Densitometric Estimation of Radiation Absorbed Dose to Patients Undergoing X-Ray Examination in Five Government Owned Hospitals in Nigeria.

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ABSTRACT

The radiation dose received by patients from medical X-ray examinations in Nigeria has shown large variations within and among diagnostic centers for similar examinations. As it is required by the Conference of Radiation Control Program Directors (CRCPD), it was suggested that a standard for Quality Assurance (QA) and Quality Control (QC) within facilities using X-ray radiation-producing machines for medical diagnosis should be met. In this study the absorbed X-ray dose received by patients for six different body examinations like skull (SK), chest (CH), spine (SP), pelvis (PEL), upper limb (UL) and lower limb (LL) were examined using densitometric technique.

A total of five hundred and thirty three (533) adult radiographic X-ray films collected from five government-owned hospitals in South–West Nigeria were used in this study. The hospitals where this study was carried out are: Hospital A in Ondo State: Hospital B in Oyo state: Hospitals C and D in Osun State, and University of Benin Teaching Hospital (UBTH), Benin City, Edo State. This work is to estimate the absorbed dose X in centi gray (cGy) that each patient has absorbed during the course of an X-ray examination. Optical density (D) of each of the radiographic X-ray films was measured with the aid of a densitometer; model MA 5336, with range 0 to 4.0 optical density an accuracy of ±0.02. density and reproducibility ±0.01 density.

Each optical density, D measurement was carried out at five different spots (D_1 to D_5) on the radiographic X-ray film with the densitometer reset after each measurement. A mean optical density (MOD) was obtained for each measurement and converted to absorbed dose via an established mathematical relation. The average absorbed dose for hospital A was 4.20 ± 1.21 cGy, B was 3.29 ± 0.66 cGy, C was 3.30 ± 0.88 cGy, D was 4.33 ± 0.63 cGy, and UBTH was 4.25 ± 1.90 cGy. The various absorbed doses were compared with the excess dose of 0.10 Gy recommended by International Commission on Radiological Protection (ICRP), which is considered injurious or harmful to the human body. About 2.61% of the total X-ray radiographic film was found to be above the excess dose.

(Keywords: absorbed dose, radiation, exposure, exposed, optical density, radiographic film, health physics, ionizing radiation)

INTRODUCTION

Medical exposure of man to ionizing radiation arises from practices such as diagnostic, therapeutic and nuclear medicine procedures. Consequently, the patients, medical radiation specialists and the general population receive significant exposure to ionizing radiation, from artificial or man–made radiation sources, contributes the largest component of radiation dose to general population (Akinlade et al., 2016).

Film densitometer was employed in the process of optical density measurement and it is an accurate dosimetry system peripheral device for the measurement of optical density information, captured on a standard size X-ray film exposed to ionizing radiation. As light source, the system utilizes special highly efficient light emitting diodes and color compensated solid state detectors in a balanced ratio metric circuit, making the device insensitive to ambient light. The light source/detector assembly is driven in finite incremental steps and a resolution over the entire scanning area to ensure precise positioning with a high degree of repeatability (Scarlat et al., 2008). This paper presents the optical density notion, the method of the absorbed dose determination by means of the dosimetric film irradiation and the results of dosimetric measurements performed.

The film densitometer is a simple to use peripheral device for the measurement of the blackening density film exposed to ionizing radiation. Since X-ray image on the film is a black and white image with various blackening densities, the densitometer accepts standard X-ray films (Gammex, 2016).

The film is of a rectangle shape and it is supported on a stationary film table unobstructed by the scanning head. The light source/detector assembly is driven in finite incremental steps with a high degree of repeatability.

It is true that radiographers are extremely careful when exposing their patients to X-ray diagnostic tests where radiation is involved. There is the need to take note of causative effect of excess dose, for example nausea and vomiting, diarrhea, headache, fever, dizziness, disorientation, weakness/fatigue, hair loss, bloody vomit and stools, poor wound healing, and low blood pressure (Mayo Clinic, 2016).

