Journal Africain d'Imagerie Médicale 2020, volume 12 (numéro 3) journalafricain.jaim@gmail.com

JAIM
ISSN 1810-4959
Journal Africain d'Imagerie Médicale

ARTICLE ORIGINAL / RESEARCH ARTICLE

Comparative evaluation of entrance surface doses for chest and lumbar spine x-rays in three radiology units in Yaounde, Cameroon

Évaluation comparative des Doses d'Entrées de Surface pour les radiographies du thorax et du rachis lombaire dans trois services de radiologie de Yaounde, Cameroun

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Keywords:
Chest X-ray, lumbar spine X-ray, Entrance Surface Dose (ESD), Diagnostic Reference Level (DRL).

***Mots*-clés :**
Radiographie du thorax, radiographie du rachis lombaire, Dose d'Entrée de Surface. (DES), Niveau de Reference Diagnostique (NRD).

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ABSTRACT

Objectives: The aim of this study was to evaluate the Entrance Surface Dose (ESD) in patients undergoing two routine most frequent diagnostic radiographic procedures (frontal Chest X-ray (CXR), frontal and lateral views of the lumbar spine X-rays (LSXR)) in three radiology units

Material and Methods: The ESD was determined by calculation using the Davis formula. The 3rd quartile of ESD were selected as Local Diagnostic Reference Level (LDRL) and compared to existing data for each specific examination.

Results: The result reveal LDRL ranging between 0.09 - 0.34 mGy, 2.8 – 7.79 mGy and 6.9 – 13.39 mGy respectively for frontal CXR, frontal LSXR and lateral LSXR. Important variability of the exposure parameters within and between radiologic units was noted. The LDRL in this study were lower than international recommendations for frontal CXR and frontal LSXR

Conclusion: The wide variability of exposure parameters highlights the contribution of radiographer in patient dose management. This study brings out the need of establishing national DRLs, heightening awareness of radiographers on the optimization of patient's doses during routine procedures

RÉSUMÉ

Objectifs : Le but de cette étude était d'évaluer la dose d'entrées de surface (DES) chez les patients subissant deux procédures radiographiques diagnostiques de routine les plus fréquentes : radiographie thoracique incidence de face, radiographie du rachis lombaire incidence de face et de profil dans trois services de radiologie

Matériel et méthodes : La DES était déterminée par calcul en utilisant la formule de Davis. Le 75e percentile de la DES était considéré comme Niveau de Reference Diagnostic Local (NRDL) et comparé aux données existantes

Résultats : Cette étude révèle des NRDL compris entre 0,09 - 0,34 mGy, 2,8 - 7,79 mGy et 6,9 - 13,39 mGy respectivement pour les radiographies du thorax, du rachis lombaire de face et de profil. Nous avons noté une importante variabilité des paramètres d'exposition pour les mêmes examens au sein et entre les unités radiologiques. Les NRDL dans cette étude étaient inférieurs

aux recommandations internationales pour les radiographies du thorax et du rachis lombaire de face
Conclusions : La grande variabilité des paramètres d'exposition met en évidence la contribution des techniciens de radiographies à la gestion des doses de radiations administrées aux patients. Cette étude ressort la nécessité d'établir des NRD nationaux et de sensibiliser les radiologues et techniciens de radiographie à l'optimisation des doses aux patients lors des procédures de routine

1. Background

Radiography is an important tool for diagnosis and its use has increased both in term of volume of request and spatial distribution of radiographic devices. The risk associated to the radiation exposure cannot be undermined and there is no safe dose of ionizing radiation. Thus, limitation of the potential risk of radiation in any procedure by the optimization of the doses is of fundamental importance [1]. Quantification of radiation exposure is a proper way to evaluate the dose. The entrance surface dose (ESD) and the dose area product (DAP) are easily accessible for diagnostic radiography by direct measurement or simple calculation.

