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Original Article

Compliance of Radiation Dose and Image Quality in a Nigerian Teaching Hospital with the European Guidelines for Pediatric Screen-Film Chest Radiography

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Abstract

Introduction
Over the years, the consequences of ionizing radiation have prompted major efforts towards producing radiographs of acceptable quality with dose values in compliance with safety standards and the ALARA principle. The aim of this study is to assess the compliance of radiation dose and image quality in a major Nigerian teaching hospital to the guidelines established by the Commission of European Communities (CEC) on optimized pediatric radiography.
Materials and Methods
The entrance skin dose (ESD) and image quality were studied among pediatric patients (age range: 0–15 years), referred to the hospital for chest radiographic examinations. Radiographic exposure factors were recorded in each examination. ESD was determined using a dose calculation software program (DoseCal®). The calculated ESD values were weighed against the CEC recommended doses and compared among different age groups through mean comparison. Based on the CEC image quality criteria, the resulting chest radiographs were assessed in terms of image quality.
Results
The overall image quality was high in over 70% of images (Fleiss' kappa=0.63). The obtained ESD values were higher than the recommended CEC values (80 and 100 µGy for children aged 0-1 and 5 years, respectively). Also, the ESD values were higher than the recommended values by 26% in the age group of 0–1 year and 9-10% in the other age groups. However, there was no significant difference between the age groups in terms of radiation dose.
Conclusion
The findings show that a considerable reduction in radiographic exposure factors (or doses) could still produce images with an acceptable diagnostic quality. This dose reduction could be achieved by reducing mAs, increasing kVp and adopting high-performance X-ray generators.

Keywords: Chest, Film, Image Quality, Pediatric, Radiation Dose, X-ray

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1. Introduction

The aim of quality control in diagnostic radiography is to specify or define acceptable levels for radiographic images in order to meet the expected clinical goals [1]. Overall, high-quality radiological practice is based on two dependent and fundamental factors, i.e., image quality and radiation dose.

Over the years, the consequences of ionizing radiation have prompted major efforts towards producing radiographs of acceptable quality with dose values in compliance with safety standards and the 'As Low As Reasonably Achievable (ALARA) principle [2]. In practice, the balance between image quality and the doses used in diagnostic examinations is of great significance [3-5]. This balance is even more important with respect to pediatric X-ray imaging.

At similar effective doses, late manifestations of detrimental radiation exposure are more likely in children, compared to adults [6]. The greater radiosensitivity in children, in addition to the prolonged opportunity for the presentation of induced malignancies, raises concerns about pediatric radiation doses and highlights the importance of minimizing radiation doses from medical sources in pediatric patients [7]. Overall, application of a proper radiographic technique is cost-effective and integral to quality improvement in diagnostic radiology. Moreover, the staff's experience and commitment are essential to delivering high-quality imaging services [8, 9].

By applying the image quality criteria proposed by the Commission of European Communities (CEC) [10] and the recommended entrance surface doses (ESDs) for children, we aimed to establish the level of adherence or compliance of a teaching hospital in Nigeria with international standards.

In previous studies, differences have been reported in adherence to the recommended guidelines for optimized practice [11]. The present study is of great significance considering the paucity of similar research on pediatric radiographic examinations in the region. In fact, the conducted studies have not considered radiation dose and image quality in pediatric patients but have mainly focused on adults [9, 12, 13]. Therefore, this study could set the grounds for radiation dose and image quality in optimized pediatric radiography in Nigeria.

2. Materials and Methods

A total of 104 children were examined with a combination of two single-phase two-pulse X-ray generators, i.e., a Philips Practix 300 (Philips Inc.) with a total tube filtration of 2.5 Al equivalent at 70 kV), and a TMX+ (GE Medical), with a total tube filtration of 2.7 mmAl equivalent at 70 kV. The performance characteristics (i.e., output, kVp and time reproducibility) of the tubes were determined, using a factory-calibrated Accu Pro 60cc radiation detector (Radcal Corporation, USA). Other X-ray generator parameters are presented in Table 1.

Radiographic examination parameters including tube potential (kVp), tube current (mAs), and focus-to-film distance (FFD) were recorded for each subject. ESDs were mathematically calculated, using DoseCal® software, developed by St. George's Hospital, London, UK. This software, used in radiation dose studies, has shown good agreement with thermoluminescent dosimeter (TLD) measurements [14-16]. The software required the determination of calibration data for the respective X-ray tubes and using the same as input, along with patient data including age, weight, and radiographic exposure factors for the respective examinations, to determine the entrance surface doses.

