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Density characterization of radiochromic film through source axis distance (SAD) technique in linac with slab phantom for radiotherapy applications

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Abstract. Characterization of radiochromic film density is accomplished through Source Axis Distance (SAD) technique in a slab phantom Linac with various depths and breadths of field. Type of the film used is gafchromic RTQA2. The dose of radiation exposure of the film may cause changes in the film density. This research aims to determine the relation between the density and the dose depth through the characteristic of curves to identify the depth of the dose and particular breadth of the field as a reference for the dose of radiotherapy patients. The result shows that the higher the dose is absorbed, the darker the film will be, yet the lower the density is obtained. The dose depth is determined by measuring the amount of dose received at various depths and breadths of field using film that is placed on the slab phantom with 6 MV linac radiation and dose of 300 cGy. The variation of the depth at 1.5 cm; 4 cm; 6 cm; 8 cm; 10 cm, the field size at 4x4 cm^2, and the dose depth at 359.7 cGy; 315.3 cGy; 281.4 cGy; 241.2 cGy; 220.5 cGy were settled. The field size 6x6 cm^2 takes the dose depth 354.6 cGy; 314.1 cGy; 282.6 cGy; 244.5 cGy; 224.7 cGy. The field size 8x8 cm^2 takes the dose depth 351.6 cGy; 313 cGy; 283.8 cGy; 247.2 cGy; 228 cGy. The field size 10x10 cm^2 takes the dose depth 348.9 cGy; 342.6 cGy; 248.4 cGy; 249.6 cGy; 231 cGy.

1. Introduction

2014's World Cancer Report (WCR) recorded 12.4 million deaths caused by cancer [1]. Cancer is a disease caused by the abnormal growth of body tissue cells (growing extremely fast and irrepressible; infiltrates and suppresses body tissues thus affecting organs [2]). Cancer is frequently found as cervical cancer, breast cancer, nasopharyngeal cancer, and skin cancer [3]. During this time, the treatments for cancer include surgery, chemotherapy, and radiotherapy. Radiotherapy is a treatment using ionizing radiation, such as *X-rays, gamma rays*, or high-energy electrons [4]. The use of ionizing radiation and radionuclides in cancer treatment is common among the societies. According to *Brazzilian Journal of Physics* in 2009, 50% of cancer treatments used radiotherapy [5]. Treatments with radiotherapy can be divided into two types: *Teletherapy* (External Radiotherapy) and *Brachytherapy*. External Radiotherapy is performed by giving radiation on the surface of the patient body at a certain distance with the best modalities of Linear Accelerator (Linac) with a certain dose. While *Brachytherapy* is performed by inserting the radiation source into the body [6].

Linac can produce photon beam which is used in irradiating cancer [5]. It also produces dose rates that varies in units called Monitor Units (MU) in its applications. This MU is equivalent to one cGy. Determination on the variation of the dose rate should be concerned as it affects biological tissues [6]. The radiation dose given should meet the purposes of radiotherapy which include curative radiation and palliative radiation. Excessive dosage will cause damage to normal tissues that can lead to tissue necrosis. While insufficient dosage in killing the malignant cells will lead to relapse or recurrent [7]. In a previous study [8], by Linac superficial dose variation through Source Surface Distance (SSD) technique, radiation dose is obtained with high accuracy values at the result of the irradiation characteristic curve with 6 MV photon energies above 150 cGy. In another study [8], obtained characteristic of gafchromic RTQA2 film gradient curve tends to decrease after the administration of radiation dose at 150 cGy.

Based on this background, a research must be conducted to measure the dose accuracy of the characteristic curve which can be used as a reference in determining the dose depth of radiation therapy by using a film through Source Axis Distance (SAD) technique in Linac which varies in the depth and field size. Researchers choose the gafchromic RTQA2 film since it is fluorescenceat high energies and resistant to temperatures up to 70^0 C [9]. Average selection of SAD technique is reinforced by research [10]. Department of Radiation Oncology, Virginia Commonwealth University Health System, USA, declares that the technique Source Axis Distance (SAD) which gives IMRT (Intensity Modulated Radiation Therapy) effect in Linac increases the equal distribution of the dose in the target.

Characteristic curve is a graph showing the relationship between the number of exposition and the results of the film density, with exposure doses given by Linac at 300 cGy and irradiation angle at 0 ° with a Slab Phantom, which makes the level of darkness or density of the resulting film visible. The dose absorbed in the film can be read through the level of darkness or film density by using a densitometer. The photon energy used in this study is 6 MV. This number was chosen as the photon energy commonly used in radiotherapy for patients lies in this range. By knowing the depth of the dose and the density of the film, we are able to find the characteristic curve to obtain the accurate dose depth to be used as a reference in radiotherapy.

