EBT2 FILM DOSIMETRY USING IMAGEJ SOFTWARE ANALYSIS AT HIGH ENERGY PHOTON BEAMS

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By

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Dissertation submitted in partial fulfillment

of the requirements for the degree

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CERTIFICATE

This is to certify that the dissertation entitled "EBT2 FILM DOSIMETRY USING IMAGEJ SOFTWARE ANALYSIS AT HIGH ENERGY PHOTON BEAMS" is the bona fide record of research work done by Ms Nur Amirah Nabila Binti Ramli during the period from January 2016 to May 2016 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfillment for the degree of Bachelor of Health Science (Honours) Medical Radiation.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

....

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Date: ....

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Alhamdulillah. Thanks to the Almighty for with His Mercy, I have completed my undergraduate research project entitled **"EBT2 FILM DOSIMETRY USING IMAGEJ SOFTWARE ANALYSIS AT HIGH ENERGY PHOTON BEAMS".**

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LIST OF SYMBOLS AND ABBREVIATIONS

Name	**Definition**
%	Percentage
PDD	Percentage depth dose
MV	Megavoltage
SSD	Source to surface distance
D max	Dose at maximum

ABSTRACT

The aim of this study is to evaluate the dosimetry parameters using ImageJ software and conventional software, Verisoft software. The EBT2 film was irradiated with 400 MU for 6 MV and 10 MV energy photon of Siemens Primus (LINAC). The film was cut into 3 x 3 cm and exposed to 0 cGy - 600 cGy doses for calibration purposed. Another film from the same batch of EBT2 film was used to measure percentage depth dose (PDD) and beam profile.The film was scanned 24 hr after irradiation with Epson Expression 10000 XL flatbed scanner. The percentage depth dose (PDD) and beam profile were analyzed using Verisoft (5.1) and ImageJ softwares. The result showed that the calibration curve using ImageJ for 6 MV and 10 MV energy photon excellent linearity (R^2 = 0. 982 and 0.981 respectively).The percentage discrepancy for PDD was calculated for each 1 cm depth. The small percentage discrepancy between ImageJ and Verisoft is 0.72 % and between ImageJ and ionization chamber is 0.23 % for 6 MV PDD. The percentage discrepancy of 10 MV between ImageJ and Verisoft is 0.41 % and between ionization chamber is 0.28 %. The flatness of beam profile by ImageJ is 3.2 % and Verisoft is 5.0 % for 6 MV energy photon the beam flatness of 10 MV energy photon for ImageJ is 4.27 % and Verisoft is 1.97 %. The penumbra at 6 MV energy for Verisoft is -5.5 and + 5 and for ImageJ is -4.5 and +4. At 10 MV for Verisoft, the penumbra is - 4 and +5 and for ImageJ - 4 and + 4.5. The symmetry at the 6 MV is 0.96 % for Verisoft and 1.6 % for ImageJ. The symmetry of the 10 MV for Verisoft and ImageJ is 0.17 % and 0.054 % respectively. As the conclusion the ImageJ can be used as the alternative film quality assurance software due to its good agreement with conventional software, Verisoft.

ABSTRAK

Tujuan kajian ini adalah untuk menilai parameter dosimetri menggunakan perisian ImageJ dan perisian konvesional, perisian Verisoft.The EBT2 filem telah diradiasi dengan 400 MU selama 6 MV dan 10 MV tenaga foton Siemens Primus (LINAC) . Filem ini dipotong menjadi 3 x 3 cm dan didedahkan dengan dos 0 cGy – 600 cGy untuk penentukuran berazam. Satu lagi filem dari kumpulan yang sama EBT2 filem telah digunakan untuk dos kedalaman peratusan kajian (PDD) dan profil alur tuju. Filem ini telah diimbas selepas 24 jam dengan Epson Expression 10000 XL flatbed scanner.Kedalaman peratusan dos (PDD) dan profil alur tuju dianalisis menggunakan Verisoft (5.1) dan perisian ImageJ. Hasilnya menunjukkan bahawa keluk penentukuran kelinearan sangat baik (masing-masing R^2 = 0. 982 dan 0.981) menggunakan ImageJ untuk 6 MV dan 10 MV foton tenaga. Percanggahan peratusan bagi PDD dikira untuk setiap 1 cm mendalam.Percanggahan peratusan kecil untuk 6 MV PDD antara ImageJ dan Verisoft adalah 0.72 % dan antara ImageJ dan kebuk pengionan adalah 0.23 %. Percanggahan peratusan 10 MV antara ImageJ dan Verisoft adalah 0.41 % dan antara kebuk pengionan adalah 0.28 %. Rataan profil alur bagi ImageJ ialah 3.2 % dan Verisoft 5.0 % untuk 6 MV foton tenaga. Rataan profil alur untuk 10 MV foton tenaga bagi ImageJ ialah 4.27 % dan Verisoft ialah 1.97 %. Penumbra pada tenaga 6 MV untuk Verisoft ialah -5.5 dan + 5 dan untuk ImageJ ialah -4.5 dan 4 . Pada 10 MV untuk Verisoft , penumbra adalah - 4 dan 5 dan untuk ImageJ - 4 dan + 4.5. Simetri pada 6 MV 1.42 untuk Verisoft dan 1.76 untuk ImageJ . Simetri 10 MV untuk Verisoft dan ImageJ ialah masing-masing 0.3 dan 1.07.Sebagai kesimpulan yang ImageJ boleh digunakan sebagai perisian jaminan kualiti filem alternatif kerana perjanjian yang baik dengan perisian konvesional,Verisoft