X-ray films (blue base) with calcium tungstate screens (standard film-screen cassette combination) were used in this study [17, 18]. The films were manually processed, based on the standard clinical darkroom protocols for maintaining the processing consistency and image quality. Considering the extended period of the study (six months), the tubes' performance was checked bi-monthly to ensure output consistency throughout the study.

Table 1. X-ray generator parameters

Generator type and characteristics		
Parameters	Philips Practix 300	TMX+
Generator type	Single phase two pulse	Single phase two pulse
Maximum kVp	125	125
Maximum mA	0.1-200 (mAs)	300
Total filtration	2.5 Al	2.7 Al
Nominal focal spot size	0.6/1.5	1.3
*AEC	Not used	Not used
**FFD	70 –200 cm	130 cm
Additional filtration	None	None

*AEC: Automatic exposure control, **FFD: Focus-to-film distance

Table 2 The image quality criteria by the Commission of European Communities (CEC) for pediatric chest imaging

Criteria codes (C) and the anatomical landmarks of interest on the radiographs
C1 Examination performed at peak inspiration except for the suspected foreign body aspiration
C2 Reproduction of the thorax without rotation or tilting
C3 Reproduction of the chest must extend from just above the apices of the lungs to T12/L2.
C4 Reproduction of vascular patterns in central 2/3 of the lungs
C5 Reproduction of the trachea and bronchi
C6 Visually sharp reproduction of the diaphragm and costophrenic angles
C7 Reproduction of spinal and paraspinal structures and visualization of the retrocardiac lung and mediastinum.

Since the current study was aimed at assessing the overall compliance in the hospital, the radiographs were not categorized with respect to the involved x-ray unit. All radiographs were pooled together, and the calculated ESDs were matched to the respective radiographs after image quality assessments. The radiographs were assessed independently in terms of image quality by three consultant radiologists. The average experience of the observers in the assessment of pediatric chest images was 12 years (range: 8 - 15 years).

2.1.Image assessment

The radiographs were assessed for image quality, based on the image assessment criteria set by CEC (Table 2) [10]. Each observer studied the radiographs while reviewing clinical films and recorded the scores in a chart prepared for this purpose. The observers worked in three different rooms and were not informed about the reports by other observers. The viewing boxes and ambient lighting conditions were checked for uniformity in the three reading rooms.

The observers rated the images from zero to one. A score of zero was given to a radiograph fulfilling less than five out of seven CEC criteria, while a score of one was given to radiographs meeting five to seven CEC criteria. The films in which pathologies or artefacts obscured relevant areas were excluded from the study, and the corresponding ESDs removed from the final computation.

It was not possible to get the observers' second opinion for determining intra-observer consistency, owing to the pressure to release the films for patient management. However, the inter-observer agreement was determined by calculating Fleiss' kappa coefficient among the three readers. The radiograph scores reported by the three observers were averaged to determine the overall image quality score for each radiograph.

Moreover, the scores (and standard deviations) related to each image criteria, reported by each observer, were calculated. The mean values were averaged over the observers to determine the overall score for each criterion, which could indicate the areas requiring attention in chest radiography at the department. Analysis of means was used to assess the differences in radiation doses between the age groups.

3. Results

The X-ray tubes had an average kVp reproducibility of < 6% [19]. The tube current and exposure time had a 10% variation. The average X-ray tube output for the two units varied between 5% and 7% throughout the study period. The average ambient room light was less than 50 lux, while the luminance values for the viewing boxes were greater than 2500 (with a ±3% variation between the boxes).

The overall image quality score was 0.76±0.4, based on the average score of each film, reported by the three observers (Figure 3). The inter-observer agreement yielded a kappa value of 0.63 (P <0.05). The mean ESD calculated for the pediatric chest radiographs was 107.6±16.3 µGy. Table 3 shows the results of radiation dose and image quality assessments in the respective age ranges. As the findings indicated, an insignificant reverse correlation was detected between image quality scores and ESD estimates (r=-0.11).

