Analysis of Sensitometry in Radiographic Films using Optical Density Measurement

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Abstract— The sensitivity of radiographic films is an important factor to the clarity and accuracy of X-ray exposure to patients during treatment or diagnostic periods. It is therefore important to do a thorough analysis of the sensitivity of the radiographic film before and after exposure to enhance the Quality Assurance (QA) and the Quality Control (QC), of the exposure procedures. The optical densities (OD) of each film was measured, with a densitometer model MA 5336, made by GAMMEX. These values were then converted to the absorbed dose (X mGy), which is the amount of dose absorbed by each patient. The optical density versus the dose curve, followed the expected pattern, showing a good prediction from the General model, that the films employed in the exposures were of good quality and standard. Hence the optical density versus dose sensitometric curves depicts the outcome of the various films sensitivity after an exposure to the X-ray radiation through the patients.

Index Terms — Absorbed, exposure, density, dose, optical, radiation, radiographic, sensitivity, sensitometric.

I. INTRODUCTION

X-ray examinations can lead to an increased radiation dose to the patient. To reduce this risk, quality assurance methods are very essential. In the processing and production of X-ray films, quality assurance is required for quality images. It is needful to maintain a high level of film processing quality, and so a daily check of the film processor is required. A sensitometer is used to expose a grey wedge with 21 steps on a test strip of the X-ray film. After developing the film, a densitometer will be used to measure the density of various steps of the grey wedge. Errors in the film processing such as changes in speed and contrasts of the exposed film are detected by this method [1].

One way of knowing practically a two (2-D) relative dose distribution in vast portions of radiographic films with high spatial resolution, is to employ radiographic films. With a good arrangement, the inclusion of film affects an insignificant distortion of distribution of the dose. These properties make film dosimetry useful technique for dose verification in a phantom for evaluating the accuracy of dose calculations performed by a treatment planning system [2], [3], to verify advanced conformal techniques applying intensity modulated beams [4], [5], and for quality control tests of specific properties of radiation beams [6].

For film dosimetry, radiation interaction with film is quantified by relating the dose to the blackening of the film

(optical density, OD), yielding the sensitometric curve. The necessity and purpose of the sensitometric curve should display clearly the sensitivity of a particular film for example, to radiation exposed to it. However, some of the parameters that determines the value of the optical density measured after film exposure in photon beams like, photon energy, irradiated conditions, composition of the emulsion, processing of the film and characteristics of the film scanner (densitometer).

A difficulty of variable like the phantom energy spectrum cannot be totally avoided, which is bound to change for a particular photon beam quality with both depth and field size due to the variation in phantom scatter and beam hardening. Some past works have shown large differences in magnitude of the depth – field size effect. These conflicting data might be related to differences in film exposure techniques such as irradiating the film parallel or perpendicular to the control beam axis [7]. Good dosimetric results can, however, be obtained if films from the same batch are irradiated with small to moderate field sizes (up to about 15cm x 15cm), at moderate depths (up to about 15cm), using a single calibration curve for a 10cm x 10cm field [7].

II. MATERIALS AND METHODS

Adult radiographic films, totaling thirty (30), already irradiated from patient exposure to X-ray were collected as samples. The optical densities (OD), of the films were measured, using a densitometer, model 5336. The measured optical densities were used to estimate the X-ray radiation absorbed dose to the patients at the radiological center. The radiographs were from different examinations, namely, Skull (PA, PAL L., LAT R., LAT L.) and Mandible (LAT R., LAT L., PA). The following abbreviations were adapted for the purpose of this study:

PA: Posterior Anterior

AP: Anterior Posterior

LAT. RT: LATERAL RIGTH

LAT. LT: LATERAL LEFT

MAND: MANDIBLE

X: Absorbed X-ray dose

NOD: Net Optical Density

MOD: Mean Optical Density

D_{MOD} : Mean Optical Density

OD or D: Optical Density

OD₁, OD₂, OD₃, OD₄ and OD₅: Measured Optical Densities

S/N: Film Serial Number.

TABLE I: FEATURES OF THE DENSITOMETER [8]

Model MA 5336 (made in USA by	Features
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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.)

