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Radiation Doses to Patients Undergoing Common X-ray Examinations from Selected hospitals in Dar es Salaam and Zanzibar, Tanzania

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Abstract

This study involved 300 patients, comprising 113 females and 187 males, from six X-ray units. The study focused on evaluating the patient dose for common X-ray examinations at selected hospitals in Dar es Salaam and Zanzibar, Tanzania. The achieved results were compared with previous studies and Diagnostic Reference Levels (DRLs). Entrance surface air kerma (ESAK) was calculated for chest posteroanterior (PA), cervical spine anteroposterior/lateral (AP/Lat), abdomen anteroposterior (AP), and lumbar spine anteroposterior/lateral (AP/LAT) examinations. The study results revealed the following average ESAK values: chest posteroanterior (PA), 0.34 mGy; abdomen anteroposterior (AP), 1.92 mGy; lumbar spine anteroposterior (AP), 2.78 mGy; and lumbar spine lateral (Lat), 11.8 mGy. When these results were compared to previous published results, there was only a slight deviation among calculated ESAK. A serious deviation was found in chest examinations. The results from this study highlight the importance of optimizing and justifying procedures, as well as the establishment of National Diagnostic Reference Levels (DRLs). The values described in this study could further contribute to the development of local, regional, and international DRLs

Keywords: Entrance Surface Dose; Diagnostic Reference level; Diagnostic radiology

Introduction

The use of X-ray examinations in modern medical diagnostics is fundamental, providing valuable insights into numerous health conditions through non-invasive imaging (Dolic et al. 2013) While these diagnostic procedures compromise essential information for medical practitioners, concerns arise concerning patient safety due to the related radiation exposure (Kalra et al. 2015, Hussain et al. 2022). X-ray imaging, a basis of diagnostic radiology, is engaged in a diversity of examinations such as chest radiography, abdominal imaging, and lumbar studies (Babikir et al. 2020). The application of X-ray technology enables healthcare specialists to visualize internal structures, aiding in the identification and diagnosis of various medical conditions (Babikir et al. 2020). However, the benefits of X-ray examinations must be carefully secure with the impending risks related with ionizing radiation exposure.

Considerate and counting patient doses during common X-ray examinations is essential for ensuring diagnostic efficiency while minimizing radiation related risks (Alshamrani et al. 2021). By investigative patient doses in the context of common X-ray procedures, this research seeks to contribute valuable insights into current practices, recognize areas for enhancement, and eventually enhance patient safety significant source of ionizing radiation for the population. The amplified use of medical radiation devices and technology has led to outstanding improvements in the medical field (Zuzana et al. 2021). However, concerns have arisen about the benefits to patients from radiation examinations, which also involve documented risks of developing radiogenic cancer (Zhang et al. 2015).

In Tanzania, like in other developing countries, has involved this technology (Muhogora et al. 2015, Nkuba and Nyanda 2017).Not in the ref list While conventional radiography is the preferred diagnostic tool compared to other imaging techniques such as magnetic resonance imaging (MRI) and ultrasonography, computed tomography (CT) and digital radiography are commonly applied due to their convenience and affordability (Do 2016). Previous studies in Tanzania have revealed that significant discrepancies in the reported patient doses exists, exceeding recommended levels for certain X-ray examinations (Masoud et al. 2015). This undesirable outcome challenges the ALARA (As Low as Reasonably Achievable) principle, which underscores the requirement and effort to keep exposure as low as reasonably achievable for patients requiring these examinations or other medical uses of radiation (Muhogora et al. 2012). Thus, the need for optimization and justification strategies should be applied to common diagnostic procedures without compromising the image quality. As an initial step in the optimization of patient doses and identification of some strategies in need for mitigating such doses, an assessment of the radiation doses to patients exposed to conventional diagnostic radiography examinations is imperative. Therefore, the objective of this study was to assess the patient dose for common X-ray examinations at selected hospitals in Dar es Salaam and Zanzibar, Tanzania. and compare with Diagnostic Reference Levels (DRLs) of previous international literatures.