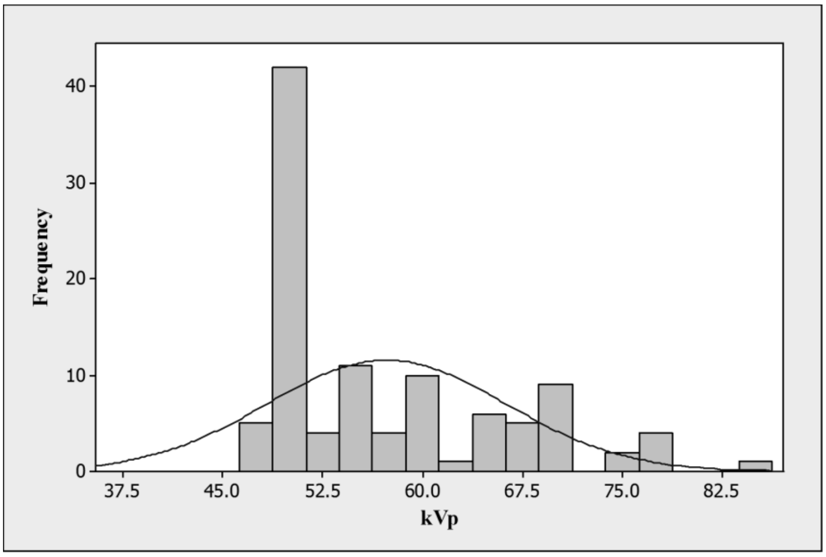

Figure1: Distribution of tube potentials (kVp) used in radiographic examinations of the subjects in the study.

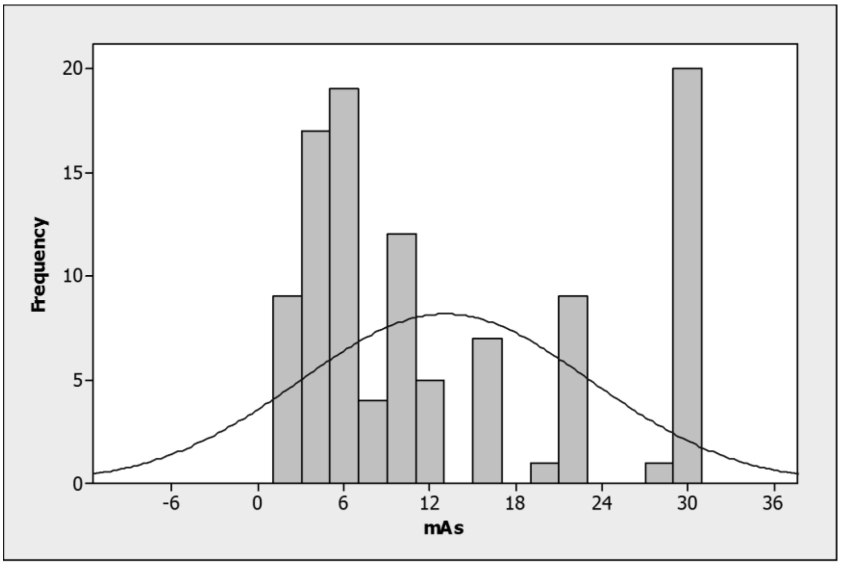

Figure 2. Distribution of tube currents (mAs) used in the radiographic examinations of the subjects in the study.

Table 3. Patient dose and image quality scores in different age groups

Age range (years)	Number of subjects	Mean IQS*	Mean ESD (µGy)	CEC**(µGy)
0 – 1	31	0.72±0.4	110.4±14.6	80
1 – 5	52	0.69±0.4	109.4±16.6	100
5 – 10	10	0.80±0.3	109.0±16.8	100
10 – 15	11	0.83±0.4	101.4±9.7	100

*IQS: Image quality score averaged over the three observers
**CEC: Recommended values by the Commission of European Communities (CEC)