A film densitometer, model MA 5336 for the measurement of optical density was used. The light source / detector assembly is driven in finite incremental steps and resolution over the entire scanning area to ensure precise positioning with a high degree of repeatability [9]. 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 [9].

The optical densities of each radiograph were measured repeatedly five times at different spots on each image of the film as optical densities OD₁, OD₂, OD₃, OD₄ and OD₅. The average of the five optical densities was then taken to obtain the MOD. The optical densities were converted to the absorbed X-ray radiation doses X, in milli gray (mGy), which is the amount of X-ray radiation dose that each patient was exposed to. The mean absorbed dose, range of absorbed dose, standard deviation, kurtosis, first and third quartiles were also calculated for the samples. The blackening of the film after X-ray radiation exposure is expressed in terms of its optical density as [10]:

$$D = \log_{10} \left(\frac{I_0}{I} \right) \dots \dots \dots (1)$$

Where I_0 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 and the maximum number of sensitized grains results in a relation between the optical density and the absorbed dose X. Thus:

$$D = D_{max} [1 - e^{-kX}] \dots \dots \dots (2)$$

where,

$$D_{max} = 4$$

(this is the maximum measurable OD obtainable with the densitometer) [10],

$k = 9.36$ (k is a conversion constant) [10].

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

$$D = 4[1 - e^{-9.36X}] \dots \dots \dots (3)$$

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

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

Equation (4) was used to convert the measured optical densities of the radiographs to absorbed X-ray radiation dose, in milli gray (mGy).

III. RESULTS AND DISCUSSIONS

The results obtained in this work are presented in Tables II, III and IV for the radiographic examinations for the values of OD, X, NOD and MOD.

TABLE II

S/N	Examination	OD (OD ₁ to OD ₅)	X (mGy)
1	Skull: PA L	0.10	0.002704894
		0.63	0.018310002
		0.22	0.006043841
		0.02	0.000535528
		0.12	0.003254189
		NOD	1.09
MOD		0.218	
2	Skull: LAT R	0.38	0.010664566
		0.73	0.021528245
		0.56	0.016113557
		0.04	0.001073754
		0.35	0.009782820
		NOD	2.06
MOD		0.412	
3	Skull: PA	0.21	0.005761575
		1.83	0.065338375
		1.97	0.072463522
		1.78	0.062904612
		1.33	0.043185458
		NOD	7.12
MOD		1.424	
4	Skull: AP	2.30	0.091417319
		2.06	0.077308375
		0.82	0.024509953
		2.26	0.088932612
		1.18	0.037345884
		NOD	8.62
MOD		1.724	
5	Mandible: LAT R	1.93	0.070378820
		1.51	0.050642270
		2.05	0.076759080
		1.81	0.064358207
		1.10	0.034357225
		NOD	8.40
MOD		1.68	
6	Skull: PA	1.87	0.067326109
		2.05	0.076759080
		1.75	0.061470528
		1.90	0.068841562
		1.78	0.062904612
		NOD	9.35
MOD		1.87	
7	Mandible: LAT L	1.84	0.065831853
		1.39	0.045613690
		1.03	0.031809018
		1.71	0.059587879
		1.95	0.071416086
		NOD	7.92
MOD		1.584	