Numerous national and regional surveys have revealed large dose variation in patient undergoing the same type of diagnostic radiographic procedures [2]. Diagnostic Reference Level (DRL) is the third quartile of the ESD and is expected not to be exceeded for standard procedure when good and normal practice is applied regarding diagnosis and technical performance [3]. The concept of diagnostic referral level was first proposed by the ICRP as recommendation in 1990, and further developed into Diagnostic Reference Level (DRL) in 1996 in the ICRP publication 73 [3]. The implementation of this publication was left to the national regulatory boards to set at local, national and regional levels based on dose distribution.

In Africa, studies have been published in some few countries, but no established guideline have yet been validated [5-18]. The practice of radiation safety in sub-Saharan Africa is preoccupant due to limited law and regulation existing in the domain. An assessment of knowledge, attitude and practice of radiology professionals done in 2013 in Yaounde, reveal that about 34.3% of professional in diagnostic radiology had a poor knowledge of principle of radiation safety [5].

Few studies on the evaluation of ESD have been done in Cameroon [6,7,18] and no validated national norms have yet been established in the country. To be able to establish DRLs at the national level, it appears necessary to provide enough and regular data on the practice of radiography from different radiology units around the country.

The objective of this study was to measure the Entrance surface dose (ESD) for frontal Chest X-ray (CXR), frontal and lateral views of the lumbar spine X-rays (LSXR) in three different radiology units and establish local Diagnostic Reference Level (LDRL) for these examinations.

2. Matériels et Méthodes

2.1 Design

We carried on a cross sectional descriptive study in three radiology units in Yaounde (the capital city of Cameroon). These included a public hospital (HCY = PuH), a para public hospital (*HGOPY* = PPH) and a private radiology unit (CARIM = PrH). The study was done during eleven months between august 2018 and June 2019. It included patients of 18 years and above received for one of the following examinations: frontal Chest X-ray (CXR), frontal and lateral views of the lumbar spine X-rays (LSXR). Patients were recruited on a consecutive non probabilistic mode in each of the three study sites.

2.2 Data of interest

Data collected included information on:

- the radiologic device used: the brand, the serial number, the dates of manufacturing and installation, filtration (total filtration); **Table I**
- patients: (age, gender, weight and height)
- exposure parameters: tube voltage (Kv), tube loading (mAs), Focus to Film distance (FFD), thickness of the region of Interest.

The Body Mass Index (BMI) was calculated using the weight and the height of the patient. The Focus to Skin distance (FSD) was obtained by subtracting from the FFD the thickness of the region of interest. The anatomical thickness of the region of interest was measured for the chest radiograph at the midline between the lower angle of the shoulder blade, for the lumbar radiograph at the midline 10 cm above the symphysis pubis both for the front and lateral views.

Table I : Characteristics of the X-ray machine used for examination

	PuH	PPH	PrH	
Type	Analogic	Digital	Computed Radiology	
Brand	SIEMENS® 576082	WANDONG® XSI-2	Primax International®	SHIMADZU®
Serial number			84H092	83702
Installation Year	2003	2013	2010	2007
Puissance		150kVp	150kVp	150kVp
Total filtration*	2,5mm	2 mm	1,5 mm	2,5mm
Fluoroscopy	No	No	No	Yes
Output (S)=µGy/mAs	18,09	47,501	48,97	35.35

* : equivalent Al/100 kV

Estimation of the output of the four radiological devices used for the study was done using the dosimeter PTW DIAVOLT®, at a voltage of 80Kv and 20mAs tube loading with Retro Diffusion Factor (RDF) of 1.35. This value of the RDF used (1.35), is the one recommended by the European commission and has also been used in many other studies [6,7,8,10].

The ESD was calculated using the Davis formulas stated below [8,17,19]

$$\mathbf{ESD = S \times Q \times (U/80)^2 \times (1/FSD)^2 \times B}$$

- **S**: standard output factor in (mGy/mAs) for the radiographic equipment used, measured under minimal scatter conditions at 1m from the tube focus at nominal voltage of 80 kV;
- **Q** or **mAs**: tube loading, product of tube current and exposure time;
- **U** or **kV** is the tube potential or tube voltage;
- **FSD**: Focus-to-Skin Distance;
- **B**: backscatter factor, equal to 1.35;
- **ESD:** Entrance Skin Dose expressed in mGy.