The aim of this work is to estimate the amount of X-ray dose absorbed to patients undergoing X-ray examination, using radiographic X-ray films and densitometer, at selected hospitals in South-West zone of Nigeria and it is intended to provide users of X-ray equipment one means of achieving compliance with the International Commission on Radiological Protection (ICRP), rule, ICRP (2000). Samples of radiographic X-ray films were collected from five government owned hospitals in the South-West zone of Nigeria for the study. The hospitals are:

1. Hospital A, in Ondo State.
2. Hospital B, in Oyo State.
3. Hospital C, in Osun State.
4. Hospital D, in Osun State.
5. University of Benin Teaching Hospital (UBTH), Benin City, Edo State

MATERIALS AND METHODS

Samples of adult X-ray radiographic films were collected from four different hospitals across the South - West zone of Nigeria. The X-ray radiographic films were divided into six different examinations as follows:

1. Skull
2. Chest
3. Spine
4. Pelvis
5. Upper Limb
6. Lower Limb

The following abbreviations were adopted for the purpose of this study:

Absorbed X-ray dose: X
Net optical density: NOD
Mean optical density: MOD
Optical density: D
Skull: SK
Chest: CH
Spine: SP
Pelvis: PEL
Upper Limb: UL
Lower Limb: LL

Table 1 presents the summary of the quantities of the X-ray films for the various examinations. Table 2 presents the features of the film densitometer.

Table 1: Summary of the Quantities of the X-Ray Films for the Various Body Examinations in the Five Hospitals.

Hospitals	SK	CH	SP	PEL	UL	LL	Total
A	10	54	26	17	20	26	153
B	25	47	21	24	22	06	145
C	05	22	04	14	11	12	68
D	31	32	46	21	-	25	155
UBTH	02	02	02	02	02	02	12
Total	73	157	99	78	55	71	533

Table 2: Features of the Densitometer.

Model	MA 5336 (made in USA by Gammex)
Range	0 to 4.0 optical density
Accuracy	± 0.02 density
Reproducibility	± 0.01 density
Warm up time	none
Measuring area	2mm diameter and 1mm diameter
Power supply	Four rechargeable AA NiCad batteries, 4.8V total rated at 600mAh (included)
Battery charger	SE 30 – 45 (115 VAC) or SE – 30 (230 VAC) 50 to 60 Hz
Charge time	Approximately 14 hours
Size	5.08 X 7.46 X 17.8 cm (2 X 2.9 X 7 in)
Weight	0.7 Kg (1.5 lbs.)

The optical density (D), of the radiographic films was measured with a densitometer. This was done for the various radiographic films. Optical density (D) is the degree of blackening of the radiographic film image, as a result of the X-ray energy deposited on the film. It is a dimensionless quantity. The radiographic film is the image-receptor, where the image of the X-rayed object is formed. The final image of the object can be developed for further use by the radiographer or radiologist.

Note that there are different types of radiographic film manufacturers, but they all achieve the same purpose of X-ray radiography. The excess dose, ICRP (2000), of the X-ray radiation examination was considered, as the optical densities of the radiographic X-ray films were been measured. When measuring the dose absorbed in a human due to X-ray exposure, unit of absorbed dose is used, this is the centi gray (cGy), in the SI system of units (Love,1979).

The optical densities of each of the X-ray radiographic films, was measured repeatedly five times at different spots on each film as optical densities D1, D2, D3, D4 and D5. The average of the five optical densities was then taken to obtain the mean optical densities (MOD). The optical densities were converted to the absorbed X-ray radiation doses X, in centi gray (cGy), which is the amount of X-ray radiation dose that each patient was exposed to. The various standard deviation (SD) was also calculated for each mean optical densities (MOD) of the radiographic film.

The blackening of the film after X-ray radiation exposure is expressed in terms of its optical density as (Artur , 2003):

$$D = \log_{10}\left(\frac{I_o}{I}\right) \quad \textbf{(1)}$$

Where I_o and I is the light intensities before and after passing the exposed film material.

Optical density is a numerical value indicating the degree of blackening on an X-ray radiographic film.

The correlation between the optical density D and the maximum number of sensitized grains results in a relation between the optical density D and the absorbed dose X. Thus:

$$D = D\text{max}\left[1 - e^{-kX}\right] \quad \textbf{(2)}$$

where, $D_{max} = 4$

$k = 9.36$ (Artur, 2003)

Therefore, Equation (2) for the measured optical density becomes:

$$D = 4\left[1 - e^{-9.36X}\right] \quad \textbf{(3)}$$

Solving Equation (3) for the absorbed X-ray radiation dose X, gives:

$$X = \left(-\frac{1}{9.36}\right)\log_e\left(1 - \frac{D_{MOD}}{4}\right) \quad \textbf{(4)}$$

Equation (4), was used to convert the measured optical densities of each radiographic film to absorbed X-ray radiation dose, in centi gray (cGy).

