Modelling of Dose Area Product by Application of Computer Programming in Diagnostic Radiology

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ABSTRACT
The study seeks to develop a means of Quality Control (QC) in radiological procedures, with the aid of Dose Area Product (DAP) method, that can be used as a reference level in radiology. Some samples of x-ray radiographic films were collected from various hospitals. The Optical Densities (OD) of each radiographic films were measured, using the instrument, film densitometer, after which they were converted to the amount of absorbed dose, by each film, representing the various human body parts or anatomy. Afterwards, the DAP for each film was calculated using a computer programming code written in WAMP (Windows, Apache, MySQL and PHP). The DAP ranges from 741.6 cGy.cm^2 to 10, 853.5 cGycm2, corresponding to Skull (SK) and Chest (CH) examinations respectively. The various film areas were between 720 cm^2 to 1,505 cm^2. Optical Densities were from 0.30 to 2.30 and the absorbed dose, X varied from between 0.83 cGy to 9.14 cGy. The DAP on the average was found to be 4,579 cGy.cm^2, which can the said to be a reference level for use during diagnostic or radiological procedures.

Keywords
Dose area product, film areas, optical densities, radiographic films.

1. INTRODUCTION
Radiography and fluoroscopy can have wide use of the Dose Area Product (DAP) or Kerma Area Product (KAP) method for its radiation monitoring, even now till recent. Digital Radiography (DR), as broadly used and accessible x-ray modality in clinic, plays a significant role, not only in radiology department, but also beyond most clinical establishments, such as emergency management [1] and also beside Covid – 19 examinations [2]. Ever since, when x-rays have been widely used in diagnostic imaging technology, it has been a very pivotal tool, for clinicians to consider in illness and injury diagnosis, for patients [3]. However, there may be an associated radiation – induced risks to the health of patients, typically pediatric and pregnant patients, have brought about increasing public awareness and concerns [4,5].

Researchers and professional societies have been making a lot of serious efforts targeted to address the radiation dose control and optimization to improve health risk management, such as committed task groups from American Association of Physicist in Medicine [6].

[7 - 9], the Radiation Protection of Patients (RPOP) project [10] and the guidelines and manuals from the Image Gently Alliance [11].

Due to the unforeseen limitations to be able to use and deliver the amount of reasonably low adequate x-ray dose to patients during diagnosis times, by the technologists or radiologists, so as to reduce the likelihood of any injury or radiation induces sickness, to patients such as pediatrics or pregnant patients, the study has taken time to sample some x-ray radiographic films across human body parts like chest, pelvic, upper limb, lower limb, skull, abdomen and dental radiographs. The amount of adequate doses, small enough to do the diagnosis during exposure, without causing any injury or sickness, shall be determined, and can serve as a reference point, for further use, in any radiological procedures.

2. METHODOLOGY
2.1. Materials and Experimental Set Up
In x-ray DR, DAP is measured directly at the exit of the x-ray beam, and so it depends on imaging parameters that influences x-ray output. During clinic, some parameters are adjusted like collimation, or imaging field sizes, as based on size and posture of the patient. This is done to guide the patient from radiation not necessary, through limiting the beam field size to the particular anatomy under exposure, thereby reducing the tissue volume that is irradiated. Also, the kilovoltage peak (kVp), which is the x-ray tube potential that is applied, which accelerates electrons from cathode to the anode in radiography and computed tomography together with milliampere-seconds (mAs), which is measure of the radiation produced (milliamperage) over a set of time (seconds) through an x-ray tube, and these values are also put together based on thickness of the body and purpose of diagnosis.

The research study used some materials for the work, as follows;

a. Samples of x-ray radiographic films of different film sizes, were collected from a government owned hospital in Nigeria, with the dimensions as follows,
   30 cm x 24 cm
   35 cm x 35 cm
   40 cm x 30 cm
   43 cm x 35 cm
b. An x-ray film densitometer instrument (model MA 5336 (made in USA by Gammex)).

Table 1. Features of the film 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	Five 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.)

Figure 1. Densitometer model MA 5336.

c. The following abbreviations were adapted for the purpose of this research work:

Absorbed x-ray dose: X (measured in Gy or cGy or mGy)

Optical Density: D (this is a dimensionless quantity)

Total Optical Density: TOD

Mean Optical Density: D_{MOD}

Maximum Optical Density: D_{Max}

Skull: SK, Chest: CH, Spine: SP, Pelvis: PEL, Upper Limb: UL, Lower Limb: LL

kilovoltage peak: kVp; milliampere – seconds: mAs; Dose Area Product: DAP,

Kerma Area Product: KAP

Dimensions of x-ray film: DIM

Area of x-ray film: A (cm^2) and Body

Parts: BP

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Figure 2. Diagram representing a radiographic film during measurement

From Figure 2 above, R represents the Right side of the radiographic film, while L represents the Left side of the radiographic film, going by the convention of the Posterior Anterior (PA) and the Anterior Posterior (AP) views. The measured points are represented by D all over each radiographic films.