2. Materials and methods

Materials and tools used in this experiment are:

2.1. *Linear accelerator (linac):*

The specifications of Linac involve date of install April 2013, Model/ tipe 2300 Ix,Serial number 5578, Varian Medical System USA,SSD 100 cm,MLC 120Photon, energy 6 MV, Field size of maximum radiation 4x4 cm^2, 6x6 cm^2, 8x8 cm^2, 10x10 cm^2 on Isocenter position, and depth of target 1,5 cm, 4 cm, 6cm, 8cm, 10cm [1].

2.2. *Densitometer*:

As the film density gauges the absorbed dose in the film; specifications include Model/tipe 10000 XL, Seri number 028872, Scanner Epson and made of Japan in 2013 [2].

2.3. *Gafchromic film*:

RTQA2 Model, International Specialty Products (ISP), Temperature resistance reaches 70 , Field size 14 cm x 17 cm, high spatial resolution intensity of light, can be used in ambient light [2,6].

2.4. *Slab phantom*:

Consists of Water equivalent white polystyrene “RW3” Material for high-energy photon and electron energy, Energy field Photons: Co-60 – 25 MV Electrons: 4 – 25 MeV, Material composition of Polystyrene (C_8H_8) with an admixture of 2.1% ± 0.2% TiO_2, Plate dimension Surface area: 300 x 300 mm ± 0.1 mm Thickness: 1 mm ± 0.05 mm 2 mm ± 0.05 mm 5 mm ± 0.05 mm 10 mm ± 0.05 mm

Adapter plates: 20 mm ± 0.1 mm Mass density: 1.045 g/cm3 (Z/A)r value: 0.536 Electron density (e/g): 3.386 x 1023 Electron concentration (e/cm3) 3.539 x 1023[10].

In this research, the first step is the preparation of Linear Accelerator (LINAC) equipment to organize K-fil therapy consul; Turn-on on a computer consul and wait for time delay. Prepare MLC (Multi-leaf Collimator) with jaw to set the field size with variations of 4x4 cm², 6x6 cm², 8x8 cm² and 10x10 cm². Adjust the depth on a slab phantom with variations of 1.5 cm, 4 cm, 6 cm, 8 cm, 10 cm. Warm-up with the selection of energy at 6 MV. And as the last step, on a plane linac, set-up a film source gafchromic RTQA2 on the slab phantom with distance at 90 cm.

On the preparation of RTQA2 gafchromic film, put the film between slab phantom and depth variation with 90 cm's distance above the flat table surface of slab phantom with radiation sources. Slab phantom is placed just below the radiation source with irradiation angle of 0 °. Determination of the film density is a measurement of air dose Linac output absorbed in the film. The film is irradiated with the plane linac. After the film is exposed to radiation, the film color will change. This change in color indicates the magnitude of the dose absorbed by the film. The dose absorbed in the film is measured by using a densitometer. This treatment is implemented with a variation of field size and depth on energy 6 MV of Linear Accelerator. The next step is to take the TMR (Tissue Maximum Ratio) data of TPS (Treatment Planning System) computer produced by isodoses curve obtained from CT-Scan. Characteristic curve is obtained from the calculated ratio of density and dose depth. The characteristic curve is a curve graph showing the relation between the number of exposition and the results of the film density to get a reference picture of dose in radiotherapy.

3. Results and discussion

3.1. Radiation of gafchromic RTQA2 film on slab phantom

Irradiating gafchromic RTQA2 film is performed by modulating energy 6 MV linac. The energy selection is based on the standard commonly used in radiotherapy. Linac has two kinds of beam; photon beam and electron beam. In medical field, Linac used for cancer radiotherapy can be divided into three tiers based on the value of energy and the type of particle accelerated. Those are low-energy photons and electrons (4-6 MV), medium energy photons and electrons (6-15 MV), and high energy photons and electrons (15-25 MV) [11]. Multi energy beam of electrons and photons in third edition of The Physics of Radiation Therapy for the purposes mentioned, electron energy ranges around 4-22 MV and photon energy around 6-18 MV - 6 MV photon energy included [6].