The standard deviation (SD), σ, of each of the measured optical densities (D) was calculated from the relation:

$$\sigma = \sqrt{\left(\frac{1}{N}\sum_{i=1}^{N}(D_i - D_{MOD})\right)^2} \qquad \textbf{(5)}$$

where:

N: is the total number of times the optical densities were measured per radiographic film

D: is the optical density

D_{mod}: is the mean optical density (MOD) of the radiographic film

RESULTS AND DISCUSSION

The results obtained in this study are presented in Tables 3 and 4 for the different X-ray examinations at the five hospitals.

Table 3 show the values of the maximum and minimum of X-ray dose for the different body examinations. Table 4 show the values of the average X-ray dose for the body examinations. Table 5 show the percentage dose levels for the X-ray examinations at the four hospitals.

Table 3: Maximum and Minimum X-Ray Dose (cGy) for the Different Body Examinations in the Five Hospitals.

HOSPITAL	SK	CH	SP	PEL	UL	LL
A **Max**	3.96	11.11	7.53	9.20	9.88	11.39
Min	1.03	0.83	1.78	2.36	2.13	1.69
B **Max**	6.90	7.73	8.61	6.61	6.40	5.32
Min	0.68	0.67	1.67	1.03	1.31	1.35
C **Max**	2.72	5.62	5.40	4.89	8.16	8.19
Min	1.56	1.13	2.83	1.15	1.07	1.41
D **Max**	9.54	8.77	16.23	9.07		8.12
Min	1.37	0.90	0.90	1.25	-	1.57
UBTH **Max**	7.36	5.65	5.73	4.94	4.72	6.03
Min	3.45	3.47	1.74	2.23	4.65	1.05

(**Note**: **Max** is Maximum X-ray radiation dose; **Min** is Minimum X-ray radiation dose)

Table 4: Average X-Ray Dose (cGy) for the Different Body Examinations in the Five Hospitals.

HOSPITAL	SK	CH	SP	PEL	UL	LL
A	2.18 ± 0.78	4.04 ± 2.06	3.51 ± 1.52	5.15 ± 2.22	0.0514 ± 0.67	0.0519 ± 0.73
B	2.29 ± 1.25	2.77 ± 1.45	3.94 ± 1.75	3.18 ± 1.67	0.0367 ± 0.62	0.0386 ± 0.86
C	1.92 ± 0.47	3.01 ± 1.33	3.94 ± 1.11	2.82 ± 1.32	0.0426 ± 0.63	0.0386 ± 0.46
D	4.09 ± 1.82	4.22 ± 1.98	3.45 ± 2.34	4.94 ± 2.70	-	0.0495 ± 0.52
UBTH	5.40 ± 0.29	4.56 ± 0.79	3.73 ± 0.23	3.59 ± 0.21	0.0468 ± 0.38	0.0354 ± 0.31

Table 5: Percentage Dose Levels for the Various Hospitals.

HOSPITALS	No of Available films	No of films	% Below Excess Dose	No of films	% Above Excess Dose
A	153	150	98.04 %	03	1.96 %
B	145	145	00 %	00	00 %
C	68	68	00 %	00	00 %
D	155	154	99.35 %	01	0.65 %
UBTH	12	12	100 %	-	00 %
Total = 533		Total no of films below Excess Dose = 517		Total no of films above Excess Dose = 04 Total % above Excess Does = 2.61%	

Table 3 show the values of the maximum and minimum estimated absorbed X-ray radiation doses of the examinations for each of the five hospitals, which represents the ranges of the estimated absorbed X-ray doses.

The value of the absorbed X-ray radiation doses, X (cGy), represents the amount of the dose, that each of the patients was exposed to during their X-ray examination from the different hospitals. The values of the absorbed X-ray radiation doses, X (cGy), vary from one hospital to the other for each different body examinations.

Table 4 shows the average values of the estimated absorbed doses for each X-ray examinations at the different five hospitals.

