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DOSIMETRIC EVALUATION OF HIGH ENERGY PHOTONS AND ELECTRONS USING ImageJ SOFTWARE IN COMPARISON TO DOSIMETRIC FILM SCANNER

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ABSTRACT

This study evaluates the ImageJ software as dosimetric tools for analyzing the film dosimeter in high energy photons and electrons. The percentage depth dose of photons of 6 and 10 MV and electrons of 6 and 9 MeV were measured using the Gafchromic EBT2 film dosimeter. The films were scanned and analyzed using the Verisoft software and ImageJ. The beam profiles at nominal photon and electron beam parameters were also evaluated using the two methods. The PDD measured in ImageJ at high energy photons were in good agreement within 1% percentage of discrepancy at all depths in comparison to the Verisoft software. The PDD measured in ImageJ at high energy electrons also showed good agreement to Verisoft software within 8% percentage of discrepancy at all depths. The measured flatness of beam profiles at Dmax, R_{50}, R_{80} and R_{90} in ImageJ were also in good agreement to Verisoft software with flatness value between 4 and 8%. The results indicated the suitability of ImageJ software as dosimetric tool for analyzing EBT2 film dosimeter at high energy photon and electrons.

Keywords: Dosimetric, electrons, ImageJ, percentage depth dose, photons

INTRODUCTION

The dose calculation in radiation therapy involving high energy photons and electrons are very important to ensure the accuracy and successfulness of treatment delivery. The absorbed dose in the medium including the human soft tissues is influenced by several factors including beam energy, depth, field size, and distance from source (SSD) and beam collimation. The percentage depth dose (PDD) is the common parameter to determine the attenuation properties and dosimetric evaluation of a medium towards photon and electron beams. The PDD at depth in the medium is calculated by the equation:

$$PDD = \frac{Dose\ measured\ at\ depth, Z}{Maximum\ dose\ at\ D_{max}} \qquad (1)$$

Due to the difference of radiation characteristics and energy impartion by the medium, the PDD in the high energy photons and electrons are differs when they are plotted in their respective PDD curves. Dosimetric information can be obtained from a PDD curve including the surface dose, the depth of maximum dose, d_{max} and the percentage of dose at any depth in relation to the d_{max}. The dosimetry at high energy electrons are often expressed in several dosimetric parameters such as the therapeutic range (R_{80} and R_{90}), and practical range, R_p where all the electrons are completely stopped in the medium. The R_{80} and R_{90} are expressed as the dose of 80 and 90 % from the prescribed dose respectively. The available dosimetric protocols for clinical electron beams had stipulated R_{80} and R_{90} as reference depths for dosimetry work in electron beams to ensure precision and uniformity of dose delivery in treatments using electrons (IAEA, 2000). This is to ensure that the tumor volume received the radiation dose within these therapeutic ranges. The R_p on the other hand indicated the attenuation properties of the medium towards the electron. The dosimetric property for photons on the other hand is indicated at the reference depth d_{ref} within the medium measured during the output calibration of photons measured at 5 cm and 10 cm depth for 6 and 10 MV photons respectively (IAEA, 2000).

Ionization chambers had been commonly used as dosimeter to measure the PDD in high energy photon and electrons. However, the development of modern radiotherapy techniques such as intensity modulated radiation therapy (IMRT) requires more accurate and in-situ dose measurement with high spatial resolution to incorporate with the mixed-field radiation beam used in IMRT (Alves Victor et al., 2013). Radiochromic films are widely used in dosimetry and quality assurance of linear accelerators due to the better sensitivity and dose dependent as compared to the radiographic films (Carrasco et al., 2013). The major advantage of radiochromic film compare to radiographic film is almost tissue equivalent with effective atomic number between 6.0 and 6.5. The radiochromic films are also having low energy dependence, less sensitive to visible light and large dynamic range between 10^{-2} and 10^{6} Gy (Khan, 2010; Chang et al., 2015). Radiochromic films are self-developed films that blacken after irradiation with ionizing radiation without the use of chemical and physical processing (Micke et al., 2011). Cafchromic EBT2, often called the EBT2 films had been extensively used as film dosimeter involving high energy photons and electrons (Arjomandy et al., 2010; Arjomandy et al., 2012). It is manufactured with the presence of a yellow dye into the active layer of the film that improves the homogeneity of the active layer. It is also sensitive to the blue light, thus reducing the light dependence of the film (Butson et al., 2010; Carasco et al., 2013).