Materials and Methods

Data Collection

The research was conducted at six referral hospitals in Tanzania. This included : Temeke hospital (TH), Mwananyamala hospital (MH), Amana hospital (AH), Mnazimmoja hospital (MMH), Abdallah Mzee hospital (AMH), and Chake-Chake Hospital (CCH). This study encompassed 300 examinations, with patient dose determined in terms of entrance surface air kerma. For each participant, the study recorded essential information, including mass, height, exposure parameters (kVp, mAs), focus-film distance, use of grid, and radiography quality. To streamline data collection, an Excel form was devised to capture all the necessary information. Only adult patients undergoing specific examinations namely, chest posteroanterior (PA), chest lateral (LAT), abdomen anteroposterior (AP), and lumbarspine anteroposterior (AP) were eligible for inclusion in the study.

X-ray tube output

The X-ray tube output from the units was assessed using a calibrated 8206031-A Xi Classic R/F & MAM detector, connected to the 8206031-A Xi classic base unit with mAs design by Unfors Ray Safe, and calibrated as of 10/08/2022. The air kerma (K(d)) from the X-ray unit was measured for various exposure parameters (kVp and mAs) at a distance "*d*" of 1 meter from the source. Radiographic exposure was conducted, and the mAs dosimeter readings were recorded. This process was repeated three times for each similar adjustment of mAs, average kVp and the average dosimeter reading were determined. These steps are essential to ensure accuracy, reliability and compliance of the established guideline (IPSM, 1992) From the measurement of K(d), the X-ray tube output (Y(d)) in Gy per mAs was then calculated as the quotient of *K(d)* by PIt, where K(d) represents the air kerma and PIt is the tube loading during the exposure in mAs.

$$Y(d) = \frac{K(d)}{P_{it}} \qquad (1)$$

Entrance surface Kerma

According to the IAEA Code of Practice, whose methodology was implemented in this study, we measured both the incident air kerma (Ki) and the entrance surface air kerma (ESAK). The incident air kerma (Ki) is calculated using the following relationship:

$$K_i = Y(d) * P_{it} \left(\frac{d}{d_{FID-t_p}}\right)^2 \qquad (2)$$

Where

Y (d) is the output (mGy(mAs)$^{-1}$) of the x-ray tube at particular exposure setting.

d is the focus to chamber distance

P_{It} is the tube loading during the exposure of the patient

d_{FTD} is the focus to table distance

t_P is the patient thickness at the irradiation site.

The entrance surface air kerma is defined as the kerma to air measured on the central beam axis at the position of the patient or phantom inclusive of the backscattered radiation. The ESAK calculated from incident air kerma (Ki) by multiplying an appropriate backscatter (BS) factor.

*ESAK=Ki*BS*. (3)

The Ki was estimated using equation 2. ESAK was estimated using a Microsoft Excel spreadsheet by multiplying K_i with a selected BS depending on the kV (patient thickness related), filtration of the radiation, and the beam field size.

Results and Discussion

X-ray outputs

The output from each X-ray unit was measured at a distance of 100 cm from the X-ray sources, with added filtrations of 1mm Al within X-ray. The tube output results for MH, TH, AH, MMH, CCH, and AMH were 0.0997, 0.103,0.110,0.134,0.094 and 0.112mGy/s respectively. MMH recorded the highest tube output, while CCH recorded the lowest tube output.

The study, in general, observed some deviations in tube output among X-ray units at 125 kVp. The common reasons for these variations are rooted in physical factors, such as differences in inherent filtrations, manufacturing brands, the aging of radiology devices, radiographers experience, collimation, different attenuations, anode materials, X-ray tube voltage, X-ray tube current, and exposure time. These reasons have also been supported by previous literatures (Chen et al. 2012, Takaki et al. 2019, Sauter et al. 2019).

