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A SIMPLE MODEL FOR PREDICTING SKIN DOSE FOR PATIENTS UNDERGOING ROUTINE CHEST X-RAY EXAMINATIONS

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ABSTRACT: In this work, the predicted skin doses of patients undergoing routine medical examinations were carried out at Federal Medical Centre, Makurdi. Measurements were also made using phantoms and Thermo-Luminescence Dosimeter (TLD) in place of patients in order to compare the results obtained. The predicted mean chest doses for 100 patients undergoing routine medical examinations at Federal Medical Centre Makurdi were 724.964μGy using Edmonds' formula. The predicted average dose using our modified formula was 723.138μGy. We repeated the above measurements but this time with TLD badges using phantoms in place of patients. Twelve measurements were carried out. The results were found as follows: The average skin dose from TLD badges was 1137.70μG. While the results of our modified formula are in close agreement with the Edmonds' formula, there is disagreement between the measured and predicted data. These discrepancies in the results could be as a result of excess workload and the age of the machine.

KEYWORDS: Dosimetry, Radiation Protection, Phantoms.

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1 INTRODUCTION

The use of X-rays for diagnostic and therapeutic purposes has become very common recently. It is common to find X-ray machines in almost all hospitals and some clinics all over the world. It is not surprising that 90% of the man-made irradiations are from this source. There is therefore concern as to the effects of X-rays exposure dose rates such as those encountered in diagnostic and therapeutic radiology. Genetic mutations due to gonadal dose, congenital defects caused by foetal irradiation and somatic effects of X-ray such as cancer induction and premature aging may arise as a result of X-ray exposure [1]. Indeed, there has been growing concern that the quantities of X-radiation delivered during diagnostic and therapeutic procedures may produce significant amount of cancer and other disorders [2]. Emphasis now is on producing the maximum benefit from radiology with the minimum amount of radiation consistent with good quality control in medical X-ray [3].

For effective radiation monitoring and protection from medical X-rays, accurate determination of patient skin dose prior to and during radiographic and radio-therapeutics procedures is often essential in the administration of patient dose within recommended guidance levels in hospitals. Since the results of skin dose measurement depends vastly upon the kind of measurement technique employed, several approaches encompassing analytical sequencing of computation models and in-situ monitoring of administered dose using state of the art equipment has been reported based on stipulated dose specification parameters [4]. The relevant dose specification parameters required on any occasion depends critically on the kind of non-invasive procedure considered [5]. These specifications typically allows for the adoption of the best practicable combination required in achieving a dose level capable of yielding acceptable results without compromising the quality of the application.

Recently, a great deal of research has been devoted to the improvement of the existing measurement techniques in order to achieve higher levels of accuracy at lower doses. Remarkably, these studies have been very successful and well documented, and almost all systematic information obtained point to the fact that any protective measure to be adopted has to align with the measurement technique. In this regard, several theoretical models have been proposed to account for the whole body dose during any radiological examination. Patient dosimetry is now widely accepted as a vital point of quality assurance process in diagnostic radiology, and the use of thermoluminescent dosimeters (TLDs) is a recommended method of entrance dose measurement [4]. Whilst it is one of the most convenient methods for dosimetry as its use in the clinical environment is simple, it is a somewhat time consuming technique with several draw backs [4]. It primarily measures the dose to itself and not that of the whole patient geometric size. The use of software suites and analytical methods to carryout entrance dose and effective dose evaluation is a modern resource in dosimetry and is being widely accepted in Hospitals.

In this study, we present a simple model for estimating entrance skin dose from the knowledge of X-ray output parameters. We used X-ray machines based on single-phase generator output.

2 MATERIALS AND METHOD

2.1 MATERIALS

The X-ray machines used for this work were from the Federal Medical Centre, Makurdi, Benue State.

The single-phase mobile diagnostic X-ray machine has the following specifications as shown in the Table 1 below.

Table 1. Technical specifications of the X-ray machine used at Federal Medical Centre, Makurdi

Total filtration	2.1 mmAl
Manufacturer	GEC medical; equipment limited Wembly, Middle Sex, England.
Year of manufacture	1980
Model	Meditronics Diagnox 4006
Type	R105
Anode type	Rotating anode with 1.0mm focus.
Exposure time	From 3ms to 5s (selected by the processor according to mAs selected).
kV range	40-120kV (steps of 1kV)
%load	The selection of the tube load depends on the quality of the main supply. If the main supply regulation is very good this should always be selected to 100%.
Phase type	Single-phase.