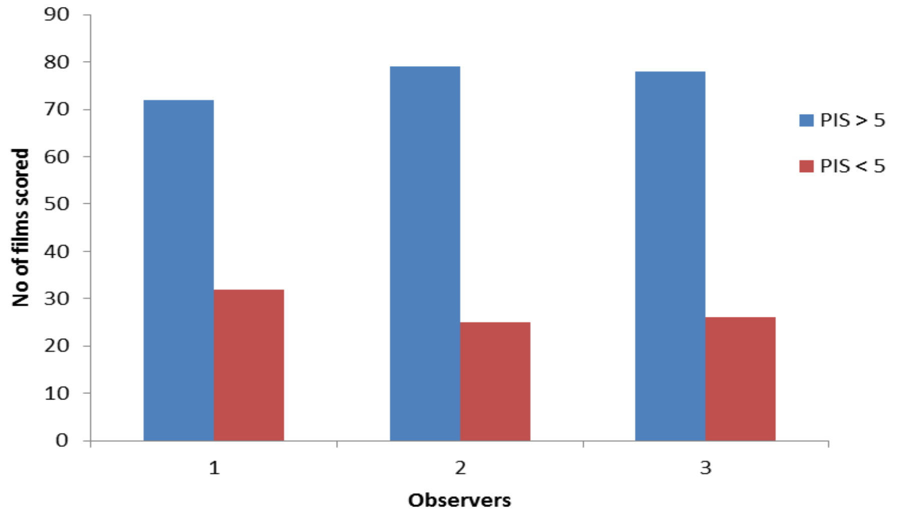

Figure 3. Number of films meeting the respective scores (0: < 5 criteria; 1: ≥ 5 criteria) by the respective observers. PIS = per image/radiograph score .

Figures 1 and 2 demonstrate the distribution of tube potentials and tube currents, applied in pediatric chest radiography at the hospital, respectively. Clearly, over 60% of the subjects were examined with tube potentials below 60 kVp. Up to 30% of the studied subjects might have received doses with the product of the tube currents and exposure times greater than 20 mAs. As reported by the observers, more than 70% of the radiographs met more than five of CEC criteria (Figure 3). Based on the assessment of each criterion, the first, second and fourth image criteria received the lowest ratings by the observers (Figure 4).

4. Discussion

In the present study, patient entrance doses and image quality were determined. The mean ESD was 107.6±16.3 µGy, and the average radiation doses for each age range were found to be higher than the values recommended by CEC for pediatric radiography (Table 2) [10].

The established CEC values for pediatric doses are specified at 80 µGy for the newborns and 100 µGy for a normal five year old child; a radiation dose of 100 µGy has been also reported in 10 and 15 year old subjects.

Previous studies have reported dose values of 76.3 [20], 298 [16] and 179 µGy [21], indicating variations in practice [11]. In this study, the average doses exceeded the recommended values by 26% and 9-10% in subjects within the age range of 0-1 year and other age groups, respectively. However, no significant difference was found in radiation doses between the respective age groups ($P > 0.05$).

The present results are in agreement with the doses measured in three tertiary hospitals in an earlier study in which similar high radiation doses were reported [9]. Such high doses expose children to a greater risk of cancer (as the cells actively divide) and induce genetic mutations in subsequent generations [6].

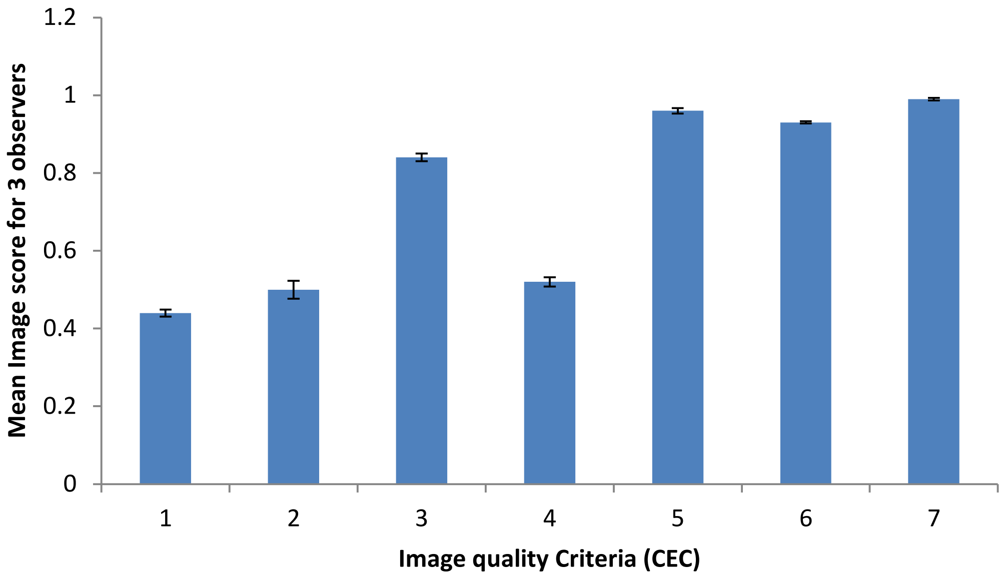

Figure 4. Image criteria scores averaged over the three observers (error bars represent SEM)