The use of film dosimeters however requires the use of film scanner in order to digitize and further analyze the signal obtained from the ionizing radiation. The typical film scanners used in film dosimetry are the red, green and blue (RGB) flatbed scanners that provide maximum emission of wavelength close to 630 nm which is close to the peak absorption of typical radiochromic films. The signal produced by the radiochromic films are called the optical density, OD expressed in the equation:

$$OD = -Log_{10}\frac{PV}{65535} \qquad (2)$$

Where *PV* is the pixel value or the scanner value and 65535 is the maximum pixel value for 16 bit channel.

The scanned images are later analyzed using dosimetric software that provides the OD-absorbed dose conversion through the film calibration process at the linear accelerator. However, studied had been conducted to study the other alternative methods in analyzing the scanned image of radiochromic films.
ImageJ (Figure 1) is an image post-processing free software (public domain) compatible to all operating system such Windows, Linux, and Mac OS X (Abràmoff et al., 2004; Dello et al., 2007). ImageJ is capable in analyzing most of the density value of a subject such as film and microscopic image structure. It had been used in radiography image analysis such as computed tomography as it provides similar range of grayscale to the radiography images (Schneider et al., 2012). It can be used to acquire images directly from scanner, and camera devices that is compatible with TWAIN and FireWire ports. However, the evaluations of ImageJ on radiochromic film dosimeters are yet to

be studied. This study focused on the evaluation of ImageJ to reconstruct the PDD curve of high energy photons and electrons in comparison to the Verisoft software which is commonly used in radiation dosimetry.

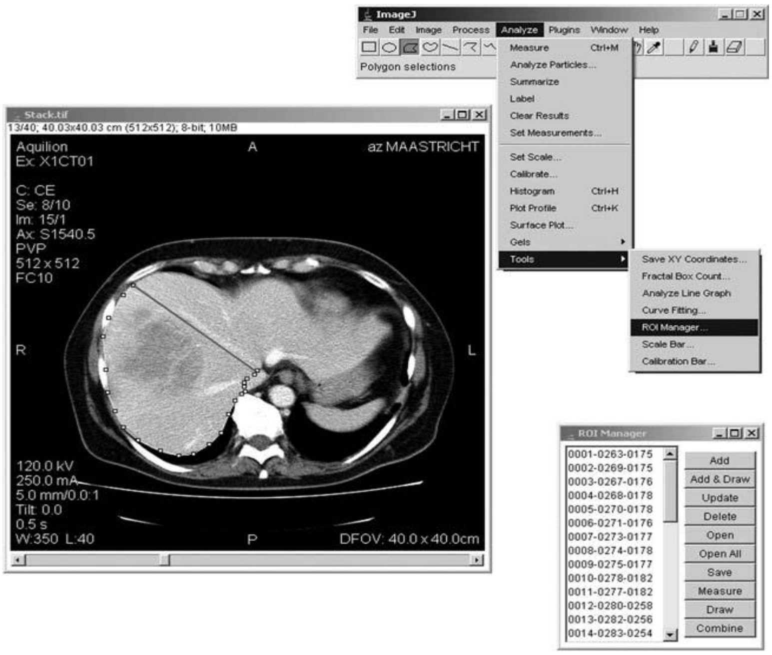


Figure 1: An interface of ImageJ software analysis

MATERIALS AND METHODS

Experiment Materials

The Siemens PRIMUS linear accelerator was used as the source of high energy photons and electrons. The solid water phantoms were used as medium to simulate the properties of human soft tissue. The Gafchromic EBT2 film was used as film dosimeter to measure the PDD in high energy photons and electrons. Gafchromic EBT2 radiochromic film dosimeter (Ashland Inc., Kentucky, USA) was introduced to improve its predecessor Gafchromic EBT film. It is manufactured with the presence of a yellow dye into the active layer of the film that improves the homogeneity of the active layer. It is also sensitive to the blue light, thus reducing the light dependence of the film (Carasco et al., 2013). The Epson Expression 10000XL scanner was used to digitize the EBT2 film. It has scanning ability is 2400 dots per inch (dpi) versus 4800 dots per inch (dpi) which is horizontal versus vertical axis. The input and output color of this scanner is 16 bits each somehow the total support color is 48 bits. The maximum scanning speed is 12.7 s and maximum OD value of 3.8.