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Radiations detectors are defined as the device or system to measure and evaluate the radiation quantities. The commonly used radiation detectors include ionization chamber, thermo luminescent, diodes and films. Radiographic film and radiochromic film are the two types of films dosimetry that widely used in radiotherapy due to the high spatial resolution and two dimensional dose measurements (Sim *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*, 2012). The major advantage of radiochromic film compare to radiographic film is almost tissue equivalent with effective atomic number is 6.0 to 6.5, lower energy dependence, less sensitive to visible light and large dynamic range (10^{-2} to 10^{6}Gy)(Khan,2003). Radiochromic films such as EBT2 and EBT3 are self-developed film that blackens after irradiation with ionizing radiation without the use of chemical and physical processing (Lewis, 2011).

The first generation of Gafchromic EBT film was widely used for dosimetry is EBT before it replaced with Gafchromic EBT2. On that time, the advantages of EBT films were the sensitivity in range 1cGy to 800cGy, energy independence between keV and MeV and nearly tissue equivalent (Z_{eff} = 6.98). EBT film can be immersed for dose measurement in water at a shorter time. The structure of EBT2 film in comparison to its predecessor EBT is illustrated in Figure 1.1.

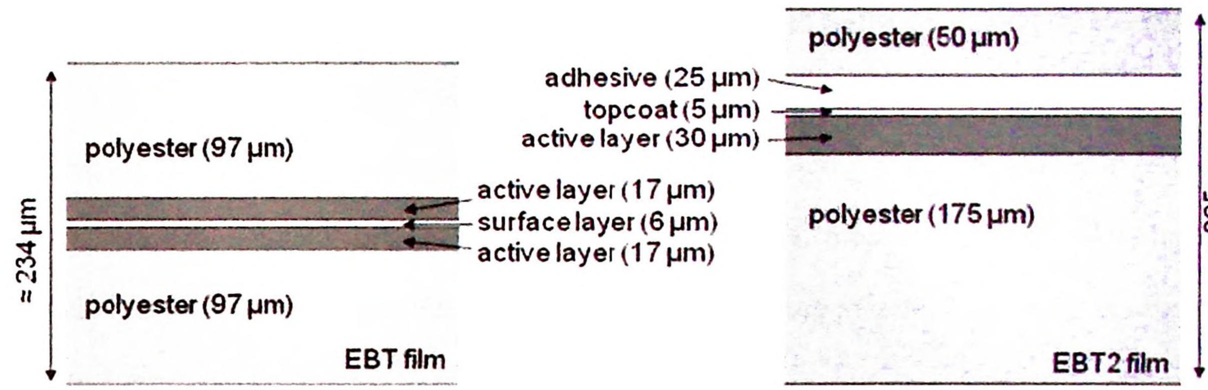


Figure 1.1: Structure of EBT2 film (right) and EBT film (left) as stated by manufacturer. Note. From "Evaluation of Gafchromic EBT2 film dosimetry system for radiotherapy quality assurance" by Aland *et al.*, 2011

The polyester laminate at the first layer of Gafchromic EBT2 intends to protect the active layer and topcoat layer at the middle from the mechanical damage. This improvement made the Gafchromic EBT2 film able to be immersed in water due to the diffusion of water through polyester is exceedingly slow compared to the Gafchromic EBT.

Another additional feature in Gafchromic EBT2 films is the presence of yellow dye within the active layer act to absorb blue light. This improvement makes the EBT2 film is less sensitivity towards the indoor light compares to its predecessor (Carrasco et al., 2012). According to the study, the result proves that under the low exposure of indoor light, the signal in the EBT2 film is less affected by light exposure compared to EBT.

Image processing software may obtain either via purchased from a commercial vendor or produced in-house by individuals with computer programming experience. The ideal image analysis software could be inexpensive, able to run on multiple operating systems and flexible to read various image formats like TIFF, JPEG, and DICOM.

National Institutes of Health, NIH had developed the ImageJ Software to analyze the film's data. The ImageJ not only the open source code and license free but also able to run in different computer operating system such as Microsoft Window, Mac OS and Linux. In an analysis conducted by Abramoff *et al.*, 2014 stated that, more than 80000 downloads indicate that it is being used mostly with Microsoft operating system, Macintosh platforms and followed by Linux.

ImageJ is one of the images processing that supports numerous image processing function beyond simple image arithmetic, such as smoothing, sharpening, edge detection masking, binary operation, Fourier transformation and watershed information. In addition, at ImageJ site, there is approximately 200 user supplied plug in. These plug-in help user in solve image processing functions including the addition of image noise, the spatial transformation of image stacks, segmentation by k-means clustering and specialized edge detection (Barboriak *et al.*,2005).

In clinical radiotherapy the dose calculation is very important as it provides the information of depth dose as well as dose to the target area. The absorbed dose 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 of a medium towards photon and electron beams. Therefore, the PDD measurement was used to determine the attenuation properties and the suitability ImageJ to analyze the attenuation of photon beam in the medium in comparison to the conventional Verisoft software.

PDD can be calculated using the equation:

$$PDD = \frac{dose\ at\ any\ depth, D}{depth\ at\ maximum\ dose, Do} \times 100 \qquad (1)$$

In addition, from the beam profile graph it is important to determine the beam flatness and penumbra of the percentage dose towards the depth.