The characteristic of the X-ray machine used for examination are presented in table I

The 3rd quartile of the ESD measured was considered to be the Local Diagnostic Reference Level (LDRL)

2.3 Variables and Data analysis

Data entering was done with Microsoft Excel 2010. Statistical analysis was done with SPSS 20 and R version 3.2.4. Categorical variables were presented as frequencies and their proportions. Continuous variables were presented as means and standard deviation where appropriate, or as frequencies and percentages. $P < 0.05$ was considered significant. The test of Kendall tau was used to assess the influence of the BMI and the exposure parameters on the ESD. Local Polynomial Regression was used to adjust the ESD curve as a function of the BMI, the voltage, the courant, and the FFD at the 95% confidence interval of the various points of the curve.

2.4 Ethical consideration

A signed consent was obtained from all patients. Authorization and ethical clearance were gotten from the different Institutional Review Boards and Administrative authorizations from the different health structures.

3. Résultats.

Table II below shows the distribution of radiographs done in the different groups and per structure. A small number of radiographs were repeated in all the study sites, this was 1% (3/303), 3.8% (6/157), 1.9% (3/154) of respectively frontal chest radiograph (CXR), frontal lumbar spine X-ray (LSXR) and lateral LSXR.

Table II: Distribution of patient per structure and according to the type of examination done

	CXR (frontal)		LSXR (frontal)		LSXR (lateral)	
Radiology Unit	**n (%)**	**NI**	**n (%)**	**NI**	**n (%)**	**NI**
PrH	100 (33, 3)	101	50 (33,1)	50	50 (33,1)	52
PuH	100 (33, 3)	101	50 (33,1)	50	50 (33,1)	50
PPH	100 (33, 3)	101	51 (33, 8)	57	51 (33,8)	52
TOTAL	**300 (100)**	**303**	**151 (100)**	**157**	**151 (100)**	**154**

3.1 Demographic characteristic of the study population

Table III below presents the sociodemographic characteristics of the patients. For the chest radiograph, the same number of patients was recruited in each study center. A total of 451 patients were recruited, 276 (61.19%) were males and 175 (38.80%) were female patients, overall male to female ratio 1.5:1. The ages were ranging from 18 to 87 years for the chest and lumbar spine radiograph.

3.2 Technical parameters used for the radiograph

The **Table IV** below presents the technical parameters used for the different radiographs done.

3.3 Entrance Surface Doses (ESD)

As far as the chest x-ray were concerned, the lowest mean of ESD (0.08 mGy) was found in the public hospital (PuH). This value of ESD was 3.75 time smaller than the average value applied in the private and para public hospital. In the same line, the lowest 3rd quartile of ESD for the lumbar spine radiographs were 2.8 mGy and 6.9 mGy respectively for the frontal and the lateral views in the public hospital and the para public hospital, respectively. The highest 3rd quartile of ESD for the lumbar spine radiograph were found to be 2.78 times greater for the frontal view and 1.9 time for the lateral view of the lumbar spine radiograph than the lowest value for the same exams (**Table V**).

3.4 Influence of BMI and technical parameters on the ESD

A significant correlation was found between the tube voltage (Kv), the tube loading (mAs), the BMI, and the ESD for the chest and lumbar spine radiographs (see ***Table VI***).