2.2. METHOD

2.2.1. MEASUREMENTS OF FILM SIZES, DIMENSIONS AND BEAM AREA

Due to the fact that there may be variations in the x-ray films used in terms of sizes or dimensions, the dimensions of each film and were measured in centimeter (cm) recorded accordingly. The beam area of each film was then calculated based on their dimensions.

2.2.2. OPTICAL DENSITY MEASUREMENTS AND OPTICAL DENSITY

The instrument, film densitometer was used to measure the optical densities (D), all across each x-ray film, involving body parts such as skull, chest, spine, pelvis, upper limb and lower limb. Each point was denoted as D spots in Figure 2. The various measured D were added together and a total was obtained as a Total Optical Density

(TOD). TOD was then averaged as a D, for each x-ray film.

2.2.3. X-RAY MACHINE kVp and mAs

All x-ray key imaging parameters, like x-ray tube voltage (kVp) and milliampere-second (mAs), which is the tube current in a time period in seconds, are noted recorded for each patient during examination.

2.2.4. DETERMINATION OF THE ABSORBED DOSE X

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 or received dose X [12]. Thus,

$$D_{MOD} = D_{Max}\,[1 - e^{-kX}] \qquad (1)$$

where, $D_{Max} = 4$ [12] and $k = 9.36$ (k is a conversion constant) [12]. We therefore had to solve this equation (1) to obtain value of the absorbed or received x-ray dose, which is X.
Therefore, equation (1) for the mean optical density, becomes,

$$D_{MOD} = 4[1 - e^{-9.36X}] \qquad (2)$$

Solving equation (2) for the absorbed or received x-ray radiation dose X, gives,

$$X = \left(-\frac{1}{9.36}\right)\log_e\left(1 - \frac{D_{MOD}}{4}\right) \quad (3)$$

The equation (3) we derived was used to convert the measured optical densities of each radiographic film to absorbed x-ray radiation dose, in centi-gray (cGy).

2.2.5. 2.2.5 DETERMINATION OF THE DAP

The **DAP** is calculated as the product of absorbed dose X and beam area (Gy.cm^2). Given as equation (4),

$$DAP = (X) \times (A) \quad (4)$$

For this study, the DAP is measured in cGy.cm^2. It is however expected that the DAP can vary from one x-ray film to another, because of the film sizes or dimensions, and also the amount of x-ray beam deposit.

2.2.6. COMPUTER PROGRAMMING CODE

A computer programming code was developed in WAMP (Windows, Apache, MySQL and PHP) to calculate, store and retrieve the output of the DAP. This allows for easy operations, use, access, storage and reference. The programming codes are given here below in this section of the research work and MATLAB software was later used to display the graphical output of the resulting DAP.

THE WAMP PROGRAMMING CODES:

```
function cal () {
      function round(value, decimals){
      return Number (Math.round(value+'e'decimals)+'e-
'+decimals);
}
var a=parseFloat(document.calculate.d1.value);
var b=parseFloat(document.calculate.d2.value);
var c=parseFloat(document.calculate.d3.value);
var d=parseFloat(document.calculate.d4.value);
var e=parseFloat(document.calculate.d5.value);


var p =round((a+b+c+d+e),2;
document.calculate.d.value=p;


if (document.calculate.d.value=="NaN"){
   document.calculate.d.value=Cal..";
}
var t = 0;
          if ( a > 0.00)
          t ++;
         if ( b > 0.00)
         t ++;
         if ( c > 0.00)
         t ++;
          if ( d > 0.00)
         t ++;
         if ( e > 0.00)
         t ++;
var q=round((p/t),2);;
document.calculate.d0.value=q;

//calculating standard deviation
var an=Math.pow((a-q),2);
var an1=Math.pow((b-q),2);
var an2=Math.pow((c-q),2);
var an3=Math.pow((d-q),2);
var an4=Math.pow((e-q),2);

var ans=an + an1 + an2 + an3 + an4;
var l=Math.sqrt(0.2 * ans);
var l=round(1,2);
document.calculate.answer.value=l;
//End
var r = Math.log (1-q/4);
var s =round( r * (-1/9.36),4);
document.calculate.input.value.value=s;

var x = Math.log (1-q/4);
var y =round( x * (-1/9.36),3);
document.calculate.input10.value.value=y;

if(document.calculate.d0.va;lue=="NaN"){
document.calculate.d0.value ="Cal...";

if(document.calculate.input.value=="NaN"){
document.calculate.input.value="Cal...";

if(document.calculate.input10.value.value=="NanN"){
document.calculate.input10.value="Cal...";
}

if (document.calculate.answer.value=="NanN"){
document.calculate.answer.value="Cal...";
}

}
}
}
```