The beam flatness commonly defined as the difference of dose relative to the central axis over the central 80 % of the field size specified at a 10-cm depth in a plane perpendicular to the central axis. A dose variation of ± 3 % is considered acceptable. (Khan, 2003)

The term penumbra refers to the region at the edge of a radiation beam, over which the dose rate changes rapidly as a function of distance from the beam axis. The penumbra width increases by increase the source to surface distance and depth. Another important parameter that determined the penumbra width is source to diaphragm distance, SDD. By extend the penumbra trimmers, the SDD can be increase. These trimmers which are consist of heavy metal bars act to attenuate the beam in the penumbra region, next sharpening the field edges. While, the physical penumbra width refer to the lateral distance between two specified iodose curve at a specified depth. The symmetry of the beam profile is measure at the side by side equality of the beam.

Percentage of discrepancy is calculated to determine the percentage different of the experimental method to the standard value. The percentage discrepancy should be less than or equal to 10 % to be accepted.

1.2 Aim

- To evaluate dosimetry parameter using ImageJ for EBT2 film at high energy photon beams.

1.3 Specific Objectives

The specific objectives of the study are:

- To derive calibration curves for 6 MV and 10 MV photon using ImageJ Software and Verisoft software.
- To compare the PDD curves of 6 MV and 10 MV photon in ImageJ Software and Verisoft software.
- To compare the PDD curves of 6 MV and 10 MV photon in ImageJ software and ionization chamber reading.
- To compare the beam profile of 6 MV and 10 MV photon in ImageJ Software to Verisoft software.

1.4 Significance of Study

The significance of the study includes:

- Determination of the effectiveness of ImageJ Software as the analysis tool.
- Alternative method to test PDD and beam profile by using the solid water phantom and film processing software, ImageJ if do not have 3D water tank and conventional software.

CHAPTER 2

LITERATURE REVIEW

In an analysis conducted by Arjumandy *et al*, (2012), they investigated the Gafchromic EBT2 film as the alternative for ionization chamber for measuring depth dose. The films were exposed to x-ray (75 kVp), electron (7 and 20 MeV), (60) Co gamma energy, high energy X-rays (18 MV), and pristine Bragg-peak proton (126 and 152 MeV). The results showed that the measurement of percentage depth dose by using the Gafchromic EBT2 film show an excellent agreement with the measurement via ion chamber. The study concluded that Gafchromic film model EBT2 is the best indirect dosimeter in measuring the percentage depth dose at various type of ionizing radiation.

The energy dependence towards the dose response is critically important in the wide range of beam qualities used in radiation therapy since it may cause systematic errors of sources that cannot be corrected easily. The Gafchromic EBT2 film was commonly used nowadays especially for clinical use due to less energy dependence. Arjomandy *et al*. (2010) in their study found that the measurement of EBT2 energy dependence was within the uncertainties which are 1 sigma = ± 4.5 % for all energies and modalities. Other studies conducted by Martin *et al*. (2010) stated that Gafchromic film model EBT2 has weak energy dependence which is 6.5 % ± 1 % variation in optical density in response towards X-ray with energy range 50 kVp to 10 MV of x-ray beam irradiations. This is better in compared with EBT film which is 7.7 % ± 2 % variation in optical density in response towards the same energy range of EBT2 film of x-ray beam irradiation.

In a study reported by M.A Carrasco et al., (2012) comparison between a radiochromic EBT2 films with EBT film model towards light sensitivity under the low exposure of indoor light was investigated. The unexposed EBT and EBT2 films were placed in a room without exposing them to direct light for 15 days. The films were scanned by using the Epson Expression 10000XL scanner every day to identify how light exposure resulted in the darkening of the film. The result found that the EBT film difference is 4.3 % in pixel value for the red channel (equivalent to 11.4 ± 1.4 cGy) in 15 days. While the EBT2 film showed the difference in pixel value below 0.5 % (0.2 ± 1.8 cGy). On the same report, they studied the darken of the EBT2 film occurs in a shorter time. They kept a piece of EBT2 film in a room with fluorescent bulb under normal indoor illuminations (500 lux). The film was scanned after 4 hours of exposure. The result showed the maximum difference of pixel value is 0.5 % for the red channel which is equivalent to a dose of 0.2 ± 1.8 cGy. So the EBT2 film is not dependence towards the light exposure.

In a study conducted by Dello *et al.*, (2007) the accuracy of ImageJ for hepatic CT volumetry was determined. Preoperative CT scans of 15 patients underwent liver resection for colorectal cancer liver metastases were analyzed. The scans were analyzed using ImageJ. The area of selected regions which are metastases, resection specimen, and remnant liver were multiplied with the slice thickness to calculate the volume. Then, the volume of virtual liver resection specimens was measured by ImageJ and compared to the actual volume. The results found that the weight and volume ratio was in agreement with the earlier findings using the CT-linked radiologic software which is 0.88 ± 0.004, the correlation between the volumes calculated by ImageJ and the actual measured weight of resection specimens also showed excellent agreement ($r^2 = 0.98$, $p < 0.0001$). This study showed that the ImageJ may be used in analysis of CT volumetric for liver on a personal computer and specifically useful for patient that already undergo CT scan and has radiographic imaging from the referring institution.

A study by Wendt, (2014) had used ImageJ as the image processing software to investigate the transformation of the red, green and blue channels of a digital scan of Gafchromic EBT2 film toward dose. ImageJ was chosen as the image processing software in this study due to plenty of internal features. In addition, it is freely available Java programming language also consist of optional modules called plug-in that help to perform principle component analysis of the image. Since the ImageJ able to automate the conversion of a raw scanned image into optical density and finally into the dose image based on the experimentally derived calibration curved. This feature makes the ImageJ is user friendly compared to others image analysis software.