In the present study, the average exposure factors including the film-focus distance (FFD), tube potential, and tube current were 105.5±15.8 cm, 58.3±10 kVp and 17.9±12.9 mAs, respectively. The average kVp and FFD were equal to and below the recommended European guidelines (60 kVp and 100 - 130 cm), respectively. The applied kVp range may partly account for the observed high doses. In this study, the tube potentials were within the range of 48 - 70 kV.

Over 67% of the subjects (especially those aged 0-1 year) were examined with tube potentials lower than the minimum recommended value (60 kVp) (Figure 1). In fact, use of a high kVp technique would reduce the dose without affecting the image quality; this has been revealed in previous research [22].

The present study showed the compliance of FFD criteria with the guidelines, as most of the anteroposterior examinations were conducted at maximum tube column distance (130 cm). The tube current and exposure time controls were linked together in the two units. Consequently, the operator had restricted control over mA contribution to the results. However, mA values in the range of 4.8 - 30 were recorded in the study.

At least one third of the subjects in this study were examined with mAs > 20 (Figure 2). Although no guidelines for mAs are available in the CEC document, the applied range of mA may be related to the high radiation doses. Also, given the fact that the ~~used~~ X-ray machines were low-powered, the use of single-phase two-pulse units encumbered the selection of exposure times less than 10 ms. This may also account for the high radiation doses.

Similar results of previous studies on adult participants indicate the need for changes in protocols and regular quality control tests [9, 13, 23]. In the present study, the image quality at high doses was sufficient to suggest the possibility of significant dose reduction without causing any decline in image quality. This finding has been demonstrated in several studies [23 - 25]. In the present research, the inter-observer agreement was satisfactory (kappa = 0.63), and high image quality was reported in more than 70% of images. The low scores on the first, second, and fourth criteria may be indicative of the need for adopting immobilization devices, which would aid patient positioning.

Clearly, there are great challenges in the diagnostic examination of younger children. The poor Pearson's correlation value (r = 0.1) indicating the link between radiation dose and image quality in this study, suggests that the operators might not have followed the standards for the acquisition of pediatric images. This in fact, highlights the need for establishing quality control programs [26].

Considering the high radiosensitivity in children [6], standard protocols are required to optimize the process of pediatric radiography. One way to meet this requirement may be the use of dedicated X-ray imaging outlets for pediatric subjects, including high-frequency generators which deliver higher outputs and allow very short exposure times and lower doses unlike the current use of two-pulse units.

5. Conclusion

In this study, pediatric chest radiography delivered high-quality images with skin doses above the established European criteria. The findings showed that a decline in radiographic exposure factors (or doses) could still produce images with acceptable diagnostic quality.

This dose reduction could be achieved by reducing mAs, increasing kVp, and using high-performance X-ray generators.

