RESPONSE CHARACTERIZATION OF X-RAY RADIOGRAPHIC FILMS USING FILM GAMMA TECHNIQUE: A BIOMEDICAL QUALITY CONTROL AND QUALITY ASSURANCE

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Abstract: *There are various types of responses that results, in x-ray film radiography. This types of outcomes of responses, can be determined from the film – gamma of an x-ray radiographic film, as described in this work. The optical densities (OD) of the films were obtained using an instrument, the densitometer, and the values were averaged as the mean optical density (ODMean). These ODMean , were converted to the absorbed dose, X in milli Gray (mGy). By considering a dose reference X0 in mGy and finding the small contrast in dose ∆X in mGy, the value of the film – gamma, Γ, was obtained from a relation. The results of the film – gamma, shows a range of values from 0.78 to 4.89. For films with Γ < 1, were found to be Ultra speed film, those with Γ > 3, the films were said to be Fast speed film, and those whose Γ is between 2 to 3, were seen to be Standard speed film. The films whose film – gamma was between 2 to 3, makes a good film selection for use.*

1. INTRODUCTION

A lot of x-ray image receptors are now been used in today's modern-day radiology. They all have a goal to achieve, in that they form an image by the action of the energy absorbed from the beam after transmission is done through the body exposed by the radiation. Thus, the exposures of the films to the radiation, can be used to characterize their various responses to the radiation. Film gamma dosimetry is a useful method for measuring the distributions of radiation dose in x-ray radiographic films, which when characterized can help with developing a Quality Control (QC) and Quality Assurance (QA) standard for x-ray radiography [1].

There are some films that their performance does not totally dependent on the radiation energy as a whole, which can be explained that, the ratio of collision stopping power in the emulsion and water can vary slowly with the electron energy [2].

The essence of this research work is to develop an approach to aid film selection, based on their response to x-ray radiation, so as to enhance a good output of x-ray film exposure and production in radiography, by using the film gamma approach.

X-ray radiographic films can be differentiated based on the film, as [3],

(1). Standard speed film
(2). Fast speed film
(3). Ultra speed film

A sensitometric curve can be plotted to show a relation between the absorbed dose X (exposure) on the X axis and the optical density (OD) on the Y axis, which is often used in radiation oncology [4,5].

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A good optical density for visualization in radiology is 2; however, the useful OD range in radiation oncology typically ranges from 0 to 3. Most Kodak films do not have a linear response outside narrow dose ranges. The response of all films to radiation is mainly due to their crystal size and the variation is significant. It is good to know that for most radiation oncology applications that is deployed, a required dynamic range will be depended on the specific application [6,7,8,9]. The dynamic range requirement for Intensity Modulated Radiotherapy (IMRT), for example, can be 0.2 – 3.0 Gy, larger than what Kodak XV film would allow.

In other to characterize the response and sensitivity of a film in x-ray radiation, the gamma has to be determined. Gamma is the slope of the substantially straight portion of the characteristic curve [10].

Talking about the speed, means the sensitivity of x-ray film bromide crystals (AgBr) to x-ray photon. There is direct relation between the speed of the film and the size of the crystals, the larger the crystal size, the faster the film speed. The faster means it need less amount of radiation to produce radiographic image, so less radiation dose is absorbed by patient [11]. Film gamma is defined as the slope of the characteristic curve between net optical densities 0.25 and 2. Contrast is directly related to film gamma. Both film gamma and speed are affected by processor performance [12].

2. METHODOLOGY

I. THE EXPERIMENTAL SET UP

The experimental set up consists of the followings:

a. X-ray radiographic film samples collected from a government owned hospital, in which the optical densities were measured.

b. The instrument Densitometer model MA 5336 that was used to measure the optical densities.

c. A dedicated Laptop Computer in which the measured optical densities were recorded in a Microsoft Excel Spreadsheet.

d. A computer program was developed in Microsoft SQL to calculate the values of the amount of absorbed x-ray radiation dose, X in milligray (mGy).

e. The Figure 1 below shows a schematic representation of how the optical density measurement was carried out on an x-ray radiographic film at five (5) different spots before the average can be taken as the mean absorbed dose.

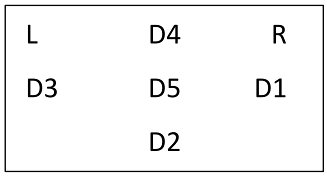

Fig. 1. Schematic representation of measurements of optical densities at five different spots on an x-ray film

In Figure 1, L stands for the Left side of the film when been measured and R the Right side. The spot D1 was the first place of measurement for the optical density, D2 the second, D3 the third, D4 the fourth and D5 the fifth. The average can thus be taken to obtain the mean optical density (OD_{mean}). This procedure was carried out for each of the films Serial Number (S/N), from 1 to 24 respectively.