3.2 Quality control measurement

The study evaluated the output reproducibility of the x-ray machine, ensuring compliance with radiation output linearity standards set at ≤0.1 (Gyekye et al. 2019) results is recorded in table 1. Measurements were taken for the accuracy and reproducibility of the x-ray tube voltage and timer, using the same instrument. Alignment of the x-ray field and light beam was assessed by exposing a demarcated area to light on a film to confirm agreement with the radiation.

The research focused on measuring and recording various parameters including ; kVp accuracy, reproducibility, and consistency ; exposure time reproducibility and accuracy and the machines' output linearity coefficient and output reproducibility.

In accordance to American Association of Physicist in Medicine (Ma et al. 2001, Hjouj et al. 2022), the accuracy and reproducibility of kVp are deemed acceptable when they are within < ±5% of the specified kVp.

Table 1 : X-ray equipment performance test results

Hospitals	**Quality control test** kVp accuracy (≤±5%)	kVp reproducibility (CoV±2%)	Output reproducibility (CoV±5%))	Status
AH	-0.58	0.14	0.36	Passsed
TH	-1.3	0.27	0.05	Passsed
MH	-1.33	0.15	1.51	Passsed
MMH	-0.23	0.15	0.32	Passsed
CCH	-0.12	0.24	0.31	Passsed
AMH	-0.15	0.32	0.42	Passsed

Examinations ESAK parameters

Tables 2, 3, 4, and 5 present the *ESAK* parameters for the X-ray units in hospitals concerning chest anteroposterior (AP), lumbar spine anteroposterior (AP), lumbar spine lateral (LAT), and abdomen anteroposterior (AP) examinations, respectively.

Table 2 specifically highlights the variations in chest ESAK parameters among hospitals. MH exhibited the highest average ESAK of 0.45 mGy compared to other hospitals. The observation indicated that MH used high kVp techniques and high mAs, resulting in a higher ESAK compared to DRLs (Muhogora et al. 2015, Makoba et al. 2024).

Table 2: Dose and parameters for chest

Hospitals	Dose and parameters for chest kVp	mAs	ESAK (mGy)	DRLs
AH	72	10	0.18	0.4
TH	90	12.5	0.30	0.4
MH	90	24	0.45	0.4
MMH	90	20	0.38	0.4
CCH	75	10	0.37	0.4
AMH	70	12	0.35	0.4

A comparison with previous studies on chest examinations revealed that this ESAK is 71% higher than earlier studies and 27% higher than the recent study in URT (Muhogora et al. 2012, Masoud et al. 2015). The lowest average ESAK for chest examinations in this study, at 0.18 mGy, was found at AH, exposing 28% more than previous studies (Muhogora et al. 2012, Masoud et al. 2015). The variation in ESAK dose between hospitals in this study can be attributed to differences in patient size, height, weight, thickness, and radiographic techniques.

Table 3 displays the ESAK parameters for lumbar spine anteroposterior (AP) examinations. The hospital employs uniform exposure techniques. A comparison of the results of this study with previous studies reveals a striking similarity (Gyan et al. 2020, Kaushik et al. 2021).

Table 3: Dose and parameters for AP Lumbar

	Dose parameters for AP Lumbar			
Hospitals	kVp	mAs	ESAK (mGy)	DRLs
AH	90	60	3.4	10
TH	92	60	2.5	10
MH	90	45	1.80	10
MMH	90	45	1.57	10
CCH	86	30	1.39	10
AMH	84	70	6.00	10

Table 4 represents ESAK parameters and doses for lateral lumbar examinations. The results range from 6.3 to 16.5mGy. The observations revealed that each x-ray unit had an exposure chart displaying radiological parameters (kVp and mAs) for each examination. The utilization of these parameters varied across hospitals, leading to some variations. The results showed a small difference between them, and the variation in kVp coefficients between hospitals was relatively narrow. Despite adherence to good radiographic practice, the study identified that a combination of high kVp and low kVp techniques was being used for examinations, resulting in wide variations in mAs and subsequently leading to substantial differences in patient ESAK among them. ESAK parameters and doses for lateral lumbar imaging. However, the results reveal significant variability in radiation doses between different hospitals. For example, the dose at AMH is approximately 15.5 mGy, which is substantially higher compared to MMH, where the dose is 6.3 mGy. This discrepancy underscores the need for standardization and optimization of imaging protocols across hospitals to ensure consistent and safe patient care, reducing unnecessary radiation exposure.

