APPLICATION OF 3D-PRINTED ANTHROPOMORPHIC HEAD PHANTOM FOR QUALITY ASSURANCE OF 3D-CONFORMAL RADIATION THERAPY

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by

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LIST OF ABBREVIATIONS

3D : Three-dimensional

3D-CRT : Three-dimensional conformal radiotherapy

AAPM TG-119: American Association of Physicist in Medicine Task Group 119 report

AM : Additive manufacturing

cGy : centi-Gray

CT : Computed Tomography

dref : Depth of reference

DTA : Distance to agreement

FDM : Fused deposition modelling

FOV : Field of view

HU : Hounsfield Unit

IAEA : International Atomic Energy Agency

ICRU : International Commission on Radiation Units and Measurements

IMRT : Intensity modulated radiation therapy

LINAC : Linear accelerator

MU : Monitor Unit

OD : Optical density

PLA : Polylactic acid

POI : Point of interest

QA : Quality assurance

ROI : Regions of interest

RPL : Radiophotoluminescence

SSD : Source to Surface Distance

TPS : Treatment planning system

TRS 457 : Practice Technical Report Series No. 457

USM : Universiti Sains Malaysia

WHO : World Health Organization

ABSTRAK

Tujuan dan objektif: Kajian ini menilai kebolehgunaan fantom antropomorfik kepala cetakan 3D untuk pengesahan dosimetri.

Bahan dan metode: Dengan menggunakan fantom RANDO bahagian kepala sebagai pengganti pesakit sebenar, satu fantom kepala telah dihasilkan mengikut tempahan menggunakan mesin cetak 3D dengan filamen *'polylactic acid'* sebagai bahan cetakan. Fantom RANDO dan fantom cetakan 3D bahagian kepala digunakan untuk membandingkan dos yang dikira dengan dos yang diukur.

Keputusan: Apabila fantom RANDO bahagian kepala digunakan untuk membandingkan dos yang telah dikira dengan dos yang telah diukur, kadar gamma lulus untuk $\gamma \leq 1$ ialah 85.1 %. Apabila fantom cetakan 3D bahagian kepala digunakan untuk membandingkan dos yang telah dikira dengan dos yang telah diukur, kadar gamma lulus untuk $\gamma \leq 1$ ialah 46.6 %.

Kesimpulan: Telah diputuskan bahawa penggunaan fantom cetakan 3D untuk pengesahan dosimetri ialah sedikit kebolehgunaan. Penambahbaikan atau pengubahsuaian dalam menghasilkan fantom 3D adalah diperlukan untuk kegunaan klinikal.

ABSTRACT

Aim and Objectives: This study evaluated the application of 3D-printed anthropomorphic head phantom for dosimetric verification.

Materials and methods: Using head region of a RANDO phantom as a substitute for an actual patient, a custom head phantom was constructed using a 3D printer, with printing material of polylactic acid filament. The RANDO head phantom and the 3D-printed head phantom were used to compare the calculated and measured doses.

Results: When the RANDO head phantom was used to compare the calculated and measured dose, the gamma passing rate for $\gamma \leq 1$ was 85.1 %. When the 3D-printed head phantom was used, the gamma passing rate for $\gamma \leq 1$ was 46.6 %.

Conclusion: It was determined that the use of 3D-printed phantom for dosimetric verification is less feasible. Efforts must be made for improvements or further refinement of the phantom construction process is needed for clinical use.

CHAPTER 1

INTRODUCTION

1.1 Background of study

Radiotherapy is the most common modality for treating human cancers. Radiotherapy most often uses X-rays, but protons and other types of energy also can be used. The term “radiotherapy” most often refers to external beam radiotherapy. In this type of radiation therapy, the high-energy beams originate from a machine called “linear accelerator”. Radiation is delivered from outside of the body. This machine aims the beams at a precise point on the patient’s body. Besides, there is a different type of radiotherapy called short distance therapy which also can be called brachytherapy. In this way, radiation is placed inside the patient’s body.

Cancer patients need radiotherapy at some time or other, either for curative or palliative purpose. Curative treatment is provided with the purpose of destroying the tumour and curing the cancer to promote recovery from the illness. Whereas, palliative treatment is provided when it is not possible to cure the cancer but only to bring comfort and relief from a serious, progressive illness that may or may not be life-limiting. Radiation therapy damages cells by destroying the genetic material that controls cell growth. While both healthy and cancerous cells are damaged by radiation, the goal of radiation therapy is to destroy as few normal, healthy cells as possible at the same time to kill targeted, cancerous cell the most. Thus, it is important to precisely measure the dose of the treatment. International Commission on Radiation Units and Measurements (ICRU) suggested that the tolerance dose delivery in radiotherapy should within ± 5% (ICRU, 1976).