II. THE TEST CONDITIONS

a. The instrument of measurement was tested first, with the sample radiographic film that was part of the instrument as an equipment, to validate the measuring capability and accuracy.

b. The reset, to zero or null, of the instrument was also ensured at every time a measurement has been taken, to pave way for the next measurement.

c. However, the main sources of errors like distance, optical effects, wavelength variations and temperature, was taken care of to a large extent, by ensuring that the instrument was well charged, the contact of the distance of instrument to the film was null, in that the film was place inside the opening measuring surface of the instrument, the reflectivity functioning of the instrument has accounted for any errors due to optical effects and the wavelength variations.

III. THE METHOD

The curve relating the optical density (OD) to the film response is called the characteristic curve of the film material. In the center part of the curve, the relation between optical density (OD) and the logarithm of the dose is approximately linear, given by,

$$OD_{Mean} = \Gamma log_{10}\left(\frac{X}{X_0}\right) \quad (1)$$

For a small contrast in dose, ΔX, is given by,

$$\Delta X = X - X_0 \quad (2)$$

Where,

OD_{Mean} is the mean optical density for each x-ray radiographic film
ΔX is small contrast in dose (mGy)
X is the absorbed x-ray dose (mGy)
X_0 is the reference dose (mGy)
So, for the small contrast in dose ΔX, the associated change in optical density (OD), is, [13]

$$OD_{Mean} = 0.434\Gamma\frac{\Delta X}{X} \quad (3)$$

The contrast Γ is known as the film – gamma and ranges between 2 – 3 (a dimensionless quantity). It corresponds directly to the slope of the linear section of the characteristic curve.
The optical densities (OD), which is a dimensionless quantity, of each x-ray radiographic film can be obtained by using the instrument called the densitometer, to do the measurement.
The measured optical density (OD), can then be converted into the absorbed dose X, using the relation,

$$X = -\left(\frac{1}{9.36}\right) log_e\left(1 - \frac{OD_{Mean}}{4}\right) \quad (4)$$

Where, OD_{Mean} , is the mean of the measure optical density (OD), for each x-ray radiographic film [13].
From equation (3), we can derive and calculate, the film – gamma, Γ, by,

$$\Gamma = \frac{OD_{Mean} \times (X)}{(0.434) \times (\Delta X)} \quad (5)$$

Note that, $\Delta X = (X - X_0)$

Figure 2 shows the picture of the instrument use to measure the various OD of each radiographic film. Table 1 contains the features of the densitometer, as well as its model.

Fig. 2. Densitometer model MA 5336

Table 1: 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	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.)

3. RESULTS

Table 2 represents the values of the measured OD and their means.

Table 2: Measured optical densities (OD) and mean optical densities (OD_{Mean})

Film S/N	OD_1	OD_2	OD_3	OD_4	OD_5	OD_{Mean}
1	1.60	1.52	1.44	0.14	1.41	1.22
2	0.86	2.20	2.04	0.83	1.54	1.49
3	1.18	0.43	0.43	3.06	0.62	1.14
4	2.70	2.06	2.96	2.33	1.22	2.25
5	0.13	0.27	0.34	0.19	0.56	0.30
6	3.52	1.30	0.95	1.12	0.84	1.55
7	0.55	0.57	0.86	0.19	0.20	0.47
8	0.42	0.54	0.63	0.34	0.47	0.48
9	2.02	2.00	1.36	1.04	1.27	1.54
10	1.19	0.52	0.19	0.38	0.44	0.54
11	1.12	0.76	1.76	1.73	0.85	1.24
12	1.37	3.93	0.59	1.07	0.24	1.44
13	0.52	0.51	0.30	0.33	0.89	0.51
14	1.92	1.51	1.50	0.44	0.40	1.15
15	2.77	3.56	0.14	2.70	1.31	2.10
16	0.82	0.39	0.40	1.26	1.03	0.78
17	1.15	0.17	0.39	1.30	0.31	0.66
18	0.58	0.83	0.62	1.39	0.68	0.82
19	1.02	0.03	0.40	0.86	0.58	0.58
20	0.49	1.55	0.71	2.15	1.20	1.22
21	0.91	1.11	0.50	1.13	1.94	1.12
22	2.23	2.16	2.16	0.32	0.68	1.51
23	0.55	0.94	1.11	2.35	0.52	1.09
24	1.00	0.44	2.22	0.96	2.59	1.44

The optical densities of each films Serial Number (S/N), were measured at five different spots, which relates the direct corresponding focus of the x-ray radiation beam to the targeted image area only, as from OD_1 to OD_5, and then the average was taken as OD_{Mean}. However, it is good to note that the tissue densities of the patient been x-rayed, can account for the variations in the measured OD from the different spots. Furthermore, any outlier can be replaced with the result of a method of finding the average or mean of the other four OD's that are seen as not an outlier. Table 3 presents the OD_{Mean}, the absorbed dose X, the small contrast in dose ΔX and the film – gamma Γ of the x-ray radiographic film.