Experimental Designs

The calibration of EBT2 film was carried out at 6 and 10 MV photons and 6 and 9 MeV electrons with dose between 0 and 600 cGy. The calibration curve was obtained using Verisoft and ImageJ software and the calibration curves were compared between the two methods. The EBT2 film was sandwiched between the solid water phantoms with lateral thickness of 15 cm. The film was exposed with the position parallel to the beam as shown in Figure 2. The exposures were made at 90° of gantry rotation angle to minimize the air gaps among the solid water phantom slabs. The films were exposed to 6 and 10 MV photons and 6 and 9 MeV electrons at 100 cm source to surface distance (SSD) and field size of 10 cm x 10 cm at the surface. Al exposures were made at 100 cGy of radiation dose indicated by the pre-exposure setting monitor unit (MU) of 100 MU.

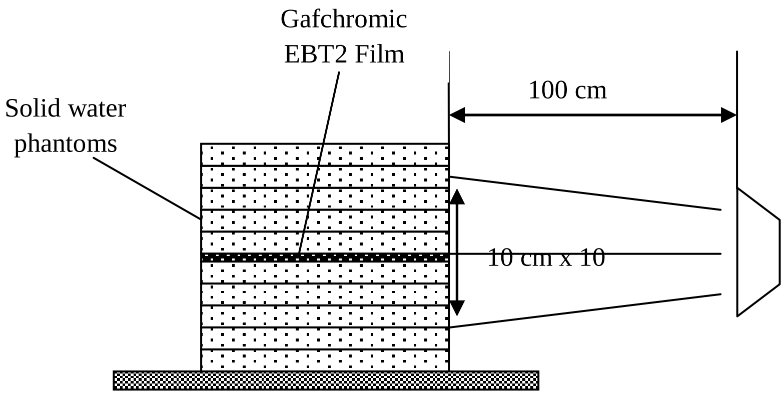


Figure 2: The experimental set up of measuring the percentage depth dose (PDD) of high energy photons and electrons using EBT2 film dosimeter

The exposed EBT2 film were scanned using Verisoft and ImageJ software and the the PDD curves using both methods were plotted and compared. The percentage of discrepancy of PDD in ImageJ to the Verisoft at all depths is calculated using the equation:

$$Percentage\ of\ discrepancy\ (\%) = \frac{PDD_i - PDD_v}{PDD_v} \times 100\% \quad (3)$$

With PDD_i and PDD_v is the PDD measured PDD in ImageJ and Verisoft sofwares respectively. The beam profiles at d_{max} at both photon and electron beams were also plotted using both Verisoft and ImageJ softwares. The beam profile at electron beam parameters of R_{80} and R_{90} were also plotted.

RESULTS AND DISCUSSION

The calibration curves of the EBT2 film at 6 MV photons and 6 MeV electrons are illustrated in Figure 3 and 4, respectively. The results showed that the calibration curve measured using ImageJ software was in good agreement with that in Verisoft software. The grayscale ranges of the ImageJ display were also in good agreement with the OD value of the EBT2 films at both photon and electron beams shown by the linear regression lines R^2 that are near to the value of 1 (Chang et al., 2015). This had indicated that the grayscale in the ImageJ is comparable to the pixel value in the Verisoft software.

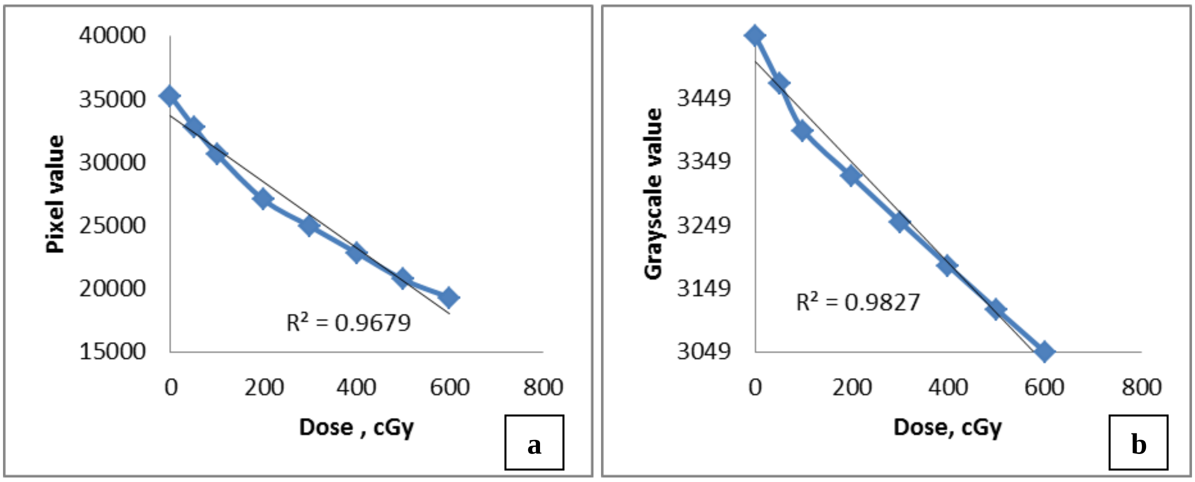


Figure 3: The calibration curve of EBT2 film using Verisoft (a) and ImageJ (b) at 6 MV photons