Table III*: *Demographic characteristics* of *patients

		Gender		Age (years)	BMI (kg/m²)
	n	**Female n (%)**	**Male n (%)**	**Means ± SD (Range)**	**means ± SD (Range)**
For CXR					
PrH	100	54 (54)	46 (46)	41.9 ± 16 (18 – 85)	25.5 ± 5 (16 – 40)
PuH	100	64 (64)	36 (36)	47.6 ± 17.1 (20 – 85)	25.6 ± 3.5 (16 – 46)
PPH	100	52 (52)	48 (48)	34,1 ± 13.8 (18-87)	26.6 ± 5,5 (16 – 49)
Total	**300**	**170**	**130**		
For LSXR (frontal and Lateral view)					
PrH	50	32 (64)	18 (36)	47.3 ± 14 (22 – 80)	28.4 ± 5.9 (17 – 48)
PuH	50	36 (72)	14 (28)	53.5 ± 14.7 (21 – 77)	28 ± 5.3 (20 – 42)
PPH	51	38 (74.5)	13 (25.5)	49 ± 19.5 (18 – 86)	26.6 ± 5.7 (17 – 41)
Total	151	106	45		

Table IV: Technical parameters used for the chest and lumbar spine x-rays

		n	Tube tension (kV) Means ± SD (min - max)	Tube loading (mAs) Means ± SD (Range)	DFF (cm) Means ± SD (Range)
For CXR					
PrH		101	118 ± 2.5 (111- 125)	3.9 ±1.9 (2.5 - 14.4)	140 ± 1.4 (118 - 166)
PuH		101	101.4 ±5.2 (70 - 118)	4 ± 0.5 (3.2 - 5)	137 ± 1.0 (120 - 167)
PPH		101	100.2 ±1.2 (100 - 110)	5.2 ± 0.7 (4 - 8)	127 ± 0.4 (115 - 135)
For LSXR (frontal and Lateral view)					
PrH	*Front*	50	90.1 ±8,2 (70 - 120)	82.3 ±17.2 (50, 125)	70 ± 4 (60, 80)
	Lat	52	97 ± 8.3 (75 - 120)	103 ± 20 (63 - 160)	66 ± 4 (55 - 77)
PuH	Front	50	87.2 ±3.2 (79 - 96)	43.7 ± 10 (8 - 60)	76 ± 6 (60 - 86)
	Lat	50	92.6 ± 3.9 (90 - 102)	86.2 ± 13.3 (45 - 110)	62 ± 7 (40 - 87)
PPH	Front	57	80.3 ± 4.6 (70 - 91)	19.2 ± 8.6 (10 - 50)	75 ± 8 (53 - 100)
	Lat	52	87.4 ± 6.2 (70 - 100)	30 ± 11.4 (10 - 80)	67 ± 10 (30 - 70)

Table V: Entrance Surface Doses (ESD) for the chest and lumbar spine x-rays

				ESD (mGy)	
			n	**Means ± SD (range)**	**3rd quartile**
For CXR	**PrH**		101	0.30 ± 0.12 (0.13 – 0.84)	0.34
	PuH		101	0.08 ± 0.02 (0.02 – 0.17)	0.09
	PPH		101	0.3 ± 0.06 (0.2 – 0.6)	0,34
For LSXR	**PrH**	Frontal	50	6.19 ± 2.46 (2.33 – 15.08)	7.79
		Lateral	52	11.87 ± 6.33 (3,45 – 34.55)	13.39
	PuH	Frontal	50	2.3 ± 0.8 (1 – 4.6)	2.8
		Lateral	50	7.9 ± 3.5 (3.2 – 23.3)	9.7
	PPH	Frontal	57	2.5 ± 2 (0.7 – 11.8)	3.1
		Lateral	52	6.4 ± 6.1 (0.9 – 36)	6.9

***Table VI*: correlation test of Kendall between the ESD and BMI, Voltage, Courant and DFP for different examinations**

	Voltage (Kv)	**mAs**	**BMI**	**FFD**
Chest radiograph				
Tau of Kendall	0,45	$0{,}2^{3}$	0,13	-0,47
p-values	$2x10^{-16}$	$5{,}8x10^{-6}$	0,001	$2x10^{-16}$
Lumbar spine radiograph (frontat view)				
Tau of Kendall	0,4	0,45	0,25	-0,33
p-values	$1{,}3x10^{-11}$	$2x10^{-16}$	$2{,}5x10^{-6}$	$4{,}6x10^{-9}$
Lumbar spine radiograph (lateral view)				
Tau of Kendall	0,6	0,67	0,28	-0,31
p-values	$2x10^{-16}$	$2x10^{-16}$	$2{,}8x10^{-7}$	$3{,}2x10^{-8}$