In presented paper by Barboriak et al., (2005) conducted a study about the image analyses can be performed directly on DICOM image using the ImageJ. DICOM images are the common image format that obtains directly from imaging equipment or PACS storage without need the conversion steps. Plus DICOM image provides valuable information include the scan parameters in MRI and CT imaging that might be lost if converted into another format of image. Therefore this study had done since the existing packages of software cannot directly utilize the DICOM image format. The ImageJ software was install in the computer in laboratory. The uses of ImageJ software in analyze the DICOM image had been demonstrated. At the end of their study, they simplified that the ImageJ is low cost, able to run on multiple operating systems, flexible and support automated analyses.

CHAPTER 3

MATERIALS AND METHOD

3.1 MATERIALS

3.1.1 Gafchromic EBT2 radiochromic film

The EBT2 film from batch number 04021502 was used for this study. The first layer of film is made up of over-laminate layer (50 μm) functions to protect the active layer and topcoat from mechanical damage when to cut the film or immersed in water. Others improvement that had made in EBT2 is the natural polymer which is gelatin act to bind the active layer and topcoat has been replaced to a synthetic polymer.

The Gafchromic EBT2 film is the presence of yellow dye within the active layer. This yellow dye acts as a marker to determine the response of film towards the thickness of the active layer. The cross section of Gafchromic EBT2 film is shown below.

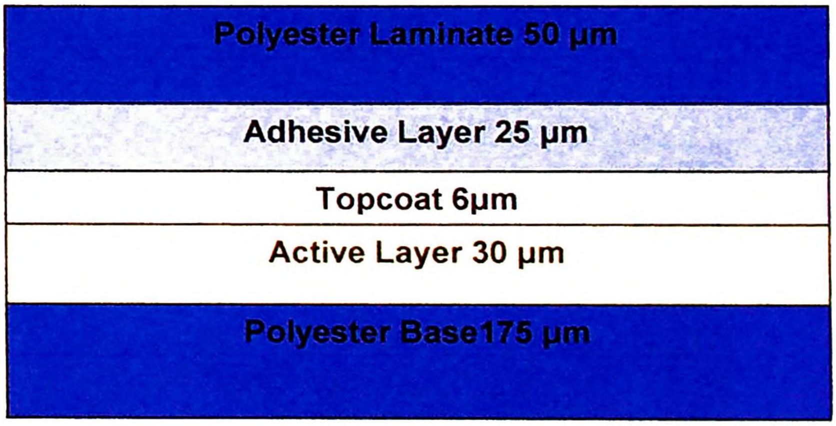


Figure 3.1: Cross section of Gafchromic EBT2 film

3.1.2 Epson^{TM} Expression 10000XL scanner and VERISOFT 5.1 version

The Epson Expression 10000XL scanner which is color scanner was used in this study as recommended by the EBT2 film manufacturer. It scanning resolution 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 scan speed of this scanner is 12.7s and support maximum optical density (OD) is 3.8 OD. This scanner response in the red and blue color channel to give the optimize the result. The TIFF image format can be analyzed in the red or green color channels for dosimetry while the blue channel for uniformity of film. The incident light of this scanner is xenon fluorescent lamp captured by a linear charged coupled device (CCD) array. Meanwhile, the conventional software, Verisoft is the Epson scanner software was used to analyze the film. It compares the dose matrices measurement with corresponding calculated matrices and verifies the dose in Intensity Modulated Radiation Therapy. The dose distribution and comparison are evaluated graphically and numerically.

Figure 3.2: Epson ^{TM} Expression 1000XL scanner at Medical Radiation Laboratory.

3.1.3 ImageJ Software

ImageJ Software was developed by Wayne Rasband of the Research Services Branch, National Institute of Mental Health. Its first version was release in 1997. To date, the developer has introduced its latest version namely version 1.31.ImageJ allowed to read and save numerous image format including TIFF, GIF, JPEG, and DICOM.

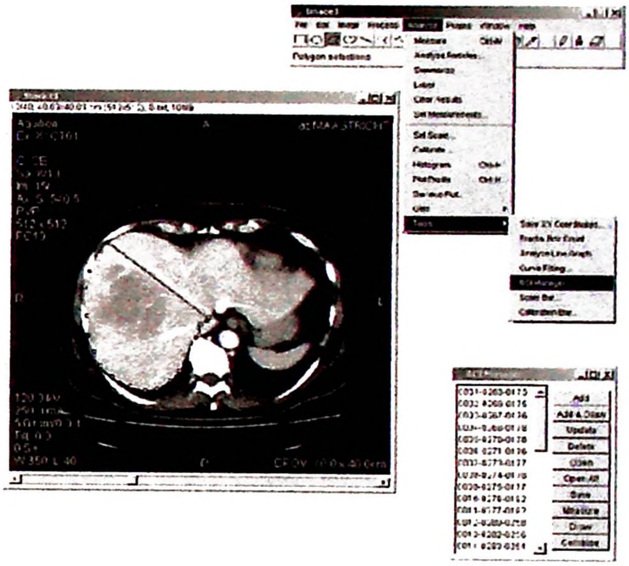


Figure 3.3: Layout of Image-J Software from Liver Volumetry Plug and Play:Do It Yourself with Image-J (Simon *et al*, 2007).