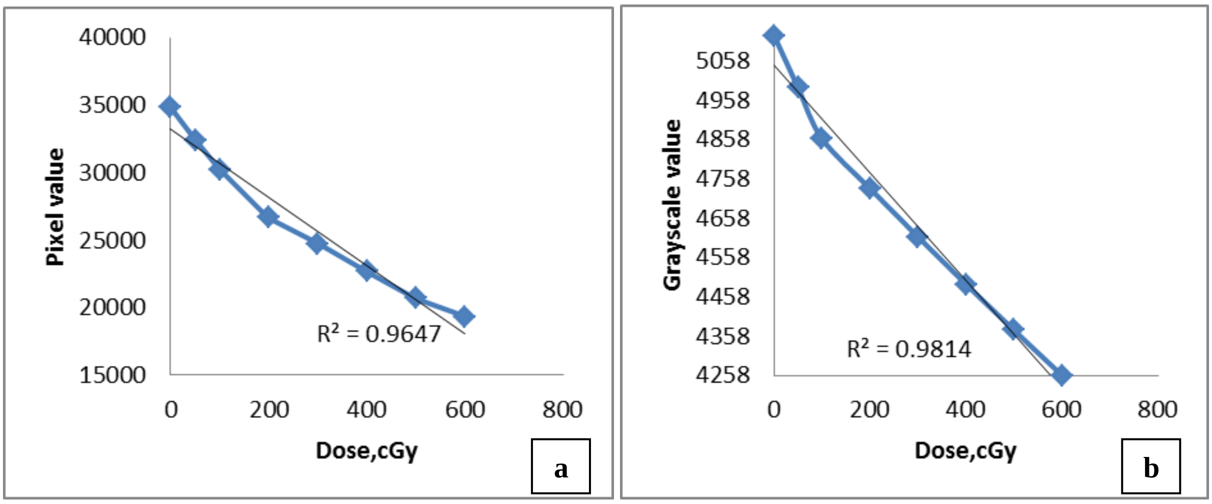


Figure 4: The calibration curve of EBT2 film using Verisoft (a) and ImageJ (b) at 6 MeV electrons

The comparison of percentage depth dose (PDD) at 6 and 10 MV photons between Verisoft and ImageJ is shown in Figure 5. The PDD of ImageJ showed an outstanding agreement to Verisoft software at both 6 and 10 MV photons. The percentage of discrepancies between ImageJ and Verisoft software were within 0.7 and 0.41% at all measured depths at 6 and 10 MV photons, respectively. A comparison to the ionization chamber measured in water also showed good agreement within 0.23 and 0.28% at all measured depths at 6 and 10 MV photons respectively. The surface dose at 6 MV photons measured in ImageJ was found to be lower than that measured in Verisoft software and ionization chamber with percentage difference of 30 and 30.5% respectively. The surface dose at 10 MV photons measured in ImageJ software was also found to be lower than Verisoft software and ionization chamber at lower percentage differences of 17 and 10.8%, respectively.