The figures below present the scatterplots of Kendall Tau trend based on the tube voltage, the mAs, the DFF, BMI and the ESD for the chest radiograph (***figure 1***), the front view of the lumbar spine radiograph (***figure 2***), the lateral view of the lumbar spine radiograph ***(figure 3)***

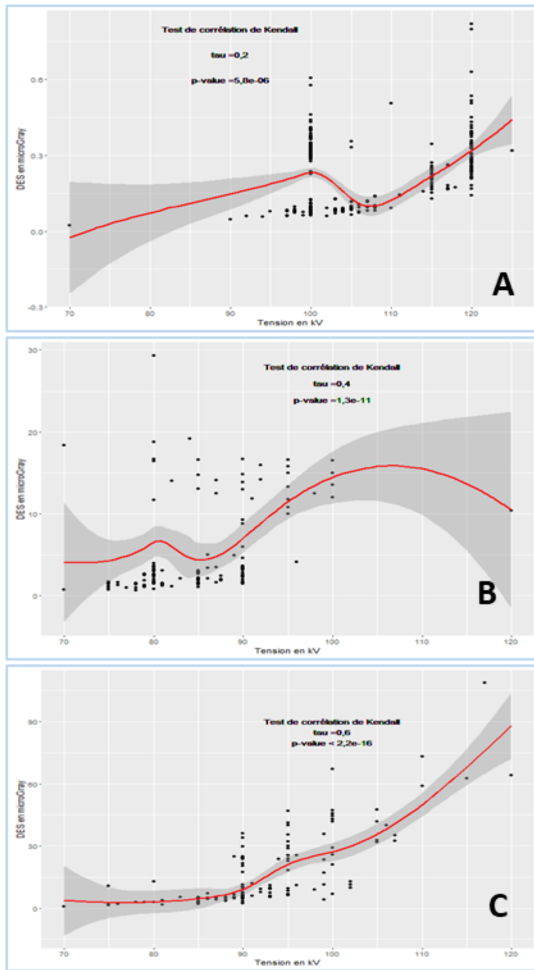

Figure 1: Scatterplots of Kendall Tau trends based on the tube voltage (Kv) and the ESD for (A) the chest radiograph, (B) the front view of the lumbar spine, (C) lateral view of the lumbar spine radiograph

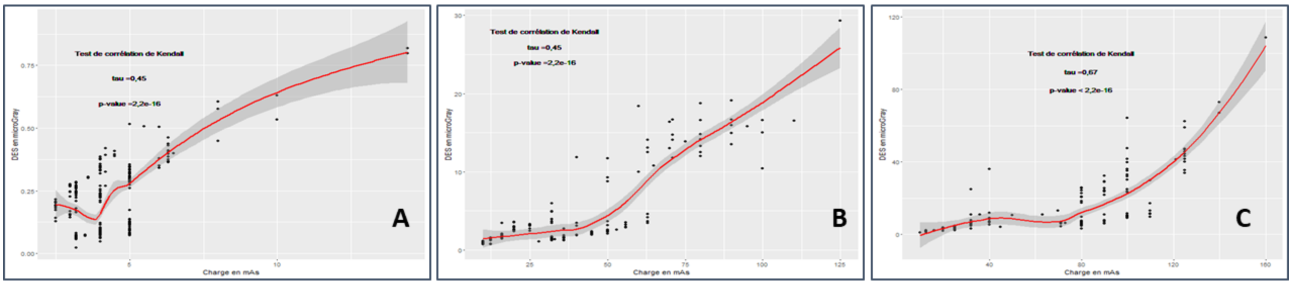

Figure 2: Scatterplots of Kendall Tau trends based on the tube loading (mAs) and the ESD for (A) the chest radiograph, (B) the front view of the lumbar spine, (C) lateral view of the lumbar spine radiograph