A graduated measuring tape was used in measuring chest thicknesses of patients, lead aprons were used as shield for workers [6]. Phantoms of different sizes were also employed.

TLD Badges and Their Specification

Table 2. TLD Badges used at Federal Medical Centre, Makurdi on the single-phase X-ray machine and their numbers.

Phantom size (cm)	SSD(cm)	TLD Number
16	139	a0000 321t
16	147	a0000 172t
16	144	a0000 433t
18	114	a0000 148t
18	135	a0000 309t
18	142	a0000 050t
20	157	a0000 276t
20	157	a0000 348t
20	120	a0000 163t
24	129.6	a0000 377t
24	136	a0000 476t
24	123	a0000 484t

2.2 METHOD

I) Patient-Machine Arrangement

100 patients were exposed at the Federal Medical Centre, Makurdi in a Posterior - Anterior position for chest X-ray examinations, using a single-phase X-ray machine. The chest exposures, during routine radiological examinations were computed using Edmonds' formula [7]. We then made several approximations to the Edmonds' method with the preset values of radiographic exposure factors of peak kilo voltage (kVp), product of tube current (mA) and exposure time(s) as (mAs) and the percentage load (%load), on a single-phase X-ray generator. The patient is asked to stand erect with the chest placed on the film enclosed in a cassette at a given distance away from the X-ray tube (source). The chest thickness of the patient is measured with the aid of a graduated tape and the source to skin distance (SSD) obtained by subtracting the chest thickness (CT) from film to focal distance (FFD) as shown in Fig. 1 below. The various appropriate values of (kVp) and mAs were subsequently read on the X-ray machine control panel, during the chest X-ray examination.

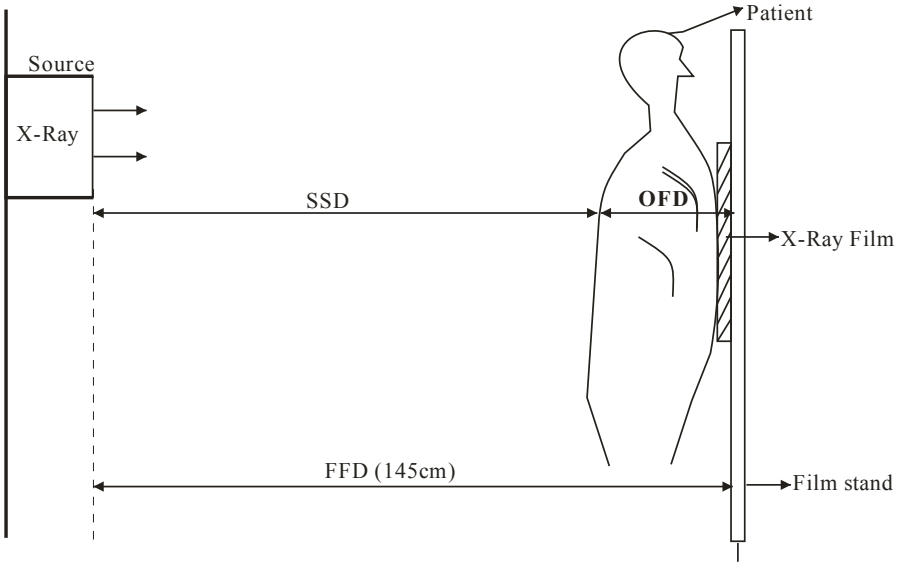

Fig. 1 Illustration of a typical diagram of patient under investigation.

II) Phantom-Machine Arrangement.

Twelve (12) TLD (thermoluminescence dosimeters) were used to measure the amount of radiation doses. The TLD badges were placed in the middle on the front view of the phantoms filled with water facing the X-ray source and their corresponding SSD, kVp, mAs and the average thicknesses of the phantom measured. The phantom – machine arrangement is shown in Fig. 3.