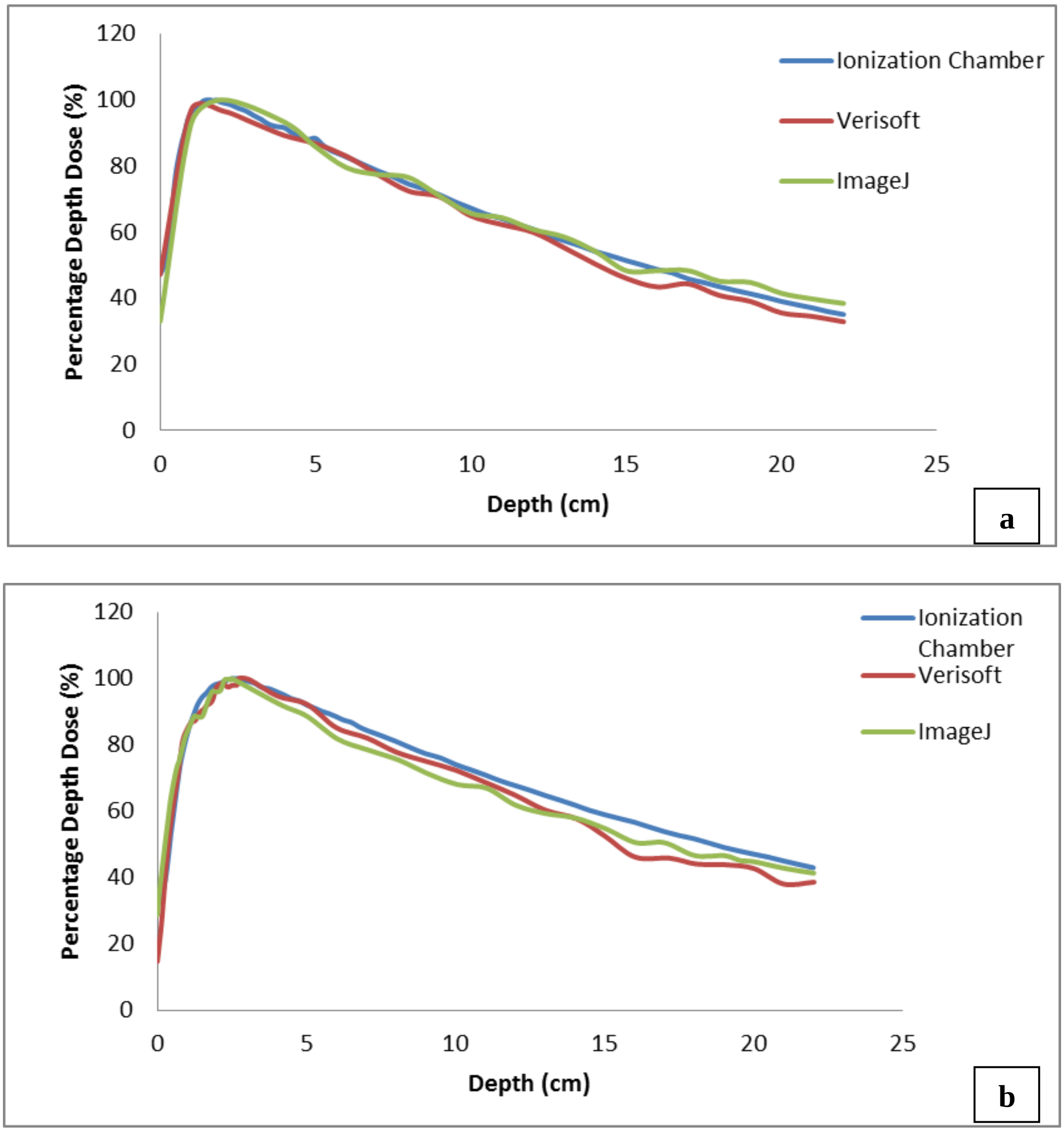


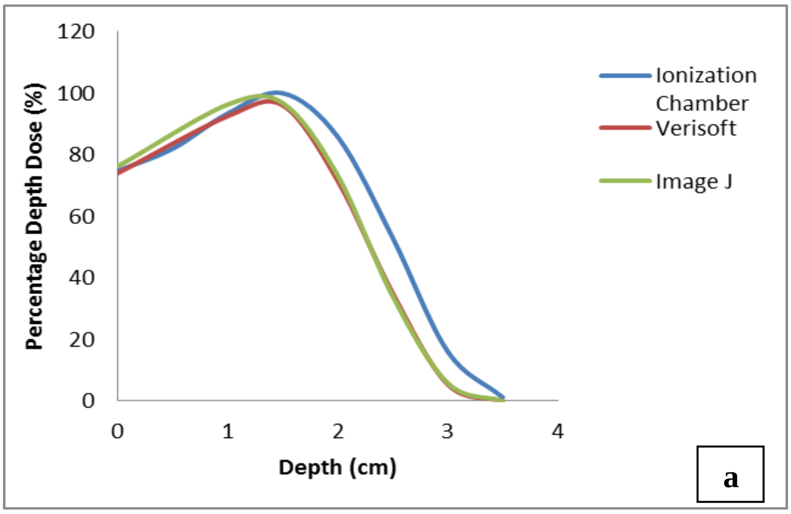
Figure 5: The comparison of PDD curves using Verisoft and ImageJ at 6 MV (a) and 10 MV (b) photons

The percentage dose at d_{ref} for 6 and 10 MV measured in ionization chamber, Verisoft software and ImageJ software is presented in Table 1. The results showed that the percentage dose at d_{ref} for ImageJ was in good agreement to the Verisoft software with percentage difference of and 1.1 and 1.2% for 6 and 10 MV photons respectively. A comparison with the ionization chamber showed an agreement within 3.6 and 3.5% percentage difference for 6 and 10 MV photons respectively. The results had indicated the suitability of ImageJ as dosimetric analysis tool for EBT2 film for high energy photons.