3. RESULTS AND DISCUSSION

3.1. RESULTS

The results of this study are presented as Dose Area Product (DAP), Absorbed dose (X), Total Optical Density (TOD), Mean Optical Density (DMOD), Dimensions of x-ray films (DIM), Area of x-ray film (A), kilovoltage peak (kVp) and milliampere – seconds (mAs). These output results covered six different body parts.

The results obtained are presented in Table 2 and graphs can be found in Figures 3 to 8. We also try to compare the results with the universally internationally recommended Dose Area Product standard reference level allowable for x-ray dosimetry applications.

However, several factors can affect film development, which may also lead to some variations in the results obtained, namely; temperature, drying conditions, film batch, fading, storage and effects of processing chemicals. Table 2. Values of the Dose Area Product (DAP) for the various Body Parts (BP) can be found in the Appendix.

3.2 DISCUSSION

3.2.1 DOSE AREA PRODUCT (DAP)

The values of the DAP varied between films, as their various absorbed dose was distinct, one from another. The x-ray beam deposited on the body parts under examination, also contributed to these variations, because different kVp and mAs, were deployed to accomplish the diagnostic imaging procedures.

DAP is a measure of the amount of x-ray dose that is deposited on a particular area of the x-ray film, during an examination or

diagnosis. It is measured in $Gy.cm^2$ (or sub units like $mGy.cm^2$ or $cGy.cm^2$).
A higher value of absorbed dose and large area of film, results in a high DAP, that has been deposited in a body part during examination, and vice versa. For this study, the highest DAP was recorded as 10,853.5 $cGycm^2$ and lowest DAP was recorded as 741.6 $cGy.cm^2$.
The response of the films to the x-ray beam deposited and absorbed, is represented by Figures 3 to 8. It gives the variations of the DAP to the film area A, for the various body parts (BP).

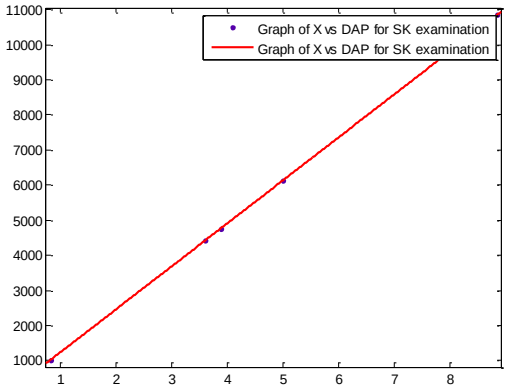

Figure 3. Graph of X vs DAP for SK examination.

Results of the curve fitting (in Figure 3)
General model:
f(x) = X*(x)
Coefficients (with 95% confidence bounds):
X = 1225 (1225, 1225)
Goodness of fit:
SSE: 0
R-square: 1
Adjusted R-square: 1
RMSE: 0

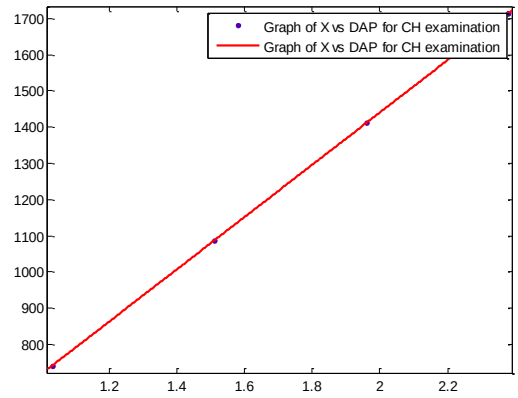

Figure 4. Graph of X vs DAP for CH examination

Results of the curve fitting (in Figure 4)
General model:
f(x) = X*(x)
Coefficients (with 95% confidence bounds):
X = 720 (720, 720)
Goodness of fit:
SSE: 6.054e-015
R-square: 1
Adjusted R-square: 1
RMSE: 3.89e-008