Before patient undergo the treatment, the delivery of dose should be planned and check properly. Since human body is complex task as radiation cannot be measured directly, thus needs to be replaced by tissue-equivalent material known as phantom (Rahman et al., 2016). Generally, phantom is used for the quality control of the absorbed dose of the x-rays in the linear accelerator. Phantom is made from tissue-equivalent materials that represents physical part of human anatomy and attenuation characteristics for radiation dosimetry studies (Kumar et al., 2010). According to the International Atomic Energy Agency (IAEA) Code of Practice Technical Report Series No. 457 (TRS 457), standard phantom should be designed and constructed so that they have the same primary attenuation and scatter production as the relevant body section of a representative patient and the energy range should be concerned. Kumar et al., 2010 added, the tissue equivalency of a material for the dosimetry study depends on type and energy of radiation.

Nowadays, commercial RANDO head phantom is used for the quality assurance (QA) for the head-related cancer treatment. However, it is quite expensive. In addition, the shape of commercial head phantom is different from patient individual anatomy (Kamomae et al., 2017). It represents standard size of human which is clearly different from real patients that have variety of sizes. There are various types of phantom available for various purposes in radiotherapy, as examples solid water phantom, anthropomorphic phantom, verification and many more.

To solve these problems, this study decided to construct an anthropomorphic head phantom by using three-dimensional (3D) printing technique. 3D printing is a tool that can be used to custom-fabricate patient-specific phantom at a lower cost. Materials and densities can be varied to produce tissue equivalence. One benefit of 3D printed phantom is that after it is fabricate, it can be subjected to daily test of CT scan acquisition, localization marking, dose calculation and treatment procedure (Ehler et al., 2014). Thus,

this application would be useful in radiotherapy where treatment can be verified with patient's specific phantom while increase the accuracy of the treatment.

A study conducted by Kamomae et al., 2017 stated that 3D printing offers flexibility in design and manufacturing for auxiliary equipment in radiotherapy. In the study, they used polylactic acid (PLA) as the raw material to produce the 3D breast phantom. PLA is chosen because they have the characteristic of thermoplastic, which means they are malleable when heated and keep in shape when cooling down. In addition, the material is cost-effective and easily available. Therefore, the study was done to compare the geometric and dosimetric properties of three dimensional (3D) printed head phantom and commercial standard RANDO phantom which irradiated with 6 MV photon beam. CT scan was done to determine the Hounsfield Unit (HU) and internal uniformity for both phantoms. Gafchromic EBT 3 film and Gamma Analysis method were used to verify accurate dose plan. Hopefully, this study would improve current radiotherapy practice here and might serve as a baseline for quality improvement in future.

1.2 Research Objectives

Aim:

- To evaluate the application of 3D-printed anthropomorphic head phantom for quality assurance of three-dimensional conformal radiotherapy (3D-CRT)

Specific Objectives:

1. To construct 3D-printed anthropomorphic head phantom
2. To calculate dose to the 3D-printed head phantom and RANDO head phantom
3. To compare the measured doses and calculated doses between 3D-printed head phantom and RANDO head phantom

CHAPTER 2

LITERATURE REVIEW

2.1 Quality assurance in radiotherapy

Quality assurance in radiotherapy includes those procedures that ensure consistency of the medical prescription and the safe fulfilment of that prescription as regards dose to the target volume and minimal dose to normal tissue (WHO, 1988). Radiotherapy is one of the major options in cancer treatment. It involves computed tomography (CT) simulation, 3-dimensional (3D)-treatment planning, and its quality assurance (QA) in order to produce highly conformal dose distributions and to ensure its safe and accurate delivery.

2.2 3D-printed phantom

In radiotherapy treatment, dose delivery to the patient involves many steps, parameters, and factors. As a result, more complex quality are required during the radiotherapy process to ensure that each step has as less error as possible. Thus, before any radiation exposure to a patient, the radiation dose that to be delivered has to be planed and checked carefully. Since radiation dose cannot be directly measured in patients, phantoms are tools used by physicists to measure radiation under different conditions. They are useful because measurement of radiation in a controlled environment with minimal risk to staff and patients can be performed. Thus, phantoms that will be constructed must have almost similar to radiation properties of humans. As part of quality assurance of patient treatment plans, patient-specific dose measurements are done using radiotherapy phantoms combined with various dosimeters. Other than that, commercially available phantom is not always anatomically correct. Most of them represents healthy

standard persons (Tino and Yeo, 2019). In addition, the process of manufacturing these phantom is high in costs.