The phantom should be of a material that absorbs and scatters photons in the same way as tissue. A phantom material should have the same density as tissue and should contain the same number of electrons per gram. Water and wet tissues absorb photons in almost the same way, and for this reason water has been used in this work. The materials used for the construction of phantom were; polyvinyl glass, RTV Silicone sealant, hawk saw, tape and a transparent cello- tape. The phantoms were made of different sizes; 16cm, 18cm 20cm and 24cm thicknesses as shown below:

Figure 2a. 24cm phantom

Fig 2b. 20cm phantom

Fig 2c. 18cm phantom

Fig. 2d: 16cm phantom

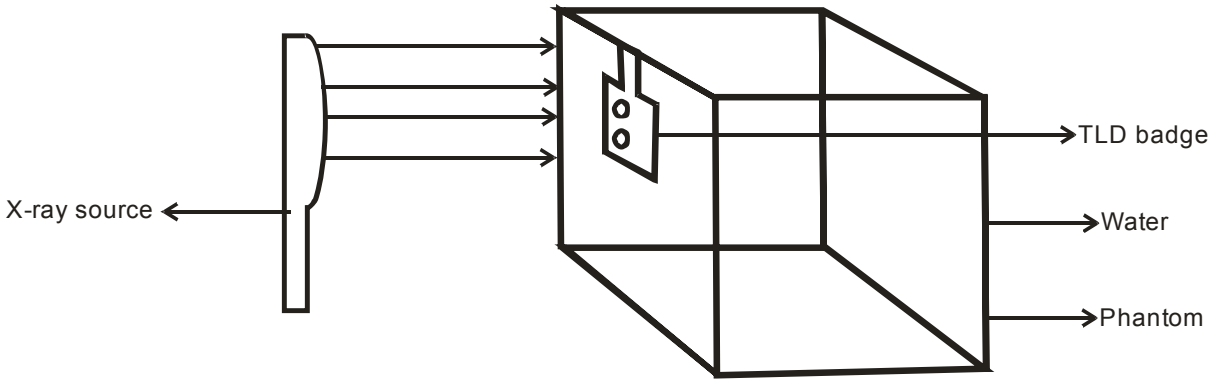

Fig 3 Showing a TLD badge being exposed

Annealing and Calibration of TLDs

The TLDs were annealed, using Hashaw 4500 TLD Reader with Win-REMS (Window based Radiation Evaluation and Measurement System). This was done as follows:

The TLD badges were removed from the plastic holder and the chips scanned with a scanner or computed by using keyboard to type the number of the chips. After which the chips were slotted into the TLD reader, then, the input key will be pressed on the keyboard, and the data will be displaced on the monitor with the peak of radiation displayed as the dose in nano-Coulomb (nC), the current in Pico-Amperes (pA) and voltage in Volts (V). This was done in 24hrs at 80^0C.

After annealing the chips, the TLD badges were irradiated for the reader calibration. The aim of annealing and calibrating TLD badges is for the recycling of the cards for future field dosimetry, using phantoms or patients. The annealed irradiated cards are stored at least for 24hours.

Finally, the annealed and calibrated TLD badges (which are tissue equivalent) were exposed with phantoms and water at Federal Medical Centre, Makurdi using single - phase X-ray generator with phantom stand of an average height of 165cm to enable us predict the skin doses of patients undergoing radiological examinations. And the final results were read at National Institute of Radiation Protection and Research, Physics Department, University of Ibadan as shown in Table 1.

3 THEORY

The skin dose prediction based on an expression derived by Edmonds (1984) [7] for a single - phase generator is as follows:

$$\text{Skin dose}(\mu\text{Gy}) = \frac{418.0(\text{KV}_\text{P})^{1.74}(\text{mAs})^{1.0}(1/\text{T}+0.114)}{(\text{SSD})^2} \quad . \qquad (1)$$

We suggest a simplified model for skin dose in the form:

$$\text{Skin dose}(\mu\text{Gy}) = Ae^{-kx}(kV_P)^{\beta}(mAs)^{\gamma}T^{\delta} \qquad (2)$$

Equation (2) has an exponential term which indicates how X-rays attenuate exponentially as an alternative to the inverse square law suggested in the Edmonds' formula.

Here A, k, β, γ, δ are parameters to be fitted to the observed skin dose data. We also noticed that for a particular X-ray machine, T has a constant value. So the dependence on T in equation (1) above is a constant for a particular X-ray machine hence we include it in the skin dose formula, as;

$$\text{Skin dose}(\text{mGy}) = Ae^{-kx}(kV_P)^{\beta}(mAs)^{\gamma} \qquad (3)$$

Here we have used β = 1.74 and γ = 1.0 as was found by Edmonds during his fit to the ICRP data, hence equation (4) becomes;

$$\text{Skin dose}(\mu\text{Gy}) = Ae^{-kx}(kV_P)^{1.74}(mAs)^{1.0} \qquad (4)$$

Equation (4) is now fitted to the data obtained by the Edmonds' formula of equation (1) through a least square method to obtain the values of A and k.