One principle of radiotherapy is the optimization of the dose given to cancerous tissue which seeking for protection from a healthy organ tissue around the cancer. Therefore, the linac output dose used in this study is 300 cGy. The previous research states that the value of high accuracy in determining dose is better done by using a higher dose around 150-200 cGy [9]. However, results confirm that the value of high accuracy in determining the dose is better at the dose higher than 200 cGy [7], as well as at the dose of 300 cGy which perceives maximum output in irradiation. Additionally, irradiation angle used in linac is 0^0. It means that the linac gantry position is perpendicular to the film that will receive radiation exposure. Angle 0^0 is selected thus the distribution of the dose received by the film as well as to produce constant exposure of the film perpendicular to standard deviation slightly [10]. Distance Determination from the radiation source to the gafchromic RTQA 2 film uses SAD (Source Axis Distance) technique. SAD is a technique setting the field and the depth of target, with distance between the source of radiation from Linac and the film surface is about 90 cm and 10 cm D-max. Selection on the distance is based on the best irradiation efficiency to deliver radiation with the best modalities linac. Following is the description of SAD techique on the film data retrieval with various depths and breadths of field.

Gafchromic RTQA2 film with various breadths of field is placed isocentric above the slab phantom. Phantom is made from a material that resembles the human body. Slab phantom is designed for medium and high energy radiation therapy dosimetry with photon energy around 4mV MV-25 and electron energy around 4-25 MeV. Phantom consists of 33 RW3 plate with dimension of 30cm x 30cm

[1]. During this measurement, dose of radiation obtaining a picture as a reference dose should be received by the patient radiotherapy using medium water phantom, since the human body is composed of 80% water [11]. Aside to suit the medium and high energy, slab phantom can perform an absolute quality control and relative dosing. Other advantages are able to vary the depth measuring up to 30 cm increments of 1mm made of water equivalent (Goettingen White Water) with thickness tolerance ± 0.05 mm. Plate adapter for various types of detectors can be inserted without an air gap [1].

The breadth variation of the field of gafchromic RTQA2 film are 4x4 cm^2, 6x6 cm^2,8x8 cm^2, and 10x10 cm^2. Selection of the breadth variation is done by a width measure of the smallest field less than 15x15 cm^2. The variation can be applied to patients of cancer therapy with relatively small size of cancer. MLC (Multi Leaf Collimator) on air Linac is comprehensively set to a large field thus it produces a square shape with a breadth variation of the required field. MLC is a mechanical component integrated with the linac gantry that can be controlled automatically by using a computer and independent to each other thus produce a field or fields in various forms [6]. In addition to the breadth variation, in this research, fields are also varied in the depth of gafchromic RTQA2 film which get the linac radiation exposure. The depth variation selected includes 1.5 cm, 4 cm, 6 cm, 8 cm and 10 cm. Selection based on the depth of the cancer position in the body that is often encountered.

3.2. The effect of field size and depth variation of the density values

Varying field size (breadth) and depth on the characterization of radiochromic film density through Source Axis Distance (SAD) technique in a LINAC with slab phantom for radiotherapy applications aims to determine the influence of the breadth and depth of the density of the resulting film. The variety of field size and depth in radiation therapy is a parameter that should be taken into account with the value of high accuracy as it relates to the principle of radiotherapy in seeking the protection of a healthy organ tissue around the cancer [7]. Gafchromic RTQA2 film density measurement results with various depths and field sizes are presented on table 1.

Table 1. The results of gafchromic film RTQA2 density

Field Size (cm)	Depth (cm)	Distance Irradiation (cm)	Radiation Angle	Density
4x4	1,5	100	0^0	60
	4	100	0^0	67
	6	100	0^0	68
	8	100	0^0	76
	10	100	0^0	79
6x6	1,5	100	0^0	71
	4	100	0^0	71
	6	100	0^0	77
	8	100	0^0	80
	10	100	0^0	85
8x8	1,5	100	0^0	69
	4	100	0^0	74
	6	100	0^0	80
	8	100	0^0	81
	10	100	0^0	80
10x10	1,5	100	0^0	63
	4	100	0^0	71
	6	100	0^0	71
	8	100	0^0	77
	10	100	0^0	81

From the density of Gafchromic RTQA2 film measurement results with various depths and field sizes presented above, the relation chart between the depth variation and density in various field sizes can be obtained as follows:

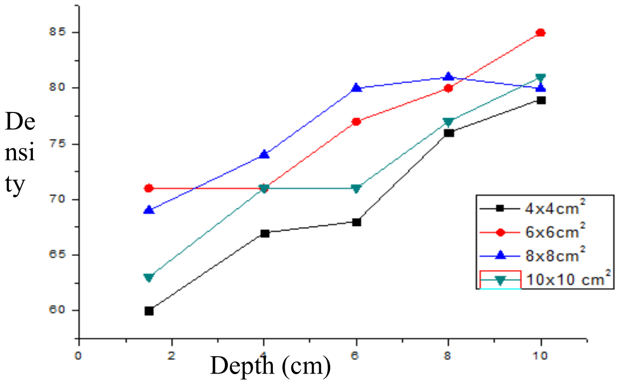

Figure 1. The Graphic relation between the depth and density variation in various field sizes

The graphic relation between the depth variation and density in various field sizes at figure 1 shows that the greater the depth value used, the higher the density obtained, and vice versa. While the density is inversely proportional to the level of darkness in the film after irradiation. The higher the level of darkness in the film, the smaller the density value is, whereas, the dose absorbed by the film increases. . It means that the higher the dose absorbed, the darker the film will be, yet the lower the density obtained. This is consistent with the theory of absorbed dose to the equation:

$$D = \frac{dE}{dm} \quad (1)$$

with D: Dose Absorption,
dE: Energy average, and
dm: Massa.

The amount of the dose absorbed will be higher in the tissues close to the surface rather than deep within the body. Absorbed dose may also be defined through the absorbed energy material per unit mass. Mathematical Analysis of the relation between density and depth is calculated in equation:

$$OD = \mu x \quad (2)$$

with µ: attenuation coefficient and
x: the absorption coefficient of the passed material.

The formulation indicates the relation between density and depth is OD = µx. Hence, the graph above shows that the higher the density level, the greater the depth value. Below is the film before and after getting radiation.

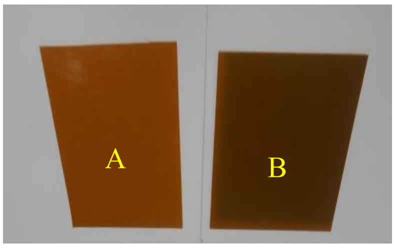

Figure 2.the film (A) before and (B) after getting radiation.

3.3. Dose figures resulting from the accuracy value of the characteristic curve between density and gafchromic RTQA2 film dosimetry results

The characteristic curve is a curve graph showing the relation between the number of exposition and the results of the film density. This curve was first discovered by Hurteen and Drifield in 1890. In this research, the characteristic curve describes the relation between the dose and the film density varied in the depth and field size. The denoted dose value % of TMR% is obtained from TPS (Treatment Planning System) presented in Table 2, to calculate the dose depth values. Dose Depth is the dose at a certain depth value received by phantom or patient. The dose values analyzed can be used as a reference picture of doses at various depths and spacious grounds with energy of 6 MV linac. The dose depth can be found using equation:

$$MU = \frac{D}{TMR\,\%\, x\, OF} \tag{3}$$

(Monitor Units) is a linac output dose, (Depth Dose), (Tissue Maximum Ratio), and (Output Factor) of linac. For the field size 4x4 cm^2, 6x6 cm^2, 8x8 cm^2, 10x10 cm^2 is 1.00. So we get the equation :

$$\text{Dose Depth (cGy)} = \text{TMR\% x MU} \tag{4}$$

The dose 300 cGy as the percentage of the dose at the maximum depth is always normalized to 100%, with the linac output dose used in this research 300 MU, which equivalent to 300 cGy. All fields obtained by calculating the dose depth (cGy) are presented in Table 2:

Table 2. The calculation result of the depth-dose of fields variation

Field Size(cm)	*Depth(cm)*	*Density*	TMR (%)	*Depth-Dose* (cGy)
4x4	1,5	79	119,9	359,7
	4	76	105,1	315,3
	6	68	93,8	281,4
	8	67	80,4	241,2
	10	60	73,5	220,5
6x6	1,5	71	118,2	354,6
	4	71	104,7	314,1
	6	77	94,2	282,6
	8	80	81,5	244,5
	10	85	74,9	224,7
8x8	1,5	69	117,2	351,6
	4	74	104,5	313,5
	6	80	94,6	283,8
	8	81	82,4	247,2
	10	80	76	228
10x10	1,5	63	116,3	
	4	71	114,2	342,6
	6	71	94,8	248,4
	8	77	83,2	249,6
	10	81	77	231

Based on the calculation results of depth-dose value above, characteristic curve showing the relation between the density with depth-dose is obtained as follow:

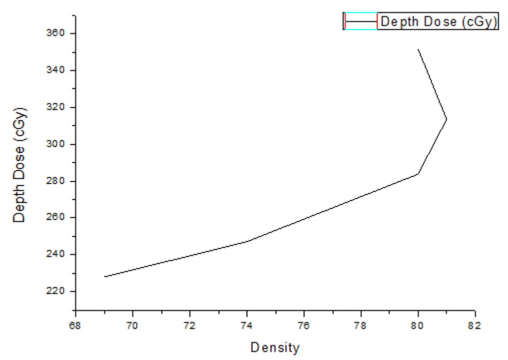

Figure 3. The characteristic curves of relation between gafchromic RTQA2 film density with depth-dose on 4x4 cm^2 field size

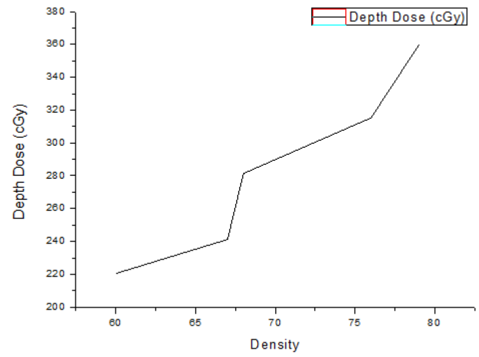

Figure 5. The characteristic curves of relation between gafchromic RTQA2 film density with depth-dose on 8x8 cm^2 field size

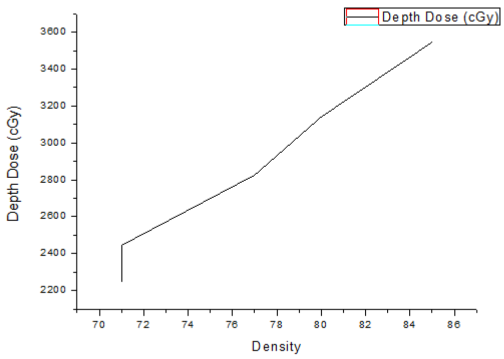

Figure 4. The characteristic curves of relation between gafchromic RTQA2 film density with depth-dose on 6x6 cm^2 field size

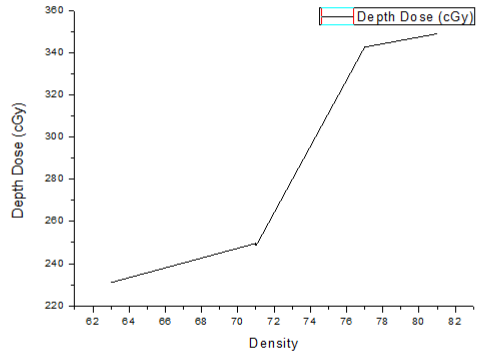

Figure 6. The characteristic curves of relation between gafchromic RTQA2 film density with depth-dose on 10x10 cm^2 field size

Analysis of depth-dose relationship with the density can be calculated by the equation:

$$\dot{X} = \frac{\Gamma A}{X^2} = D = f\frac{\Gamma A}{X^2}t \quad (5)$$

to obtain the linear equation:

$$D = \frac{a}{OD^2} = D = aOD^{-2} \quad (6)$$

Where is a constant which can be obtained from the graph of with depth dose which is the value of the gradient chart, is the conversion factor of the rate of exposure to the rate of absorbed dose (rad / R), is irradiation (R), is depth of target, is Absorbed dose (rad), is Optical density, is the power source (a specific constants) and is Activitation (Ci).

In the all of fields obtained by calculating the depth-dose (cGy) shows that the higher the density, the further depth-dose value increase. From the calculation, magnitude of specific field size can be seen and can be used as guidelines for the calculation of depth dose as a reference depth dose received by patients for the purpose of verification of the dose received by the patient using a dosimeter of gafchromic RTQA2 films.

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4. Conclusion

Based on the background and research that has been done, researchers concluded that:

1. Density film is even more valuable when the value of the current film position depth variation has greater exposure. Conversely, the lower the depth value, the density value of the film decreases. The density is inversely proportional to the level of darkness in the film after irradiation, the higher the level of darkness in the film, the smaller the density values, whereas the dose absorbed by the film decreases. This means that the higher the dose absorbed, the higher level of darkness in the film, but the density decreases.
2. The characteristic curves obtained can calculate the magnitude of the dose at a certain depth and specific field size. So, it can be used as a guide of a reference dose calculations and dose the patient received a picture for purposes of verification of the dose received by patients radiotherapy.

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