Table 4: Dose and parameters for lateral lumbar.

	Dose and parameters for lateral lumbar			
Hospitals	kVp	mAs	ESAK (mGy)	DRLs
AH	96	60	15	30
TH	96	60	16.5	30
MH	96	60	6.4	30
MMH	90	60	6.3	30
CCH	96	60	10.4	30
AMH	96	60	15.5	30

Table 5 presents the ESAK doses for lateral lumbar imaging, which range from 1.3 to 2.6 mGy, all within the recommended Diagnostic Reference Levels (DRLs). Despite minor variations in kVp and mAs settings, there is significant variation in radiation doses reported between hospitals. For instance : AH Hospital has the highest reported dose of 3.3 mGy, attributed to the use of higher kVp and mAs settings. AMH Hospital achieves the lowest dose of 1.3 mGy by utilizing the lowest imaging parameters. MH Hospital also reports a dose of 1.3 mGy, even though it employs a higher kVp compared to AMH Hospital. These discrepancies indicate that factors beyond kVp and mAs, such as equipment calibration, imaging protocols, and technique consistency, can significantly impact patient radiation doses.

Table 5: Dose with respective parameters used in abdomen imaging.

	Dose and parameters for Abdomen			
Hospitals	kVp	mAs	ESAK (mGy)	DRLs
AH	85	50	3.3	10
TH	80	35	2.6	10
MH	84	30	1.3	10
MMH	81	31	1.4	10
CCH	86	36	1.6	10
AMH	80	30	1.3	10

ESAK Analysis

The results for the X-ray facilities are presented for each X-ray room, encompassing a total of 300 ESAK calculations derived from exposure parameters and X-ray tube outputs recorded for each machine.

The average ESAK for abdomen, chest, lumbar spine anteroposterior (AP), and lateral examinations were recorded in Table 6. These findings indicate that the patient's dose is below the recommended levels of 10, 10, and 30 mGy, except for the chest, which has an average ESAK of 0.34 mGy.

Table 6: Average results of chest, AP lumbar, lateral lumbar and abdomen examinations.

	Dose and parametersfor chest			
Examinations	kVp	mAs	FFD (cm)	ESAK (mGy)
Chest PA/AP	80.3	15.1	150	0.34
Lumbar spine AP	88.7	60	100	2.78
Lumbar spine LAT	95.0	60	100	11.68
Abdomen AP	82.7	35	100	1.92

The results from this study underscore the importance of optimizing and justifying procedures to enhance good radiation practice at the facilities, aligning with recommandations from prior research (Suliman et al. 2020, Hussain et al.2022). Despite recording patient doses below the recommended levels, some examination facilities still perceive the patient's dose to be above Diagnostic Reference Levels (DRLs). For instance, MH hospital recorded a maximum patient dose of 0.45 mGy for chest examinations (Table 2).

This practice is not advisable, as it subjects patients to unnecessary radiation exposure. It is crucial to note that radiation exposure, in general, and the associated risks of ionizing radiation can have stochastic effects, where the probability of the effect increases with the dose, but the severity of the effect is independent of the dose received (including genetic risks in offspring or somatic effects like cancer).

Figure 1 illustrates the variations in ESAK across the hospitals. The patient dose results ranged from 0.18 to 0.45 mGy for chest posteroanterior (PA), 1.57 to 6 mGy for anteroposterior (AP) lumbar, 6.3 to 16.5 mGy for lateral lumbar, and from 1.3 to 3.3 mGy for AP abdomen.