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References

1. International Atomic Energy Agency (IAEA): Optimization of the radiological protection of patients undergoing radiography, fluoroscopy and Computerized Tomography.,IAEA, Vienna, Austria. 2004.
2. United Nation Scientific Committee on Effects of Atomic Radiation (UNSCEAR) Report (2000): Source and Effect of Ionizing Radiation vol.1. Report to the General Assembly, with scientific annexes; 2000.
3. Martin CJ, Sutton DG, Sharp PF. Balancing patient dose and image quality. Appl Radiat Isot. 1999 Jan;50(1):1-19.
4. Martin CJ. Optimisation in general radiography. Biomedical Imaging and Intervention Journal. 2007 Apr-Jun;3(2):e18.
5. Paolicchi F, Faggioni L, Bastiani L, Molinaro S, Puglioli M, Caramella D, et al. Optimizing the balance between radiation dose and image quality in pediatric head CT: findings before and after intensive radiologic staff training. AJR Am J Roentgenol. 2014 Jun;202(6):1309-15.
6. Don S. Radiosensitivity of children: potential for overexposure in CR and DR and magnitude of doses in ordinary radiographic examinations. Pediatr Radiol. 2004 Oct 1;34(3):S167-72
7. Lowe A, Finch A, Boniface D, Chaudhuri R, Shekhdar J. Diagnostic image quality of mobile neonatal chest X-rays and the radiation exposure incurred. Br J Radiol. 1999 Jan;72(853):55-61.
8. Cook JV, Kyriou JC, Pettet A, Fitzgerald MC, Shah K, Pablot SM. Key factors in the optimization of paediatric X-ray practice. Br J Radiol. 2001 Nov;74(887):1032-40.
9. Egbe NO, Inyang SO, Ibeagwa OB, Chiaghanam NO. Pediatric radiography entrance doses for some routine procedures in three hospitals within eastern Nigeria. J Med Phys. 2008 Jan;33(1):29-34.
10. European Union. European Commission. Directorate-General XII-Science R, Development. European guidelines on quality criteria for diagnostic radiographic images in paediatrics: Office for Official Publications of the European Communities; 1996.
11. Brennan PC, Johnston D. Irish X-ray departments demonstrate varying levels of adherence to European guidelines on good radiographic technique. Br J Radiol. 2002 Mar;75(891):243-8.
12. Ogundare FO, Ajibola CL, Balogun FA. Survey of radiological techniques and doses of children undergoing some common x-ray examinations in three hospitals in Nigeria. Med Phys. 2004 Mar;31(3):521-4.
13. Egbe NO, Inyang SO, Eduwem DU, Ama I. Doses and image quality for chest radiographs in three Nigerian hospitals. European Journal of Radiography. 2009 Mar 31;1(1):30-6.

14. Mohamadain KE, Azevedo AC, da Rosa LA, Guebel MR, Boechat MC. Dose measurements using thermoluminescent dosimeters and DoseCal software at two paediatric hospitals in Rio de Janeiro. Applied Radiation and isotopes. 2003 Jul 31;59(1):53-7.
15. Suliman II, Abbas N, Habbani FI. Entrance surface doses to patients undergoing selected diagnostic X-ray examinations in Sudan. Radiation Protection Dosimetry. 2007 Feb 1;123(2):209-14.
16. Osman H, Elzaki A, Elsamani M, Alzaeidi J, Sharif K, Elmorsy A. Assessment of Paediatric Radiation Dose from Routine X-ray Examination: A Hospital based study, Taif Pediatric Hospital. Scholars Journal of Applied Medical Sciences (SJAMS) 2013; 1(5): 511 – 5.
17. Sani KG, Jafari M, Rostampoor N. A Comparison of the effectiveness of Mammographic Film-Screen and Standard Film-Screen in the Detection of Small Bone Fractures. Iranian journal of medical sciences. 2011 Dec;36(4):306.
18. Carlton R, Adler A. Principles of radiographic imaging: an art and a science. Cengage Learning; 2012 Jan 13.
19. Test Procedures In: Assurance of Quality in the Diagnostic Imaging Department. 2nd Edition. British Institute of Radiology. London UK, 2001: 31-8.
20. Bahreyni Toossi MT, Malekzadeh M. Radiation dose to newborns in neonatal intensive care units. Iran J Radiol. 2012 Sep;9(3):145-9.
21. Gogos KA, Yakoumakis EN, Tsalafoutas IA, Makri TK. Radiation dose considerations in common paediatric X-ray examinations. Pediatric radiology. 2003 Apr 1;33(4):236-40.
22. Doherty P, O'leary D, Brennan PC. Do CEC guidelines under-utilise the full potential of increasing kVp as a dose-reducing tool?. European radiology. 2003 Aug 1;13(8):1992-9.
23. Egbe NO, Egong EA, Ekpo EU, Inah GB. A Reduction in Radiographic Exposure and Image Quality in Film Screen Postero-anterior Chest Radiography. Nigerian Journal of Medicine. 2012;21(1):21-4.
24. Hart D, Hillier MC. Doses to patients from radiographic and fluoroscopic X-ray imaging procedures in the UK-2005 review. Health Protection Agency, Radiation Protection Division; 2007.
25. Brennan PC, McDonnell S, O'Leary D. Increasing film-focus distance (FFD) reduces radiation dose for x-ray examinations. Radiation protection dosimetry. 2004 Feb 1;108(3):263-8.
26. Wambani JS, Onditi EG, Korir GK, Korir IK. Patient doses in general radiography examinations. The South African Radiographer. 2015 May 27;53(1):22-6.