The ImageJ is developed using Java format available in 32-bit and 64-bit modes and able to run on Linux, Mac OS X and Windows. ImageJ allow user to calculate the area and pixel value statistics by select the area of interest. Other than that, it can also measure distances and angles, create density histograms and line profile plots. Apart from that, it also supports standard image processing functions such as contrast manipulation, sharpening, smoothing, edge detection and median filtering. The advantages ImageJ Software compare to the conventional are public domain software thus no license required. Since it is a downloadable and free software, therefore public allow to download it in own computer, so the time spend in workstation can be reduced.

3.1.4 Solid Water Phantom

Figure 3.4: Solid water phantom

The standard phantom material using in dosimetry measurement of photon and electron is water. In this study, the solid water phantom model 74-600 was used. The major characteristic for solid water phantom to become tissue equivalent or water equivalent is must involve compliment in mass energy absorption coefficient, mass stopping power and last but not least mass scattering power for photon beam.

The composition of solid water phantom based on TRS-398:2000 state Hydrogen (0.0809 %), Carbon (0.6722 %), Nitrogen (0.0240 %), Oxygen (0.1984 %), Chlorine (0.0013 %) , Calcium (0.0232 %) with the density 1.030 g/cm^3. Solid water phantom made from acrylic which is 1 cm of acrylic equivalent to 1.12 cm of water.

3.1.5 Linear Accelerator Machine SIEMENS PRIMUS

A linear accelerator is commonly used for external beam radiation treatment in radiotherapy department. Instead of delivering the high energy of the photon, linear accelerator also delivers the electron beam. This can be achieved by removing the target inside the gantry of the linear accelerator. Electron beam is used to treat the area of interest near to the skin due to its shorter range of penetration inside the medium. Instead of photon beam is commonly use to treat deep tumor since its large range of penetration inside the medium.

The linear accelerator treatment head consist of a few components that affect the clinical photon and electron beam production, shaping, localizing, and monitoring. The electrons begin inside the electron gun and accelerated within the accelerating waveguide to the desired kinetic energy. Then, the kinetic energy into the treatment head by beam transport system in form of pencil beam. The clinical photon and electron beams are produced inside the LINAC treatment head. The clinical photon beam produced by a combination of target flattening filter while clinical electron beam with removed the target flattening filter and used the applicator to collimate the electron beams.

Figure 3.5: Linear accelerator model SIEMENS PRIMUS at Radiotherapy Department, HUSM

3.2 METHOD

3.2.1 Film Calibration

The EBT2 film sheet was cut into 3 cm x 3 cm pieces. The films were irradiated with 6 MV and 10 MV photon beam energy in solid water phantom which rested on linear accelerator table according to the calibration condition by the IAEA TRS 398:2000 codes of practice (100 cm SSD, 10 cm x 10 cm field size on the surface). The film was placed under a depth of Dmax (approximately 1.5 cm) with 15 cm solid water phantom underneath to provide sufficient backscatter. The irradiated films were set perpendicular to the central axis of the beam. The film was exposed to 50 cGy, 100 cGy, 200 cGy, 300cGy, 400 cGy, 500 cGy and 600 cGy. One piece of film was unexposed to represent the reading of 0 cGy. The procedures were repeated with 10 MV photon beam energy and film was placed under a depth of Dmax (approximately 2.5 cm) thick of solid water phantom by using the same batch number of the EBT2 film.