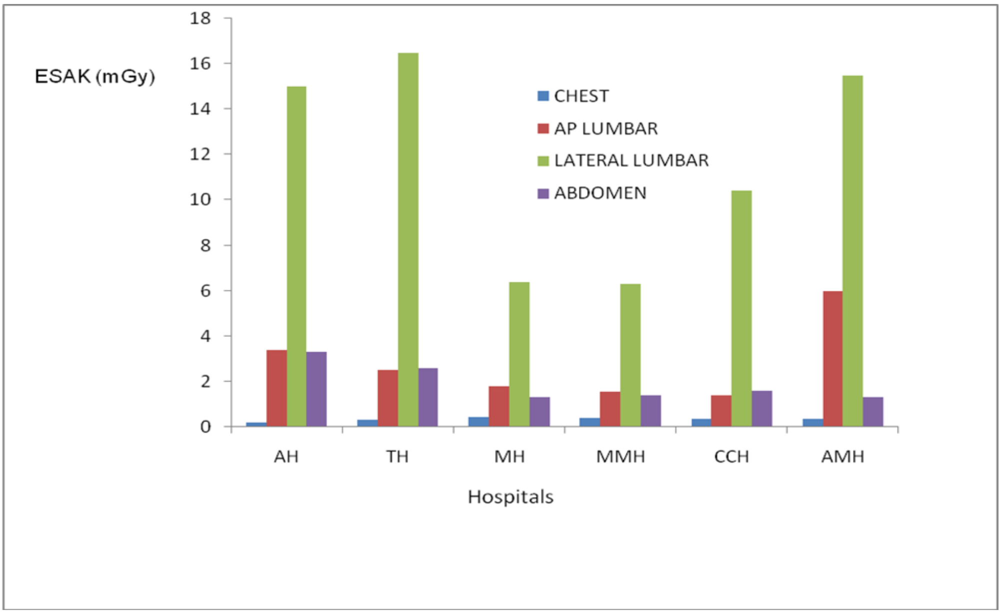

Figure 1: Comparison of ESAK dose for x-ray examinations

Previous studies (Metaxas et al. 2019, Sayed et al. 2023) indicated that ESAK values for all examinations were nearly the same, except for chest examinations. This suggests that the present results' values are relatively higher and necessitate constant monitoring of patient doses. Considering the best approach for selecting dose parameters could potentially lead to a reduction in dose factors by 3.5 (Makoba et al. 2024).

Inter comparisons of studies

The ESAK values for adults undergoing chest, lumbar anterior-posterior (AP), lumbar lateral (LAT), and abdominal imaging, associated with clinical indications such as pneumonia for chest, motor deficit for lumbar, and stomach pain for abdomen, were compared to prior literature sources (Sharma et al. 2015, Khoshdel-Navi et al. 2016, Makoba et al. 2024).

The ESAK of this study ranges are 0.18 to 0.45 mGy for chest, 1.39 to 6 mGy for lumbar AP, 6.3 to 15.5 mGy for lumbar LAT, and 1.3 to 3.3 mGy for the abdomen. A comparison is made between the international ESAK and the ESAK values from this study, as presented in Table 7. The study suggests that the ESAK values in this investigation are slightly higher for chest, while the values for the other mentioned examinations are slightly lower.

Table 7 compares the ESAK values from this study with previous literature and international diagnostic reference levels. For abdomen examinations, the ESAK dose is below those reported in the UK and Slovenia. The average ESAK dose for chest is higher compared to the UK, Slovenia, and Brazil, but lower compared to Iran.