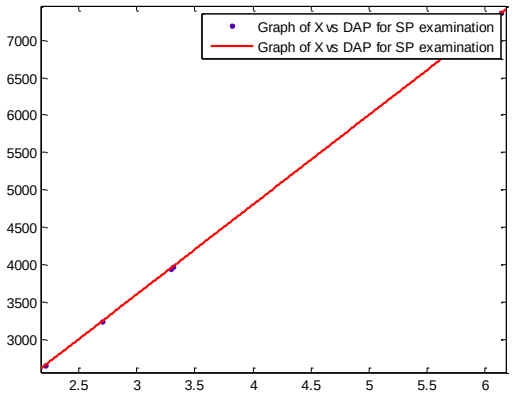

Figure 5. Graph of X vs DAP for SP examination.

Results of the curve fitting (in Figure 5)
General model:
f(x) = X*(x)
Coefficients (with 95% confidence bounds):
X = 1200 (1200, 1200)
Goodness of fit:
SSE: 0
R-square: 1
Adjusted R-square: 1
RMSE: 0

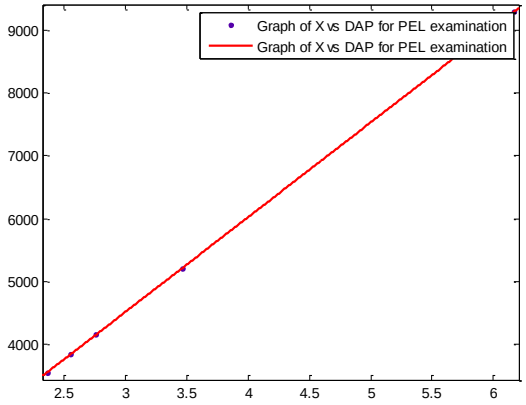

Figure 6. Graph of X vs DAP for PEL examination.

Results of the curve fitting (in Figure 6)
General model:
f(x) = X*(x)
Coefficients (with 95% confidence bounds):
X = 1505 (1505, 1505)
Goodness of fit:
SSE: 1.241e-024
R-square: 1
Adjusted R-square: 1
RMSE: 5.569e-013

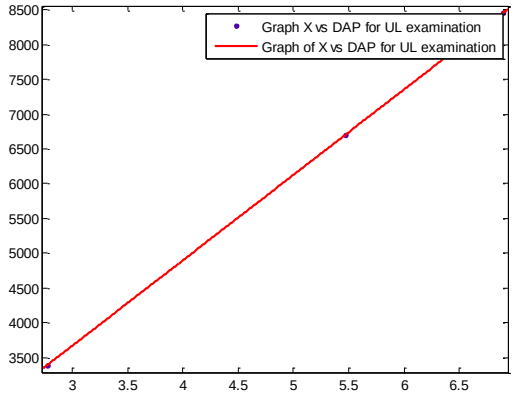

Figure 7. Graph of X vs DAP for UL examination.

Results of the curve fitting (in Figure 7)
General model:
f(x) = X*(x)
Coefficients (with 95% confidence bounds):
X = 1225 (1225, 1225)
Goodness of fit:
SSE: 0
R-square: 1
Adjusted R-square: 1
RMSE: 0

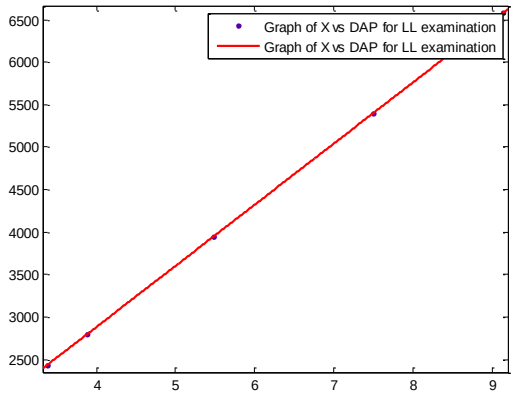

Figure 8. Graph of X vs DAP for LL examination.

Results of the curve fitting (in Figure 8)
General model:
f(x) = X*(x)
Coefficients (with 95% confidence bounds):
X = 720 (720, 720)
Goodness of fit:
SSE: 2.068e-025
R-square: 1
Adjusted R-square: 1
RMSE: 2.274e-013

In diagrams of Figures 3 to 8, the values of Dose Area Product (DAP) vary directly in proportion to absorbed of x-ray, X, in each of the examinations. The DAP is a substitute way of measuring the total amount of x-ray energy delivered to the patient, and it is a reflection of the dose within the radiation field and area of tissue irradiated [13].

