radiat Res Appl Sc. 2016; 9:274-281
35. Jecl D, Mekis N Ljubljana SI. Breast shielding significantly reduced breast dose during thoracic spine radiography. ESR. 2015. pp 1-7
36. Mekiš N, Žontar D, Škrk D. The effect of breast shielding during lumbar spine radiography. Radio Oncol. 2013; 47 (1): 26-31.
37. Fordham LA, Brown ED, Washburn D, et al. Efficacy and feasibility of breast shielding during abdominal fluoroscopic examinations. Acad Radiol. 1997; 4: 639-43.
38. Elshami W, Abuzaid MM, Tekin HO. Effectiveness of Breast and Eye Shielding During Cervical Spine Radiography: An Experimental Study. Risk Manag Healthc Policy. 2020; 13:697-704.
39. Murphy A, Bell D. Entrance Skin Dose. Reference article, Radiopaedia.org. (Accessed on 14 Sep 2021) https://radiopaedia.org/articles/52598
40. Hart D, Shrimpton PC. Fourth review of the UK national patient dose database [published correction appears in Br J Radiol. 2013 86(1021):20120341]. Br J Radiol. 2012; 85 (1018):e957-e958.
41. ICRP Publication 60 (1991) Recommendations of the International Commission on Radiological Protection. Elsevier Health Sciences. 1990; 21: 1-201.
42. Zhang Y, Li X, Segars WP, et al. Comparison of patient specific dose metrics between chest radiography, tomosynthesis, and CT for adult patients of wide ranging body habitus. Med.

Phys. 41 (2), 023901-1-7
43. Achuka JA, Aweda MA, Usikalu MR, et al. Cancer risks from chest radiography of young adults: A pilot study at a health facility in South West Nigeria. Data in Brief. 2018; 19:1250–1256
44. Ciraj O, Markovic S, Kosutic D. Patient dosimetry in diagnostic radiology. Nucl Tech Radiat Protect. 2003; 18: 36-41
45. Chaparian A, Tavakoli I, Karimi V. Organ doses, effective dose, and radiation risk assessment in radiography of pediatric paranasal sinuses. Asian Biomed. 2013; 7(5): 695-698
46. Ladia A, Messaris G, Delis H, et al. Organ dose and risk assessment in paediatric radiography using the PCXMC 2.0. J Phys Conf Ser. 2015; 637: 012014
47. Toroi P, Kelaranta A, Vock P, et al. Interpretation of measured dose data in X-ray imaging. In: 13th international congress of the international radiation protection association. Glasgov, Scotland; 2012. Available from: https://www.irpa.net/members/TS2a.9.pdf
48. De Oliveira VLS, De Oliveira PMC, Abrantes MES, et al. Applying the PCXMC® software for dose assessment in patients submitted to chest and skull X-ray examinations. INAC, Rio de Janeiro, RJ, Brazil. 2009
49. Zarghani H, Toossi MTB. Evaluation of Organ and Effective Doses to Patients Arising From Some Common X-Ray Examinations by PCXMC Program in Sabzevar, Iran. Iran J Med Phys. 2015; 12(4): 284-291

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