TABLE III

S/N	Examination	OD (OD ₁ to OD ₅)	X (mGy)
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1	Mandible: LAT L	2.35	0.094606739
		2.38	0.096567117
		1.77	0.062424442
		2.41	0.098564139
		2.36	0.095256209
NOD		11.27	
MOD		2.254	
2	Mandible: LAT R	2.02	0.075127940
		2.30	0.091417319
		2.15	0.082383410
		2.37	0.095909652
		2.27	0.089548392
NOD		11.11	
MOD		2.222	
3	Skull: PA	1.58	0.053688763
		1.33	0.043185458
		1.98	0.072991116
		1.99	0.073521329
		2.16	0.082962478
NOD		9.04	
MOD		1.808	
4	Skull: PA	1.78	0.062904612
		1.96	0.071938521
		1.86	0.066825698
		1.86	0.066825698
		2.04	0.076212595
NOD		9.50	
MOD		1.90	
5	Mandible: PA	1.91	0.069351527
		1.90	0.068841562
		1.78	0.062904612
		1.76	0.061946420
		1.66	0.057280281
NOD		9.01	
MOD		1.802	
6	Skull: PA	2.80	0.128629573
		2.37	0.095909652
		2.14	0.081807465
		2.30	0.091417319
		2.37	0.095909652
NOD		11.98	
MOD		2.396	
7	Mandible: LAT L	1.86	0.066825698
		1.50	0.050214063
		2.07	0.077860508
		1.50	0.050214063
		1.73	0.060525057
NOD		8.66	
MOD		1.732	
8	Mandible: LAT R	1.40	0.046023816
		1.67	0.057737831
		1.87	0.067326109
		1.40	0.046023816
		1.05	0.032530896
NOD		7.39	
MOD		1.478	

TABLE IV

S/N	Examination	OD (OD ₁ to OD ₅)	X (mGy)
1	Skull: PA	1.98	0.07299112
		1.91	0.06935153
		2.07	0.07786051
		1.51	0.05064227
		1.81	0.06435821
		NOD	9.28
	MOD	1.856	
2	Mandible: LAT L	1.77	0.06242444
		1.47	0.04893964
		1.01	0.03109198
		1.51	0.05064227
		1.75	0.06147053
		NOD	7.51
	MOD	1.502	
3	Mandible: LAT R	1.57	0.05324819
		1.45	0.04809840
		1.23	0.03925716

		1.23	0.03925716
		1.36	0.04439268
	NOD	6.84	
	MOD	1.368	
4	Skull: PA	2.35	0.09460674
		2.38	0.09656712
		2.44	0.10059920
		2.41	0.09856414
		2.36	0.09525621
	NOD	11.94	
	MOD	2.388	
5	Mandible: LAT R	2.02	0.07512794
		2.30	0.09141732
		1.77	0.06242444
		2.37	0.09590965
		2.27	0.08954839
	NOD	10.73	
	MOD	2.146	
6	Mandible: LAT L	1.58	0.05368876
		1.33	0.04318546
		2.15	0.08238341
		1.99	0.07352133
		2.16	0.08296248
	NOD	9.21	
	MOD	1.842	
7	Mandible: LAT L	1.55	0.05237247
		1.70	0.05912235
		1.22	0.03887216
		1.33	0.04318546
		1.42	0.04684882
	NOD	7.22	
	MOD	1.444	
8	Mandible LAT R	1.90	0.06884156
		1.55	0.05237247
		1.71	0.05958788
		1.97	0.07246352
		1.88	0.06782888
	NOD	9.01	
	MOD	1.802	
9	Skull: LAT L	2.36	0.09525621
		1.67	0.05773783
		2.07	0.07786051
		1.95	0.07141609
		2.21	0.08590585
	NOD	10.26	
	MOD	2.052	
10	Skull: LAT R	2.28	0.09016774
		2.32	0.09268168
		2.27	0.08954839
		0.49	0.01396136
		2.37	0.09590965
	NOD	9.73	
	MOD	1.946	
11	Skull: PA	1.68	0.05819735
		1.79	0.06338695
		1.67	0.05773783
		1.62	0.05546943
		1.17	0.03696770
	NOD	7.93	
	MOD	1.586	
12	Skull: PA	1.97	0.07246352
		1.93	0.07037882
		2.10	0.07953424
		1.91	0.06935153
		1.91	0.06935153
	NOD	9.82	
	MOD	1.964	
13	Mandible: LAT L	1.24	0.03964356
		1.73	0.06052506
		1.22	0.03887216
		1.29	0.04159677
		1.29	0.04159677
	NOD	6.77	
	MOD	1.354	
14	Mandible: LAT R	1.25	0.04003135
		1.88	0.06782888

	1.87	0.06732611
	1.94	0.07089619
	1.70	0.05912235
NOD	8.64	
MOD	1.728	
15 Skull: PA	0.39	0.010960106
	0.15	0.004083463
	0.25	0.006895141
	0.06	0.001614705
	0.10	0.002704894
NOD	0.95	
MOD	0.19	