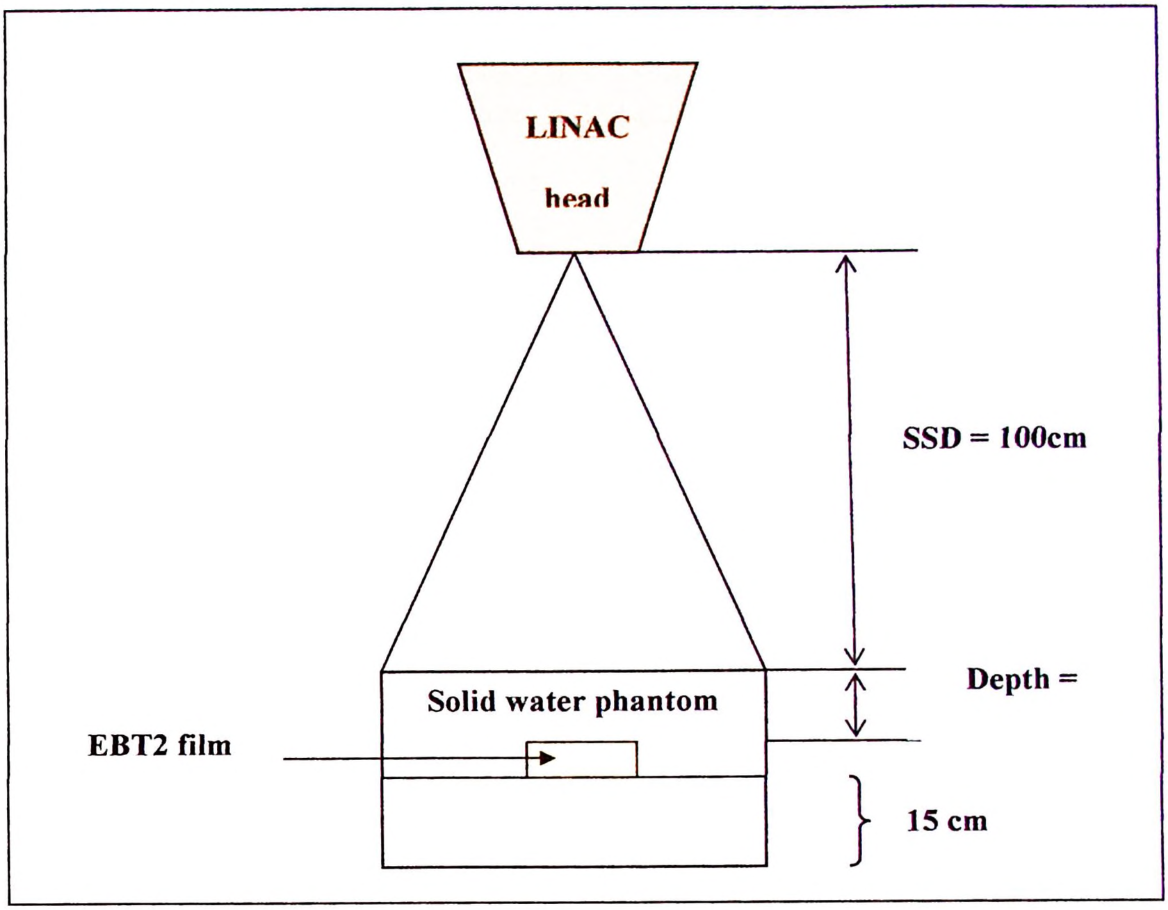


Figure 3.6: Schematic diagram of film calibration set up based on IAEA TRS 398:2000

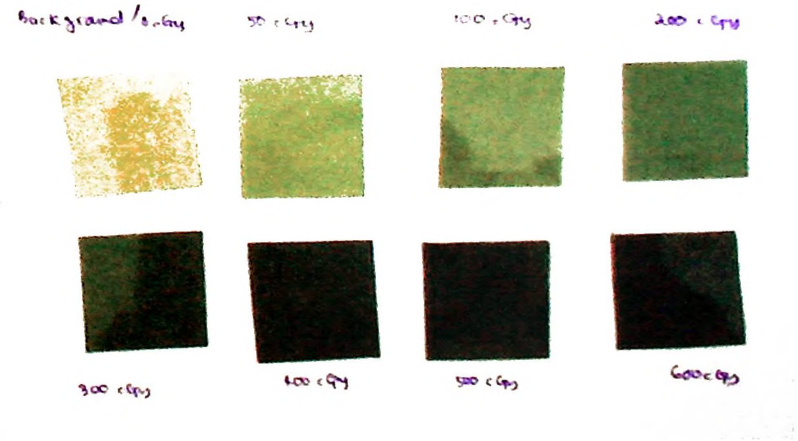
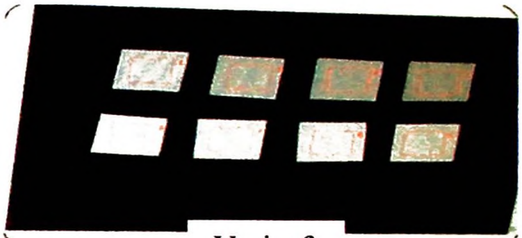


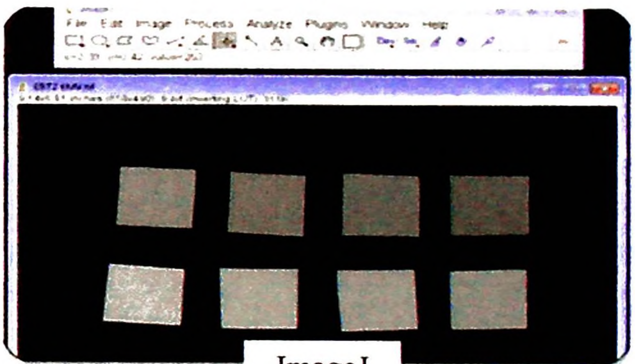
Figure 3.7: The EBT2 film irradiated with different dose (50 cGy up to 600 cGy) at 10x10 cm^2 of field size.

Open film by using FilmCal (Verisoft) /ImageJ (choosed from the previous scanned film)

Choosed "Tools"for FilmCal (Verisoft) and "Point" for ImageJ and drag '+' at centre of film



Verisoft



ImageJ

Make sure the unit was set in cGy and the film was labelled as 0 cGy,50 cGy,100 cGy, 200 cGy, 300 cGy, 400 cGy, 500 cGy , 600cGy

Figure 3.8: The flow charts indicating the process of film calibration analysis using Verisoft and ImageJ.

3.2.2 Beam Profile and Depth Dose Determination

The solid water phantom and the EBT2 film sheet were in vertical position. The gantry was at 0° so that the phantoms and film were aligned perpendicular toward the central axis of the beam as shown in Figure 3.9. The film was sandwiches between 22 cm (11 cm on each side) of solid water phantom slabs right in the middle. The phantom was rested on the linear accelerator table with the source to surface distance (SSD) is 100 cm and field size is 10 x 10 cm^2. The film was exposed to 6 MV photon energy and 400 cGy dose at the central axis. Meanwhile, the depth dose was measured by compared dose at any depth relative to the maximum absorbed dose at maximum depth is water phantom. The same setup was used for 10 MV photon. The films were scanned using the film scanner and analyzed using Verisoft software and ImageJ. The PDD was measured using Verisoft and ImageJ. The PDD can be calculated using the equation (1).

The beam flatness can be calculated using the equation:

$$Beam\ flatness = \frac{Dmax - Dmin}{Dmax + Dmin} \times 100 \qquad (2)$$

With D_{max} and D_{min} is maximum dose and minimum dose along the axis respectively.