Table 1: The percentage dose at d_{ref} for 6 and 10 MV photons in ImageJ, Verisoft software and ionization chamber

	Percentage Dose at d_{ref} (%)		
Photon Energy	**Ionization Chamber**	**Verisoft**	**ImageJ**
6 MV	89.08	86.77	85.81
10 MV	74.06	72.30	71.44

The comparison of PDD at 6 and 9 MeV electrons between Verisoft and ImageJ is shown in Figure 6. The results showed that the PDD in ImageJ was in good agreement with Verisoft software at both 6 and 9 MeV electrons. The percentage of discrepancies at 6 MeV electrons between ImageJ and Verisoft were within 7.7% at all measured depths. The percentages of discrepancies at 9 MeV electrons however were lower than that in 6 MeV within 4.4% at all measured depths. The percentages of discrepancies were also observed to be higher at the depths beyond the d_{max} at both 6 and 9 MeV electrons. A comparison of PDD in ImageJ and Verisoft to the ionization chamber measured in water showed significantly higher percentage of discrepancies within 28% observed prominently at the depths beyond the d_{max}. A comparison to the ionization chamber at 9 MeV electrons however showed an agreement with percentage of discrepancies within 9% for both ImageJ and Verisoft software.



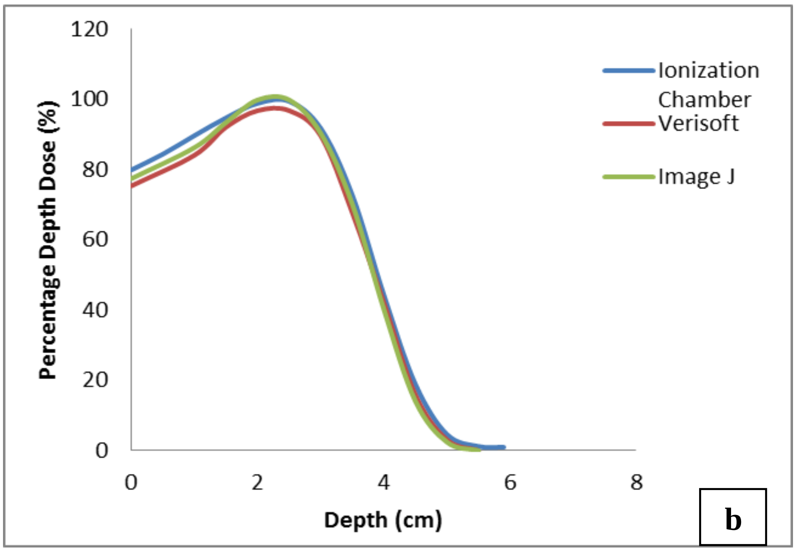


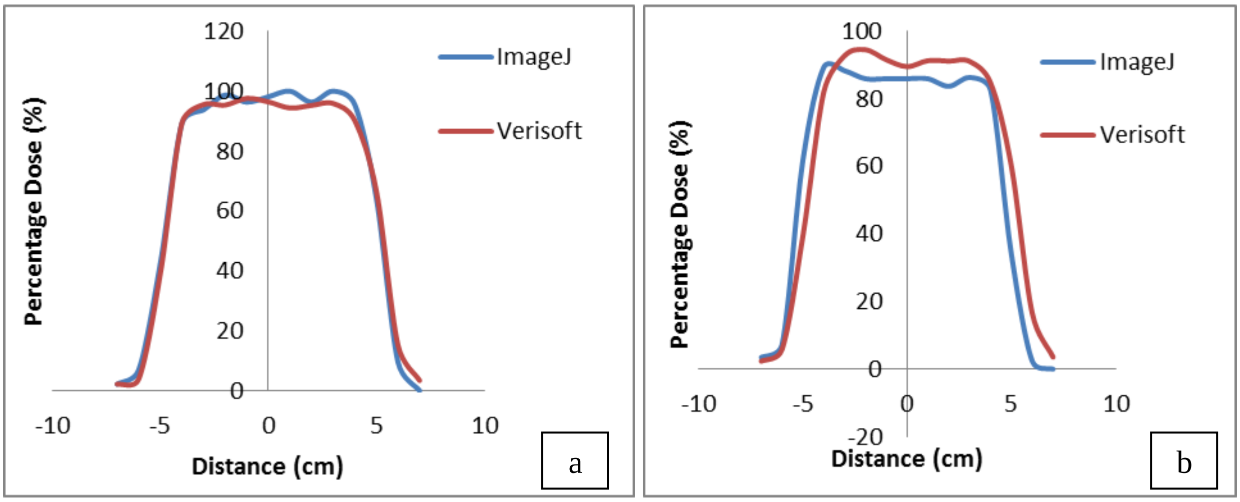
Figure 6: The comparison of PDD curves using Verisoft and ImageJ at 6 MeV (a) and 9 MeV (b) electrons