Table 5 shows the percentage dose levels of the absorbed X-ray doses across the five hospitals as compared to the excess dose. Some percentages of the estimated absorbed dose were found to be above 2.61% of the total X-ray film, while the remaining samples of x-ray radiographic films were below the excess dose.

The characteristic curve of the measured optical density and the estimated absorbed X-ray radiation dose for hospital A are shown in Figures 1 – 6.

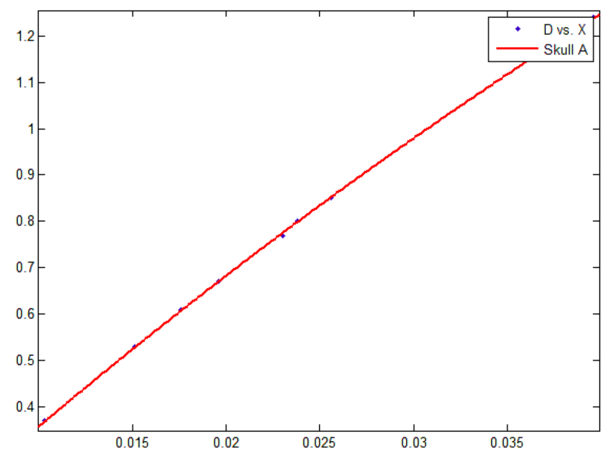

Figure 1(a)

```
General model:
       f(x) = Dmax*(1-exp(-k*x))
Coefficients (with 95% confidence bounds):
       Dmax =       3.974  (3.743, 4.206)
       k =        9.43   (8.808, 10.05)

Goodness of fit:
  SSE: 5.113e-005
  R-square: 0.9999
  Adjusted R-square: 0.9999
  RMSE: 0.002528
```

Figure 1 (b)

Figure 1: (a) D vs X for Skull at hospital A
(b) Result of the fit

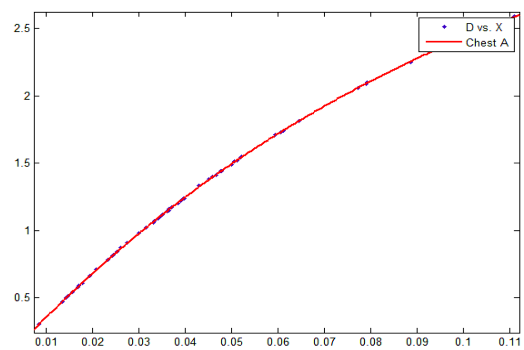

Figure 2 (a)

```
General model:
       f(x) = Dmax*(1-exp(-k*x))
Coefficients (with 95% confidence bounds):
       Dmax =       4.012  (3.988, 4.035)
       k =          9.32   (9.25, 9.39)

Goodness of fit:
  SSE: 0.0005276
  R-square: 1
  Adjusted R-square: 1
  RMSE: 0.003185
```

Figure 2 (b)

Figure 2: (a) D vs X for Chest at Hospital A
(b) Result of the Fit

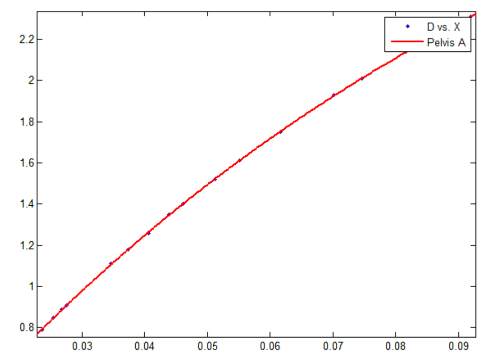

Figure 4 (a)

```
General model:
       f(x) = Dmax*(1-exp(-k*x))
Coefficients (with 95% confidence bounds):
       Dmax =       4.018  (3.984, 4.053)
       k =          9.301  (9.193, 9.41)

Goodness of fit:
  SSE: 0.0001101
  R-square: 1
  Adjusted R-square: 1
  RMSE: 0.002709
```

Figure 4 (b)