Finally, the above procedure using patients was repeated with phantoms and TLD badges. The analysis is based on the experimental values read from TLD 4500 Hashaw Reader from National Institute of Radiation Protection and Research, Physics Department, University of Ibadan.

4 RESULTS AND ANALYSIS

We now present the results of data collected at the Federal Medical Centre, Makurd**,** using the radiographic parameters, kVp, mAs, and chest thickness (CT) obtained for each patient from the single-phase X-ray machine described above to determine the doses for patient undergoing chest radiography. In our analysis, we used Edmonds' formula given by equation (1) to obtain dose A as depicted in Table 1. We also used a least square fit to get dose B based on our modified equation (4). The least square fit gave us the following equation:

$$\text{Dose B } (\mu\text{Gy}) = 0.117056e^{-0.015959x}(kV_P)^{1.74}(mAs)^{1.0} \qquad (14)$$

Table 3 shows the predicted and experimental doses calculated, dose A gives the result based on Edmonds' formula. Dose B gives the results based on our present formula while dose C give the results using phantoms.

Table 3. Predicted and experimental doses calculated from Federal Medical Centre, Makurdi.

kVp	mAs	Chest	SSD	dose A	dose B	dose C
73	20	16	139	446.016	444.85	1614
75	25	16	147	522.493	512.98	1327.2
70	20	16	144	386.317	381.81	659.8
70	20	16	134	446.128	447.87	685.6
70	20	18	142	397.276	394.19	1039.5
70	20	18	140	408.708	406.97	1718.3
69	20	18	142	387.453	384.44	1051.4
70	20	18	114	616.395	616.27	792.3
72	25	18	135	577.031	578.66	1023.6
75	25	19.5	157	458.053	437.31	1006.8
75	25	20	157	458.053	437.31	1005.9
77	25	20	120	820.805	826.26	1416
74	25	20	120	765.965	771.06	
75	25	20	140	576.048	573.61	
75	25	20	130	668.080	672.86	
73	25	23	134	599.902	602.25	
75	25	23	127	700.015	705.85	
75	20	23.4	129.6	537.768	541.73	
92	63	24	136	2194.937	2198.48	
75	25	24	123	746.285	752.38	
75	25	24	117	824.790	827.99	
75	25	17	123	746.285	752.38	
73	20	16	139	446.016	444.85	
75	25	16	147	522.493	512.98	
70	20	16	144	386.317	381.81	
70	20	16	134	446.128	447.87	
68	20	17	143	372.471	368.87	
75	25	17	123	746.285	752.38	
75	25	17	143	552.132	546.79	
70	25	17	144	482.897	477.26	
70	25	17	133	566.077	568.84	
70	25	17	137	533.504	533.67	
70	20	17	128	488.933	492.88	
72	20	17	132	482.847	485.63	
75	25	17	134	628.790	631.25	
75	25	18	150	501.802	489.00	
74	25	18	132	633.029	636.67	
75	25	18	135	619.509	621.25	
72	25	18	131	612.808	616.80	
70	20	18	135	439.543	440.78	
70	20	18	132	459.749	462.40	
70	20	18	130	474.004	477.39	
70	20	18	130	474.004	477.39	
68	20	18	129	457.704	461.21	
75	25	18	138	592.867	592.21	
85	50	18	132	1611.312	1620.59	
68	20	18	133	430.587	432.69	
75	25	18	129	678.478	683.68	