In the Tables, the measured optical densities were seen to vary across the radiographic images during the measurements. This was expected, as the density of the tissues, thickness of the tissues and thickness of the bones varies for each radiographs. The average of the measured OD's is thus taken to be Mean Optical Density (MOD). Also, the estimated doses for the radiographs and occurrence of variations in the estimated absorbed doses can be seen, for the same reason stated above. These results in Tables were in good agreement with the Nigerian Basic Ionizing Radiation Regulation (NBIRR) [11] and the International Commission on Radiological Protection (ICRP) [12]. The Figures represent the plots and the results of the OD's against the X, for the radiographs, to depict their various sensitometry properties, from a curve fitting using the MATLAB.

Fig.1 a. Skull PA L sensitometric curve of the radiographic film in Table II

Results:

General model:

$$f(x) = D_{max} * [1 - \exp(-k * x)]$$

Coefficients (with 95% confidence bounds):

$$D_{max} = 4 (3.998, 4.001)$$

$$k = 9.36 (9.356, 9.364)$$

Goodness of fit:

$$SSE: 1.112e-011$$

$$R\text{-square: } 1$$

$$\text{Adjusted R-square: } 1$$

$$RMSE: 1$$

Fig. 1 b. Mandible LAT L sensitometric curve of the radiographic film in Table II.

Results:

General model:

$$f(x) = D_{max} * [1 - \exp(-k * x)]$$

Coefficients (with 95% confidence bounds):

$$D_{max} = 4 (4, 4)$$

$$k = 9.36 (9.36, 9.36)$$

Goodness of fit:

$$SSE: 1.108e-016$$

$$R\text{-square: } 1$$

$$\text{Adjusted R-square: } 1$$

$$RMSE: 6.077e-009$$

Fig. 2 a. Mandible LAT L sensitometric curve of the radiographic film in Table III.

Results:

General model:

$$f(x) = D_{max} * [1 - \exp(-k * x)]$$

Coefficients (with 95% confidence bounds):

$$D_{max} = 4 (4, 4)$$

$$k = 9.36 (9.36, 9.36)$$

Goodness of fit:

$$SSE: 3.375e-012$$

$$R\text{-square: } 1$$

$$\text{Adjusted R-square: } 1$$

$$RMSE: 1.061e-006$$

Fig. 2 b. Skull PA sensitometric curve of the radiographic film in Table III.

Results:

General model:

$$f(x) = D_{\max} * [1 - \exp(-k * x)]$$

Coefficients (with 95% confidence bounds):

$$D_{\max} = 4 (4, 4)$$

$$k = 9.36 (9.36, 9.36)$$

Goodness of fit:

SSE: 4.624e-016

R-square: 1

Adjusted R-square: 1

RMSE: 1.242e-008

The Figures represents the sensitometric curves from the different examinations, exposed to the X-ray radiation. The curves follows the expected pattern for the OD vs Dose trend. The General model depicts coefficients with 95% confidence bounds, there is a range for the maximum optical density $D_{\max}$, as also the range for the conversion constant k . The Goodness of fit was a good expected Sum of Square Errors (SSE's), minimal enough, R-square and the Adjusted R-square were as expected, as this shows that a value of 1 or close to 1 projects good exposure factors and safe amount of doses for the X-ray radiation in use, ensuring the optimal sensitivity of the films used.

IV. CONCLUSION

The optical density versus dose sensitometric curves depicts the outcome of the various films sensitivity after exposure of the patient to X-ray radiation. In the plots, the response of the films to the radiation is seen to be linear in terms of the optical density against the dose, as shown in the Figures. The linearity means that the films have a high sensitivity to the X-ray radiation, either at minimum or maximum values.

The results of the model as shown a good fit with each of the curves linearity. These values are within the range that is expected of an exact fit. The analysis of film response to X-ray radiation using the optical density measurement approach can be used to do a Quality Assurance (QA) and Quality Control (QC) in terms of any type of radiographic film sensitivity.

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