Figure 4: (a) D vs X for Pelvis at Hospital A
(b) Result of the Fit

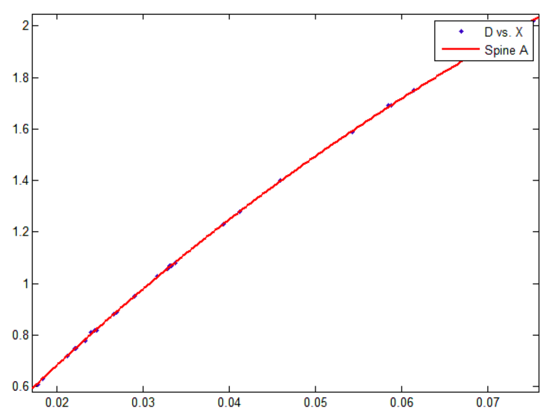

Figure 3 (a)

```
General model:
       f(x) = Dmax*(1-exp(-k*x))
Coefficients (with 95% confidence bounds):
       Dmax =       3.991  (3.943, 4.039)
       k =          9.382  (9.242, 9.523)

Goodness of fit:
  SSE: 0.0002064
  R-square: 0.9999
  Adjusted R-square: 0.9999
  RMSE: 0.002933
```

Figure 3 (b).

Figure 3: (a). D vs X for Spine at Hospital A
(b). Result of the Fit

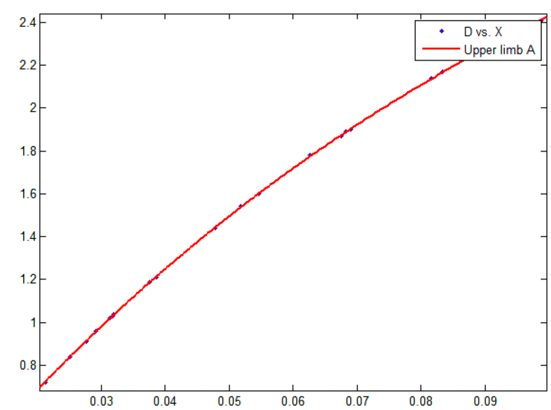

Figure 5 (a)

```
General model:
       f(x) = Dmax*(1-exp(-k*x))
Coefficients (with 95% confidence bounds):
       Dmax =       3.998  (3.961, 4.035)
       k =          9.367  (9.249, 9.485)

Goodness of fit:
  SSE: 0.0001953
  R-square: 1
  Adjusted R-square: 1
  RMSE: 0.003294
```

Figure 5 (b)

Figure 5: (a) D vs X for Upper Limb at Hospital A
(b) Result of the Fit

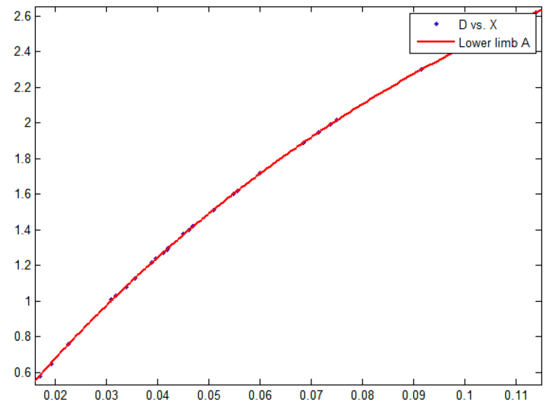

Figure 6 (a)

```
General model:
       f(x) = Dmax*(1-exp(-k*x))
Coefficients (with 95% confidence bounds):
       Dmax =       4.003  (3.977, 4.028)
       k =       9.345  (9.262, 9.428)

Goodness of fit:
  SSE: 0.0002624
  R-square: 1
  Adjusted R-square: 1
  RMSE: 0.003306
```

Figure 6 (b)

Figure 6: (a) D vs X for Lower Limb at Hospital A
(b) Result of the Fit

CONCLUSION

The optical densities (D) of the radiographic films vary across the hospitals, as well as the estimated absorbed X-ray doses. The results of the percentage dose levels show that 2.61% of the total films used recorded excess dose. However, these variations can also be accounted for as a result of the differences in the X-ray machine parameters like kVp, mA and mAs. The need for a densitometric approach in monitoring absorbed X-ray dose for Quality Assurance (QA) and Quality Control (QC) purposes is therefore emphasized.

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SUGGESTED CITATION

Ojo, O.A., M.A. Ibrahim, and P.A. Oluwafisoye. 2017. "Densitometric Estimation of Radation Absorbed Dose to Patients Undergoing X-Ray Examination in Five Government Owned Hospitals in Nigeria". *Pacific Journal of Science and Technology*. 18(1):300-307.

Pacific Journal of Science and Technology