Apart from the standard fabrication of phantom through moulding and casting, currently the use of patient imaging data to design and manufacture phantoms through a process called additive manufacturing (AM), commonly known as 3D printing keep increasing (Tino and Yeo, 2019). The AM process uses a layer-by layer method of printing from simple to complex geometries. This method indirectly aids in developing patient-specific phantom. Tino and Yeo, 2019 did a systematic review on 3D-printed imaging and dosimetry phantoms in radiation therapy, they found out additive manufacturing has a great potential to improve current practice of using different types of phantoms, due to low-cost material and extremely adaptive fabrication abilities of complex geometries.

Rahman et al., 2016 conducted a study to find out a phantom that will be cost effective and locally available. A phantom was fabricated by using paraffin wax due to the density and electron density that is almost equivalent to water. Two different techniques were used. Firtsly, a cubic phantom of 20 cm a side was made by pouring melted paraffin wax into a steel made cubic dice. Secondly, readily available paraffin wax slabs of dimension $30 \times 25 \times 4$ cm^3 was bought and cut them into a size of $21 \times 21 \times 4$ cm^3 and then joined them together after slightly heated on a hot plate at 40°C to have a cubic phantom of 20 cm a side. To insert a Farmer-type ionization chamber at the isocenter of the phantom, each phantom was drilled. Dose absorption of paraffin wax phantom is found very close to the water phantom. Paraffin wax phantom showed less deviation compared to water phantom, indicates more suitability for practical dosimetry. Thus, they concluded paraffin wax phantom can be used in radiotherapy for routine QA check and dosimetry confirmation as a replacement for water phantom or other solid

phantoms. However, the durability of the paraffin wax phantom need to be studied further.

In a study, Yea et al., 2017 assessed the feasibility of 3D-printed anthropomorphic patient-specific head phantom for quality assurance (QA) in intensity modulated radiotherapy (IMRT). They used fused deposition modelling (FDM) to construct an anthropomorphic patient-specific head phantom with a 3D printer. An established quality assurance (QA) technique and the patient-specific head phantom were used to compare the calculated and measured doses. During the established technique was used, the gamma passing rate for $\gamma < 1$ was 97.28 %, while the gamma failure rate for $\gamma > 1$ was 2.72 %. During the 3D-printed patient-specific head phantom was used, the gamma passing rate for $\gamma < 1$ was 95.97 %, while the gamma failure rate for $\gamma > 1$ was 4.03 %. Thus, they concluded that 3D-printed patient-specific head phantom has great potential for patient-specific QA for IMRT.

Furthermore, Kamonae et al., 2017 constructed a system for producing patient-specific phantoms, using a low-cost personal 3D printer with a PLA filament to evaluate the feasibility of this 3D-printed phantom for artificial in vivo dosimetry in radiation therapy quality assurance. Anthropomorphic head phantom was used with radiophotoluminescence (RPL) glass dosimeter was inserted in the 3D printed phantom. The phantom shape, CT value and absorbed dose are compared between actual and 3D printed phantom. Phantom's shape, CT value and absorbed dose are compared between the actual and 3D printed phantoms. They found that the modeling accuracy of the 3D-printed phantom was acceptable. The dose differences between the anthropomorphic head phantom and the 3D printed phantom were approximately within 2 %, in the experimental environment. These results show the practicality of the 3D printed phantom for artificial in vivo dosimetry in radiotherapy quality assurance.

2.3 Dose measurement and comparison

Quality assurance of external beam radiotherapy requires tools with specific characteristics. A radiochromic film dubbed ‘‘Gafchromic^{TM} EBT’’ have the characteristics of high spatial resolution, make it suitable for measurement of dose distributions in radiotherapy. While several aspects of the film characteristics have been previously reported separately, Schneider et al, 2009 conducted an evaluation centered on practical IMRT verification, leading to an optimized protocol. Therefore the reliability within one batch, the relationship between optical density (OD) and dose (dose range between 1.4 Gy and 8.4 Gy) and the dose rate dependence for four dose rates (55, 108, 217, 441 MU/min) were investigated. Moreover, energy dependence between two energies (50 kV and 6 MV), tissue equivalency, post irradiation blackening over one month, pressure and temperature sensitivity were evaluated. Then, they optimized the protocol using the G-EBT films, in combination with an EPSON-Expression^{TM} 1680 pro flatbed scanner, for IMRT QA, while either keeping the compound error as small as possible or trying to reduce evaluation time.

They found out by using the optimized protocol for IMRT QA, the compound error could be reduced to approximately 2 % for a quality-driven approach and maximum 5.5 % for an approach attempting to reduce procedure time. Though the quality-focused approach provides appropriate accuracy for individual patient QA, the procedure-time focused approach can only be used for preliminary measurements. This proves that feasibility of film dosimetry in external beam radiotherapy.