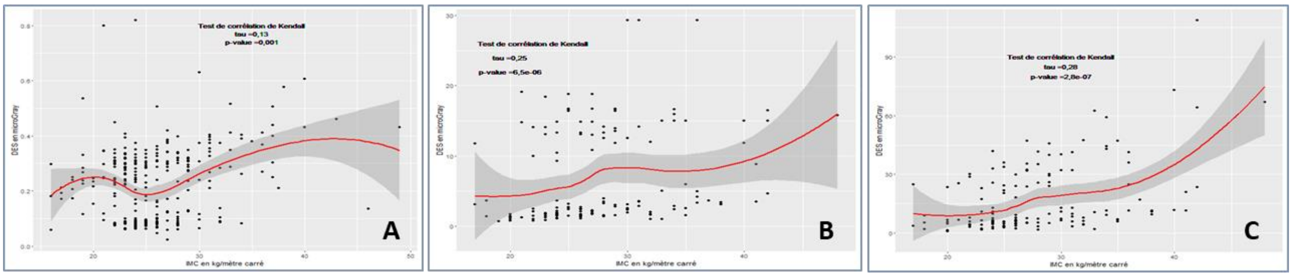

Figure 3: Scatterplots of Kendall Tau trends based on the BMI and the ESD for (A) the chest radiograph, (B) the front view of the lumbar spine and (C) lateral view of the lumbar spine radiograph

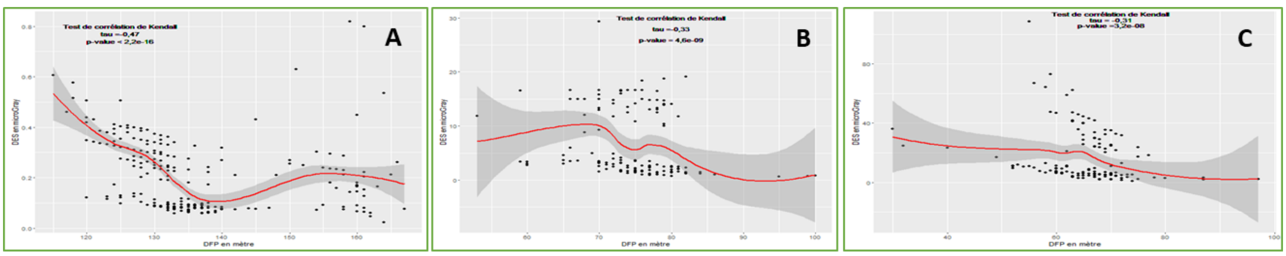

Figure 4: Scatterplots of Kendall Tau trends based on FFD and the ESD for (A) the chest radiograph, (B) the front view of the lumbar spine, (C) lateral view of the lumbar spine radiograph.

4. Discussion

The aim of this study was to estimate the exposure dose in adult patients of 18 years and above undergoing chest radiograph and lumbar spine radiographs. The European Commission directives required that this evaluation should be done periodically for frequently requested radiographic procedures either on standard phantom or groups of patients with standard specification [1]. The guideline of the European Commission required the *selection* of at least 30 patients for elaboration of Diagnostic Reference Level (DRL) [20]. The sample sizes for the chest and lumbar radiographs were above normal requirement, although smaller than the one of Samba et al in Cameroon [7] and Mohamadain et al in Sudan [8].

The four radiographic devices used in this study were of different types, both numeric and analogic, with a duration in use ranging between 5 and 15 years. The corresponding output of the DR and the two CR devices were found normal, ranging between 25 to 80 µGy/mAs as recommended by the International Atomic Energy Agency (IAEA) [22]. The output values of the analogic device of the public hospital was 18.09 µGy/mAs, far below the acceptable value. Two out of the four devices used presented a filtration below standard of at least 2.5 mm Al at 80 Kv as recommended by the IAEA [22].