With S and SSD is focal spot size and source to skin distance and SDD is source to diaphragm distance respectively.

The symmetry of the beam can be calculated using the equation:

$$Symmetry\,\% = \frac{\left[\frac{(A1+A2+\cdots+An)}{n} - \frac{(B1+B2+\cdots+Bn)}{n}\right]}{\left[\frac{(A1+A2+\cdots+An)}{n} - \frac{(B1+B2+\cdots+Bn)}{n}\right]} \times (2 \div 100) \quad (3)$$

Where A indicates the largest value of field intensity and B indicate smallest value of field intensity. The symmetry is suppose to be ± 2 % from one side of the beam to another.

The penumbra is determined by marked the width between the 20 % and 80 % value on the beam profile.

The percentage of discrepancies between Verisoft and ImageJ is calculated using the equation:

$$\% \, Discrepancy = \frac{Experimental - Theoretical}{Theoretical} \times 100 \qquad (4)$$

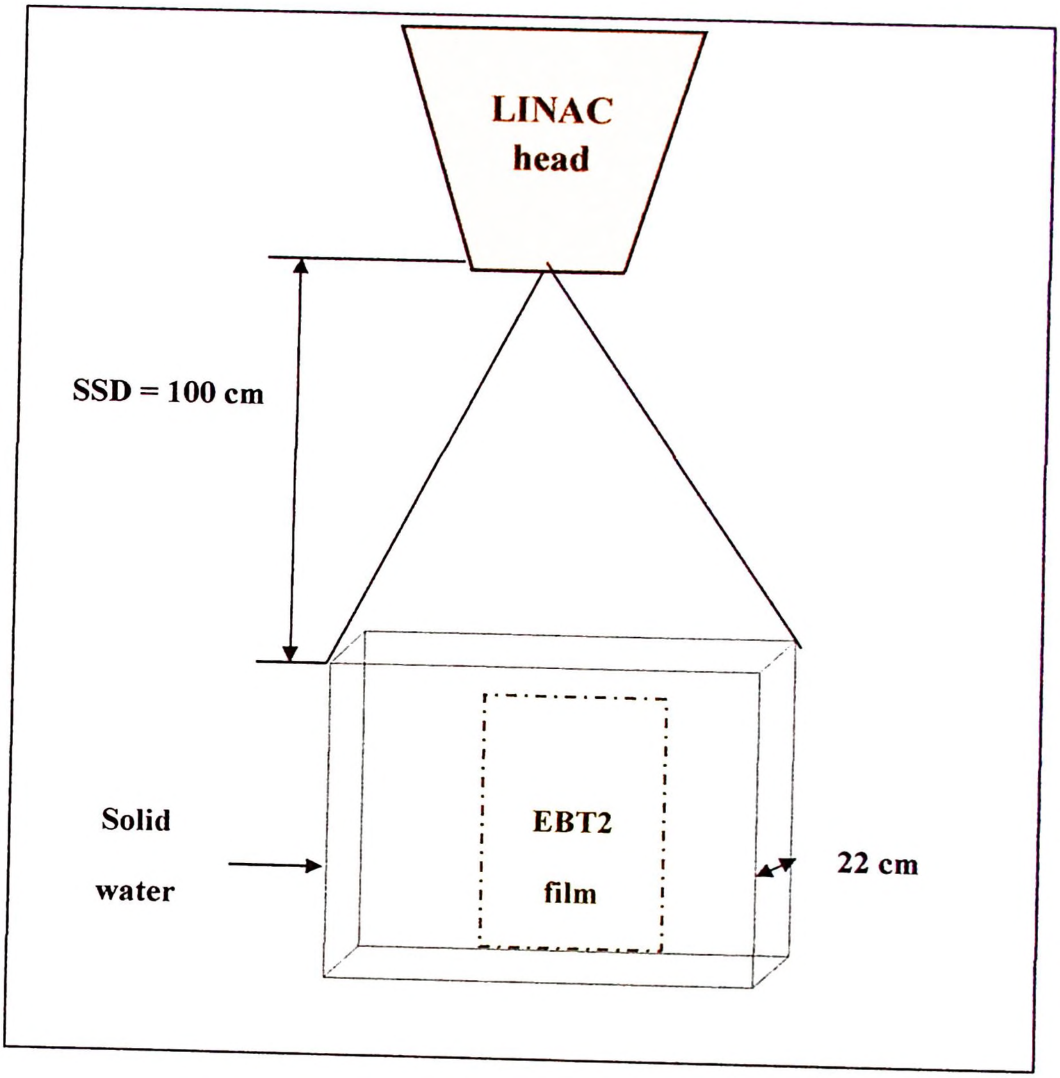


Figure 3.9: The experimental set up for beam profile and depth dose measurement

3.2.3 Analysis of Irradiated Film

The films were scanned at least 24 hours after irradiated on a flatbed scanner model Epson Expression 10000 XL. The delayed of scanning film to ensure that the film development had fully stabilized after irradiation. The film was positioned in the centre of the scanner and scanned one by one. A preview image was acquired and right after the film was scanned in a positive mode which means low pixel values in dark areas without color correction by using transmission mode. The entire image was saved in tagged image file format (TIIF) because it suitable for most image analysis software. The images were analyzed to determine beam profile and percentage depth dose using the Verisoft and ImageJ image processing software. The process of image acquisition using the film scanner is summarized in Figure 3.11. During the image analysis, the size of ROI was determined at least as large as the film in the analysis.