The electron beam parameters for ImageJ and Verisoft softwares at 6 and 9 MeV electrons are presented in Table 2. The results showed a good agreement of beam parameters measured in ImageJ in comparison to Verisoft software and ionization chamber at 6 and 9 MeV electrons. The percentage dose at respective beam parameters measured in ImageJ was observed to be slightly higher than that in Verisoft software and ionization chamber. This had shown the linearity of dose evaluation measured in ImageJ to the value by Verisoft indicating the suitability of ImageJ as dosimetry tool for high energy photons and electrons.

Table 2: The beam parameters of ImageJ, Verisoft software and ionization chamber at 6 and 9 MeV electrons

Beam Parameter		Percentage Dose (%)		
		Ionization Chamber	**Verisoft**	**ImageJ**
6 MeV	R_{50}	48.82	49.40	51.56
	R_{80}	79.50	79.75	82.61
	R_{90}	90.70	89.90	92.76
	d_{max}	100.00	100.00	96.30
9 MeV	R_{50}	50.05	51.64	50.31
	R_{80}	90.06	89.87	92.67
	R_{90}	79.43	81.49	81.28
	d_{max}	100.00	100.00	100.00

The dose profiles for 6 MeV electrons measured at d_{max}, R_{80} and R_{90} for imageJ and Verisoft software were illustrated at Figure 7. The beam profile in ImageJ was found to be consistent with Verisoft with penumbra size of 2 cm at all depths. The flatness of the dose profile in ImageJ were 4.86, 6.02 and 4.46 % compared to 3.9, 5.7 and 3.7 % measured in Verisoft at d_{max}, R_{80} and R_{90} respectively. A slight asymmetrical of the dose profile was also observed at R_{90} and R_{80} in both ImageJ and Verisoft as shown in Figure 7 (b) and Figure 7 (c), respectively.



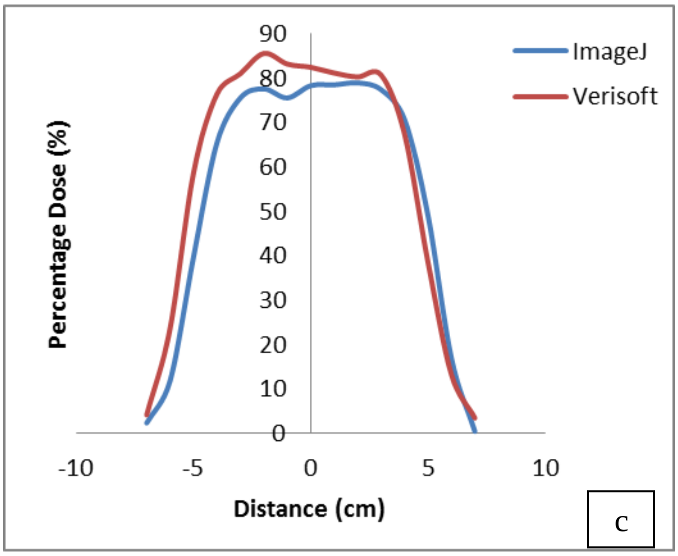
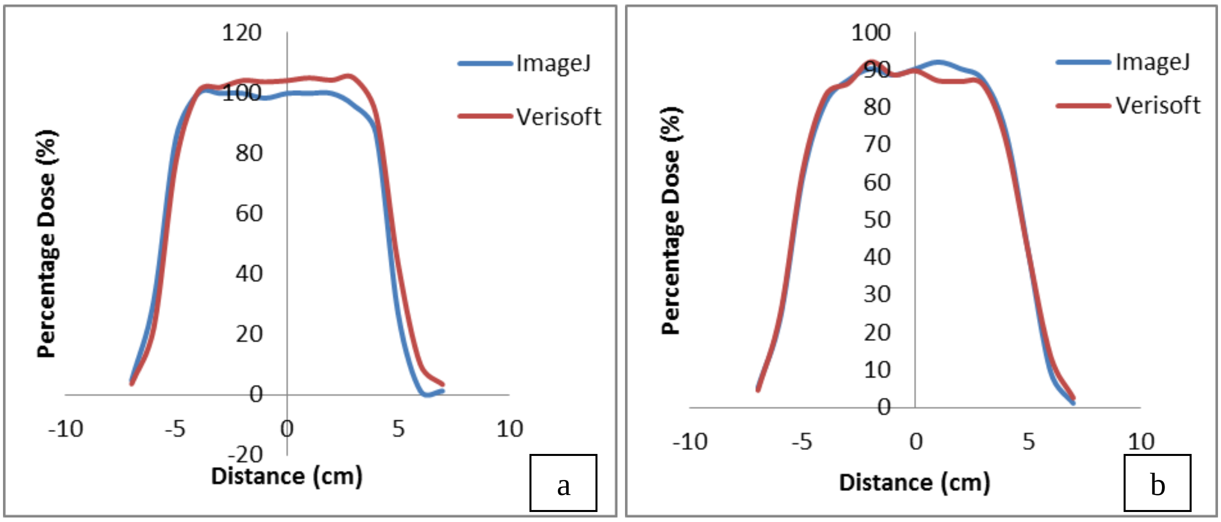