4. CONCLUSIONS

The DAP that is a most safe during examinations on the average is a value of 4, 579.5cGy.cm2. With this amount of a DAP, the patient involved can be said to not have any likelihood of over exposure to the x-ray radiation been delivered to the area of exposure. So therefore, this can serve as a guide during diagnostic or regular examination procedures.

It shall be a good and needful thing, if radiological centers or hospitals find this particular approach resourceful to use in their works.

It shall prevent overexposure or injury to any patient during examination or diagnostic times.

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6. CONFLICTS OF INTEREST

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APPENDIX

Table 2. Values of the Dose Area Product (DAP) for the various Body Parts (BP).

Films	BP	TOD	D_{MOD}	X (cGy)	DIM (cm)	A (cm^2)	DAP ($cGy.cm^2$)	kVp	mAs
1	SK	3.35	0.67	1.96	30 cm x 24 cm	720	1411.2	80 to 90	5 to 25
2	SK	2.63	0.53	1.51	30 cm x 24 cm	720	1087.2	80 to 90	5 to 25
3	SK	4.00	0.80	2.38	30 cm x 24 cm	720	1713.6	80 to 90	5 to 25
4	SK	1.84	0.37	1.03	30 cm x 24 cm	720	741.6	80 to 90	5 to 25
5	SK	3.99	0.80	2.38	30 cm x 24 cm	720	1713.6	80 to 90	5 to 25
6	CH	6.11	1.22	3.89	35 cm x 35 cm	1,225	4765.25	80 to 90	5 to 20
7	CH	7.47	1.49	5.00	35 cm x 35 cm	1,225	6125	80 to 90	5 to 20
8	CH	5.72	1.14	3.60	35 cm x 35 cm	1,225	4410	80 to 90	5 to 20
9	CH	11.27	2.25	8.86	35 cm x 35 cm	1,225	10853.5	80 to 90	5 to 20
10	CH	1.49	0.30	0.83	35 cm x 35 cm	1,225	1016.75	80 to 90	5 to 20
11	SP	3.73	0.75	2.21	40 cm x 30 cm	1,200	2652	75 to 90	5 to 30
12	SP	5.30	1.06	3.29	40 cm x 30 cm	1,200	3948	75 to 90	5 to 30
13	SP	4.47	0.89	2.70	40 cm x 30 cm	1,200	3240	75 to 90	5 to 30
14	SP	8.74	1.75	6.14	40 cm x 30 cm	1,200	7368	75 to 90	5 to 30
15	SP	5.33	1.07	3.31	40 cm x 30 cm	1,200	3972	75 to 90	5 to 30
16	PEL	3.96	0.79	2.36	43 cm x 35 cm	1,505	3551.8	80 to 90	5 to 20
17	PEL	4.55	0.91	2.76	43 cm x 35 cm	1,505	4153.8	80 to 90	5 to 20
18	PEL	8.77	1.75	6.17	43 cm x 35 cm	1,505	9285.85	80 to 90	5 to 20
19	PEL	5.53	1.11	3.46	43 cm x 35 cm	1,505	5207.3	80 to 90	5 to 20
20	PEL	4.24	0.85	2.55	43 cm x 35 cm	1,505	3837.75	80 to 90	5 to 20
21	UL	4.57	0.91	2.77	35 cm x 35 cm	1,225	3393.25	60 to 80	5 to 15
22	UL	9.37	1.87	6.75	35 cm x 35 cm	1,225	8268.75	60 to 80	5 to 15
23	UL	9.52	1.90	6.90	35 cm x 35 cm	1,225	8452.5	60 to 80	5 to 15
24	UL	8.01	1.60	5.47	35 cm x 35 cm	1,225	6700.75	60 to 80	5 to 15
25	UL	9.44	1.89	6.82	35 cm x 35 cm	1,225	8354.5	60 to 80	5 to 15
26	LL	11.50	2.30	9.14	30 cm x 24 cm	720	6580.8	60 to 80	5 to 15
27	LL	6.10	1.22	3.89	30 cm x 24 cm	720	2800.8	60 to 80	5 to 15
28	LL	5.42	1.08	3.38	30 cm x 24 cm	720	2433.6	60 to 80	5 to 15
29	LL	10.09	2.02	7.50	30 cm x 24 cm	720	5400	60 to 80	5 to 15
30	LL	8.02	1.60	5.48	30 cm x 24 cm	720	3945.6	60 to 80	5 to 15