Film scanning process

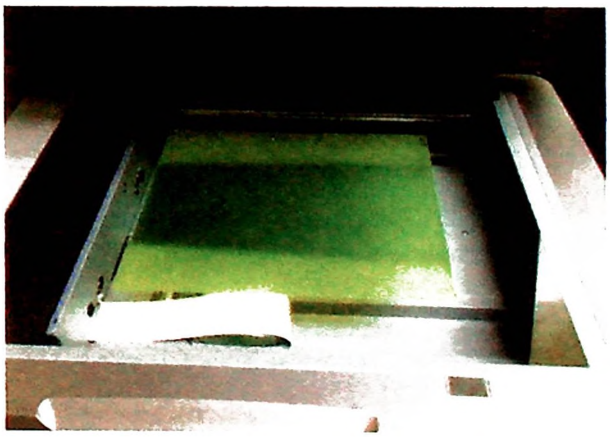


Figure 3.10: The flat bed scanner model Epson 10000XL with exposed EBT2 film.

The film was placed on the flatbed scanner in landscape orientation

The FilmScan icon was selected

Tools-Option and ensure the setting as below :
Scanner-TWAIN
TWAIN-Gafchromic Optimized
Image
Flattering Correction-No filter
OK-Select EPSON EXPRESSION 10000XL

Scan

Preview to ensure the film was in the scanning field

The ROI was selected

Save in the folder

Figure 3.11: Film scanning process

Percentage Depth Dose (PDD) and Beam Profile using Verisoft Software

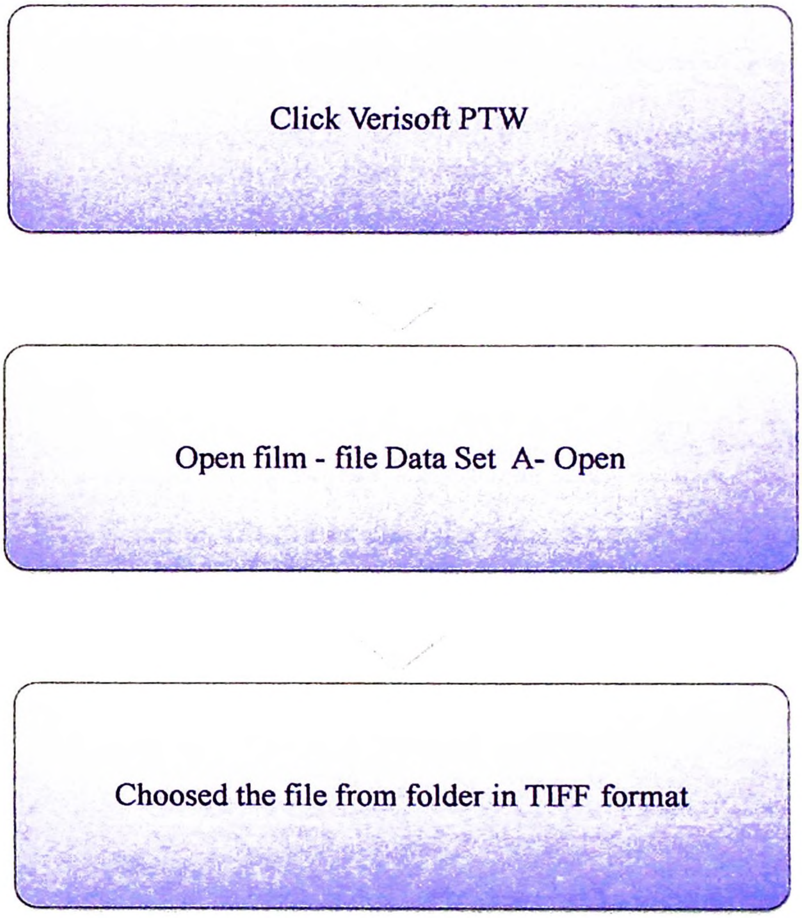
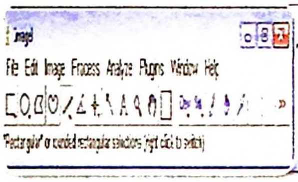


Figure 3.12: Summary of steps PDD and beam profile using scanner software.

Percentage Depth Dose (PDD) and Beam Profile using ImageJ Software

Click ImageJ software on desktop

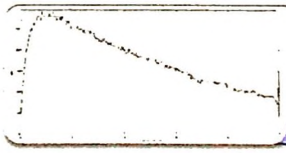


The scanned image was saved in TIFF format and open recent using the ImageJ Software.The "Straight" button was clicked to make freehand line on image

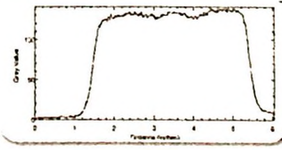
The percentage depth dose, PDD was measured by drew the vertical straight line at the centre of the image as shown above.

Beam profile obtained by draw the horizontal line at the maximum dose at depth,Dmax. The D-max identified by refer the y-axis along the irradiated area on film.

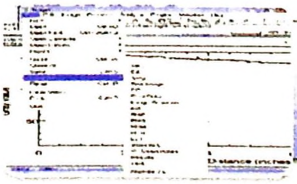
The data was analyze choosed "Analyze" and then "Plot Profile"



The percentage depth dose profile



The beam profile profile



The raw data was copied into the Microsoft Office Excel and the plot profile was saved in JPEG format

Figure 3.13: Summary of steps PDD and beam profile analysis using ImageJ software.