We noticed an extreme variability of the exposure factors for the same examination within the same structure and between different structures. This variability has also been described by other studies [1,5,7]. The tube voltage used in the three sites and the FFD for the chest radiograph were far below the recommendation. The recommended values being 125 Kv for the tube voltage and 180 cm of FFD [23]. For the lumbar spine, the FFD was far below the European commission's guidelines ranging from 100 to 150 mm [23]. We noticed important variability of the tube loading ranging from 10 to 125mAs for the front view and 10 to 160 mAs for the lateral view. Similar variability of the tube loading has also been described in other studies [1,2,12,14]. Mohamadain et al in Sudan [8] and Olowookere et al in Nigeria [15] described more lower tube voltages and tube loading for chest radiographs and lumbar spine radiographs than one applied in the private hospital in our study, but higher than the one describes in the public and para public hospital.

As described for the exposure parameters, there is an important variation of the ESD in this study, both within and between structures, similar variation has been found in other studies [1,2,12,14]. The total filtration below standard and abnormal exposure parameter can explain the high ESD and its variability. After analysis of the 3rd quartile of the ESD, we found that the doses obtained from the analogic devices of the public hospital for the chest and front view of the lumbar spine radiograph were lower than the one obtained in similar studies and to recommendation of the European commission [22]. These findings are questionable considering that the output of that device was far below the acceptable standard [22]. When considering the 3rd quartile of the device having acceptable output, the one of the private hospitals with Computed radiography was far above the standard of the National Radiation Protection Board in United Kingdom, the European commission, and similar studies [22,25,26,27]. This can be explained by the used of high tube current (mAs) and fluoroscopy for localization of the beam on the area of interest in that structure. Similar findings were made by Freitas et al in Brazil in 2009 who noticed that the used of fluoroscopy was associated to increase ESD [26].

Analysis of the ESD and the Exposure factors used in different sites of this study, prove that in many cases the recommendations of good practices where not respected concerning the tube voltage (KVp) the tube loading (mAs) and the FFD [4]. The ESD of the analogic device in the public hospital were found lower than the one of the DR and CR device except for the lateral view of the lumbar spine. Similar results have also been described in other studies [29, 30]. This differ from the commonly known rule stating that the ESD and the Exposure parameters increase progressively depending on the type of device being DR, CR or analogic [31]; and therefore, suggest that the radiographic technic is an essential determinant of exposure no matter the type of radiologic device.

Analysis of the figure 1 to 4 reveal the complex relation between the exposure factors, the BMI and the variation of the ESD. This come to emphasize on the need of respecting the recommended values of exposure parameters during examination, to expect achieve a noticeable drop in the patient's radiation exposure. To enable consistent reduction of dose by reduction of the tube loading (mAs), it appears necessary to use the highest peak kilovoltage possible that can result to acceptable image [29]. Dilger et al describe for example a peak kilovoltage of 85 to 90 KVp as an average in adult for the lumbar spine radiograph to ensure a consistent reduction of dose without alteration of image quality [31]. On figure 4, the ESD reduce with the increase of FFD. This can be explained by the inverse square law that state that the dose at any location is inversely proportional to the square of the distance to the tube [29]. Similar findings have been made by other authors revealing that an increase of FFD from 100 cm to 130 cm can lead to a reduction of up to 35,24 % of exposure dose [32,33].

5. Conclusion

This study reveals that the ESD for the chest radiograph and the front view lumbar spine radiograph remain high, although lower than the recommendation of the European commission and the International Radiation Safety Agency. The value of the LDRL of the lateral view of the spine radiograph remain higher than recommendations.
Technical limits of the radiologic devices (filtration) and the non-respect of recommendation concerning tube voltage (Kv), the tube loadings (mAs) and FFD could explain the high exposure dose. It therefore appears necessary to put an emphasis on training the radiographer on the use of optimal radiographic exposure parameters, and the importance of DRL on limiting radiation exposure to the patient.

Conflict of interest:

We, the authors, declare not having any competing interest

Acknowledgment:

The authors would like to thank the staff of the different radiology units involved for their help in data collection (Central hospital Yaounde, CARIM and the gynecological and pediatric hospital Yaounde)

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