kVp	mAs	Chest	SSD	dose A	dose B	dose C
75	25	18	129	678.478	683.68	
70	20	18	139	414.610	413.52	
70	20	18	140	408.708	406.97	
70	20	19	134	446.128	447.87	
73	23	19	144	477.918	472.34	
73	25	19	144	519.476	513.41	
71	25	19	136	554.907	555.80	
74	25	19	131	642.731	646.92	
90	63	19	131	2276.923	2291.75	
70	25	19	134	557.660	559.84	
73	25	19	134	599.902	602.25	
75	25	19	134	628.790	631.25	
75	25	19	127	700.015	705.85	
75	25	19	139	584.367	582.83	
70	20	19	139	414.610	413.52	
70	20	19	131	466.795	469.84	
70	20	19	131	466.795	469.84	
75	20	19.2	133	510.625	513.12	
85	50	19.5	132.8	1591.957	1600.03	
74	20	19.5	128.5	534.386	538.60	
75	25	19.5	136.5	605.968	606.56	
75	20	20	133	510.625	513.12	
75	25	20	157	458.053	437.31	
74	25	20	130	652.657	657.32	
73	25	20	130	637.388	641.94	
72	25	20	133	594.516	597.42	
72	25	20	133	594.516	597.42	
70	25	20	134	557.660	559.84	
75	25	20	130	668.080	672.86	
74	20	20	130	522.126	525.86	
74	20	20	126	555.803	560.52	
88	50	20	137	1588.902	1589.39	
75	25	20	126	711.171	717.21	
70	20	20	135	439.543	440.78	
75	25	20	125	722.595	728.75	
90	63	21	129	2348.073	2366.08	
74	25	21	129	662.815	667.90	
70	25	21	139	518.262	516.90	
70	25	21	135	549.429	550.98	
77	50	21	126	1488.988	1501.63	
70	40	21	126	1009.155	1017.72	
70	20	21	128	488.933	492.88	
70	20	21	128	488.933	492.88	
75	25	21	126	711.171	717.21	
88	50	22	128.5	1806.060	1820.30	
77	20	22	130	559.507	563.51	
79	20	22	129	594.142	598.70	
85	40	22	128	1370.874	1381.93	
85	40	22	85	3108.705	2744.83	
75	25	22	133	638.281	641.40	
68	20	22	122	511.734	515.73	
70	20	22	122	538.207	542.41	

kVp	mAs	Chest	SSD	dose A	dose B	dose C
75	25	22	123	746.285	752.38	
75	25	23	102	1085.212	1051.93	
75	25	23	130	668.080	672.86	
75	25	23	121	771.160	776.78	
85	63	24	128	2159.126	2176.54	
68	20	17	143	372.471	368.87	
			Total	**72496.4**	**72313.8**	**13340.4**
			Average	724.964	723.138	1111.7
			Std dev.	481.350	467.123	471.987

5 DISCUSSION

The main aim of this article is to design a model for predicting skin dose received by patients undergoing X-ray examinations at Federal Medical Centre, Makurdi, and to compare the results with measurements carried out with TLD badges using phantoms.

It was found that the predicted mean chest doses for 100 patients undergoing routine medical examinations at Federal Medical Centre Makurdi were 724.964μGy using Edmonds' formula. The predicted average dose using our modified formula was 723.138μGy.

We repeated the above measurements but this time with TLD badges using Phantoms in place of patients. Twelve measurements were carried out. The average dose using TLD badges was 1137.70μGy.

As can be seen from our results, the predicted mean dose using Edmonds' formula [7] agrees very well to within 1% with that using our modified formula. However, both results differ significantly with the results using TLD badges and phantoms. This difference may be attributed to several factors, some of which include:

i. The age of the machine. It is known that the focal spot angle of the X-ray tube increases with the age and use of the machine, and with the increases in the mA station selected. This effect called focal spot blooming can have a significant effect on the dose received by patients. We did not carry out any performance test of this effect on the X-ray machine used in this study.
ii. There may be variations on the stated kVp and the measured kVp which could significantly affect the amount of dose received by patients. We also did not carry out any performance test regarding this effect.
iii. Exposure time also directly affects the amount of radiation emitted from an X-ray tube. We did not carry out any performance test on timer accuracy as well.

6 CONCLUSION

In this paper we have successfully fitted a modified model for predicting skin dose from the Edmonds' formula [7]. In our modified model, we have used an exponential factor which shows how X-rays attenuate with distance from the source. Our fitted results agree with the Edmonds' formula to within 1%.

Finally, we have compared the results of our modified model and those of the Edmonds' formula [7] to those obtained using TLD badges and phantoms in place of patients. We have found a significant disagreement between the measured results and the predicted methods. We have advanced several arguments why these results could differ from each other.

It would be interesting to carry out performance tests on the machine to see how the effects mentioned above could affect the amount of dose received by patients.

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