Table 3: Mean optical densities (OD_{Mean}), absorbed dose (X), small contrast in dose (ΔX), and the film – gamma (Γ)

Film S/N	OD_{Mean}	X (mGy)	ΔX (mGy)	Γ
1	1.22	0.039	0.038	2.89
2	1.49	0.050	0.049	3.51
3	1.14	0.036	0.035	2.71
4	2.25	0.089	0.088	5.25
5	0.30	0.008	0.007	0.78
6	1.55	0.052	0.051	3.63
7	0.47	0.013	0.012	1.18
8	0.48	0.014	0.014	1.11,
9	1.54	0.052	0.051	3.61
10	0.54	0.016	0.015	1.34
11	1.24	0.040	0.039	2.94
12	1.44	0.048	0.047	3.39
13	0.51	0.015	0.014	1.26
14	1.15	0.036	0.035	2.73
15	2.10	0.079	0.078	4.89
16	0.78	0.023	0.022	1.88
17	0.66	0.019	0.018	1.61
18	0.82	0.025	0.024	1.97
19	0.58	0.017	0.016	1.42
20	1.22	0.039	0.038	2.89
21	1.12	0.035	0.034	2.65
22	1.51	0.051	0.050	3.55
23	1.09	0.034	0.033	2.60
24	1.44	0.048	0.047	3.39

Note that the reference dose X_0 , has a value of 0.001mGy, corresponding to the least value of the absorbed dose that could have been obtainable on the research work. However, other attainments of dose levels for further reference examples can be described from the RadiologyInfo.org, for patients [14].

The response curve, known as the sensitometric curve, was plotted from the values of the mean optical densities (OD_{Mean}) against the absorbed dose (XmGy), given by equation (3), and as shown in Figure 2. The slope of the curve gives the film – gamma, of the x-ray radiographic film. A line of best fit was employed in the plotting of the points.

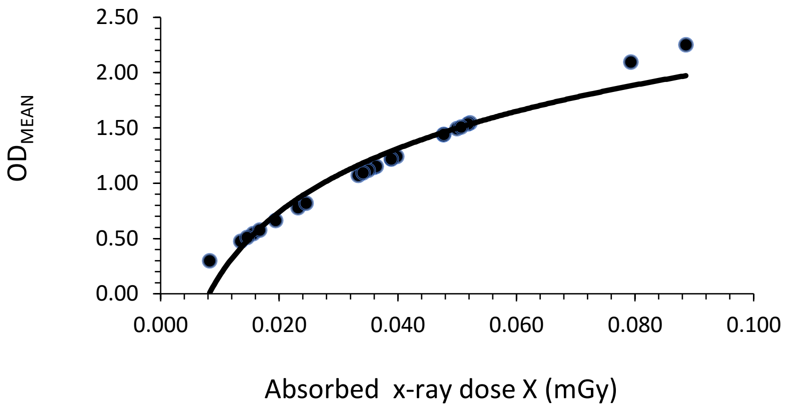

Fig. 2. Response curve of the x-ray films

4. DISCUSSION

In Table 2, the mean OD is the value for the average of the measured OD for each x-ray radiographic film, which are represented by Film S/N in the Tables. It shows a good trend in the exposures, to the patients, based on their respective values. However, in Table 3, the absorbed dose X, is the amount of the exposure dose, absorbed by the patient during an x-ray in milligray (mGy), and the values depicts a good outcome of the application of the dose settings of the facilities involved.

The film – gamma, Γ, which is a dimensionless quantity, represents the speed of response of the films to the x-ray dose, upon application and its typical value should be between 2 to 3. But from this work, it can be seen that some values of the film – gamma are higher than 3, while some are less than 2.

For Γ that is less than 1, this means that the x-ray film was an Ultra speed film, if the Γ is greater than 3, then the x-ray film is said to be a Fast speed film and for a Γ value of between 2 to 3, the x-ray film is a Standard speed film. In Table 3, the various Γ, could be placed on these types of films as explained.

5. CONCLUSION

The response of the films to the x-ray radiation can be of great importance, to know which film was good enough to the diagnostic purpose, and having more efficiency. The approach of this nature could serve has a guide for Quality Control (QC) and Quality Assurance (QA) purposes, to guide against poor outcomes in the x-ray films processing, after diagnostic exercises have been carried out.

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