Figure 2 illustrates the comparison of patient doses for chest, abdomen, AP lumbar, and lateral lumbar imaging between this study and other recent studies. The results indicate that there is a significant variation in patient doses, particularly in lateral lumbar imaging. This variation highlights the need for optimization of imaging parameters to reduce unnecessary patient exposure. Specifically, lateral lumbar imaging shows higher doses compared to other regions, suggesting that current practices may not be as efficient in minimizing radiation exposure. Therefore, optimizing the imaging parameters for lateral lumbar imaging is crucial to enhance patient safety and reduce the risk of radiation-induced harm.

Table 7: Comparison of Patients dose of this study to the previous studies

		Countries				
Type of examinations	This study	Brazil	Iran	Slovenia	UK	DRLs
Chest	0.18-0.45mGy	0.3	0.46	0.29	00.15	0.4
Lumbar spine AP	1.39-6mGy	5.2	2.66	5.40	-0	10
Lumbar spine LAT	6.3-15.5mGy	11.2	4.02	15.52	11.7	30
Abdomen AP	1.3-3.3 mGy	-	1.95	4.43	47	10

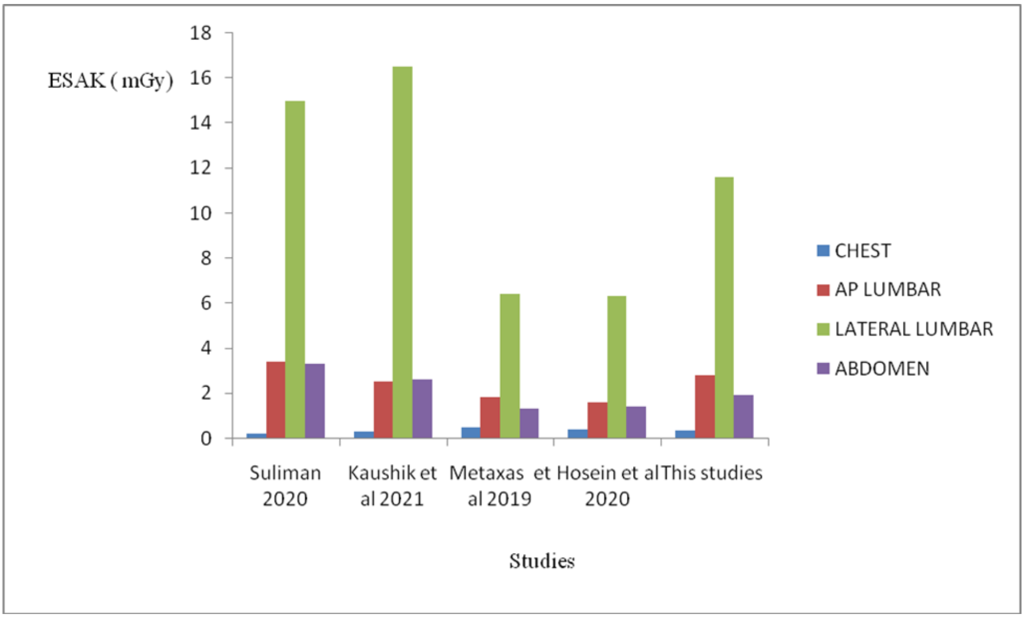

Figure 2: Comparison of ESAK Across Studies

Study limitations

This study recognizes specific constraints, notably the restricted sample size, which may not accurately reflect the actual size of the population. Furthermore, the study faced challenges in acquiring clinical indications from the doctors, thereby exacerbating limitations such as time cost and bias.

Conclusion and Recommendation

In this study, the ESAK values were derived from the technical exposure parameters of the patients and the measurements of X-ray tube output. The resulting ESAK values were compared to those reported in previous literature, revealing that they are lower than the associated DRLs but slightly higher compared to the ESAK values from those studies. The study underscores the significance of monitoring patient radiation doses in radiography to facilitate dose optimization. It contributes to both national and international initiatives for effective dose management in digital imaging. Therefore, Quality Control (QC) tests and careful selection of exposure parameters emerge as crucial factors for optimizing ESAK and justifying procedural protocol.

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