Figure 7: The beam profiles of ImageJ and Verisoft at d_{max} (a), R_{80} (b) and R_{90} (c) measured at 6 MeV electrons

Similar patterns were also observed in the dose profile of 9 MeV electrons measured at similar depths as shown in Figure 8. The penumbra however was found to be higher at 4 cm for both ImageJ and Verisoft software at all measured depths of the dose profile. The flatness of the dose profile in ImageJ was 2.35, 2.9 and 2.8% which was lower than the values of 1.6, 3.9 and 3.95% by Verisoft software at, R_{80} and R_{90} respectively. A good symmetry of the dose profile was observed in ImageJ and Verisoft. A slight asymmetrical of dose profile however was observed at R_{90} as shown in Figure 8 (b). The determination of dose profile helps in determining the dose uniformity of dose in the medium as that ensure the successful delivery of the prescribed dose in external beam therapy involving high energy photons and electrons (Udalagama et al., 2013).



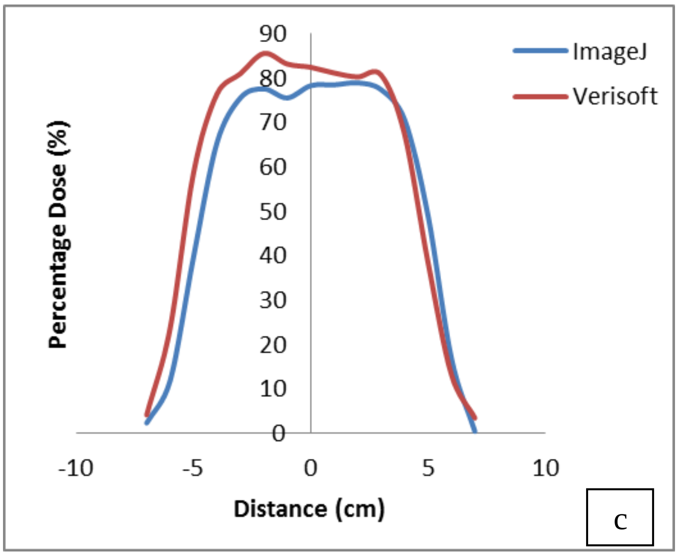


Figure 8: The beam profiles of ImageJ and Verisoft at d_{max} (a), R_{80} (b) and R_{90} (c) measured at 9 MeV electrons

CONCLUSIONS

The use of film dosimeter had been a convenient method for dosimetry works involving high energy photons and electrons. This method however requires time consumptions at the workstations of film dosimetry workstations. ImageJ had shown a good agreement of dosimetry characteristics to commonly used Verisoft software at high energy photons and electrons. This is shown by the consistency of percentage depth dose, and beam profile at high energy photons and electrons in comparison to Verisoft software and ionization chambers data measured in water. The study had indicated the suitability of ImageJ as an alternative dosimetry tool for dosimetry of high energy photons and electrons.

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