Since being introduced, the γ quantity has been used by investigators to evaluate dose calculation algorithms, and compare dosimetry measurements. The gamma (γ) index is a quantitative method of comparing two dose distributions and is routinely used for quality assurance (QA) of intensity-modulated radiation therapy (IMRT) treatments(Low,

2002). Typically, a two-dimensional measured dose distribution is compared with the planar dose calculated by the treatment planning system (TPS). Evaluation of dose comparisons using the gamma index involves the choice of the dose difference criterion, the distance to agreement (DTA) criterion, and the designation of the reference distribution (either the measured or calculated dose distribution) (Huang et al., 2014). For each point in the reference distribution, the gamma index is calculated by comparing this point to all points in the evaluated dose distribution within a given search radius, and the gamma index is calculated based on the point in the evaluated distribution that best satisfies both the dose difference and DTA criterion. Typically, the percentage of points that have passing gamma values determines the overall results of IMRT QA. For instance, a common acceptance criterion is that at least 90 % of points need to pass 3 % / 3 mm criteria for a plan to be considered passing (Huang et al., 2014).

CHAPTER 3

MATERIALS AND METHODS

3.1 MATERIALS

3.1.1 PRIMUS^{TM} Linear Accelerator (Siemens Medical System, Concord, CA, USA)

The linear accelerator (LINAC) utilized high energy photon beam (6-10 MV) to treat deep seated tumour and high energy electron beam (6-21 MeV) to treat superficial tumour. The LINAC was calibrated by using Source to Surface Distance (SSD) calibration technique where absolute dose produced was 1 cGy per 1 Monitor Unit (MU) at 100 cm SSD on standard 10 × 10 cm^2 field size. The LINAC was calibrated by a small cylindrical ionization chamber and a Victoreen water tank with depth of reference (dref) based on standard protocol of IAEA TRS-398. This is to make sure dose delivery to target organ were accurate.

Figure 3. 1: PRIMUS Linear Accelerator

3.1.2 RANDO head phantom

RANDO head phantom by Alderson Research Laboratories, USA. (Alderson et al, 1962) was used in this study. This phantom has an effective atomic number and mass density that closely mimic muscle tissue with randomly distributed fat. Eleven slices were used in this project. In addition, each slab consists of a 3 × 3 cm matrix of vertical holes with 5 mm diameter. (Angistein et al, 2007). The soft tissue material of the RANDO phantom has density of 0.985 g/cm^3 (± 1.25 %) and an effective atomic number of 7.30 (± 0.5 %) which represents a composite of muscles, body fats and fluids. This phantom was selected as a substitute for an actual patient. The reason was to allow for dosimetric measurements that would not be possible in-vivo.

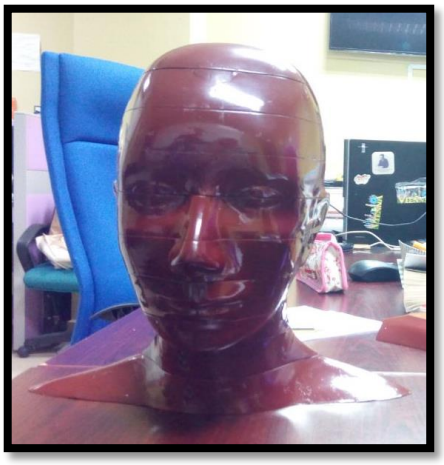

Figure 3. 2: RANDO head phantom

3.1.3 My Vista Cube 200 3D printer

My Vista Cube 200 3D printer is used in this study to print out the custom-made head and neck phantom. This printer uses Fused Deposition Method (FDM) technique to print the phantom. FDM printers use a thermoplastic filament, which is heated to its melting point and then extruded, layer by layer, creating a 3D object. This printer uses 3 types of software which are Catia, Cura and Blender. Then, the design from the software will be converted into .stl file that is readable to the printer. The print speed and travel speed of this printer are 30 mm/s. Each layer can be set as low as 0.1 mm, the nozzle diameter is 0.4 mm, the density filling can be selected from 10 %, 30 %, 50 %, 70 %, 90 % and 100 %.

3.1.4 Solid water phantom

Plastic water slab phantom model 74-609 is used in this study. It is made of acrylic material and has the characteristics of water equivalent phantom. The phantoms are virtually identical to water in dosimetric properties. The size of the water phantoms used was 30 × 30 × 10 cm^3 with different thickness ranging from 1 cm to 5 cm. This type of phantom can be used for the energy range of the photon (70 kV to 50 MV) and electron (6-20 MeV) (Tello et al, 1995). This solid water phantom attenuate in a range of high x-ray beams, the same way as water without affecting the charge storage.

Figure 3. 3: Solid water phantom

3.1.5 3D-printed PLA head phantom

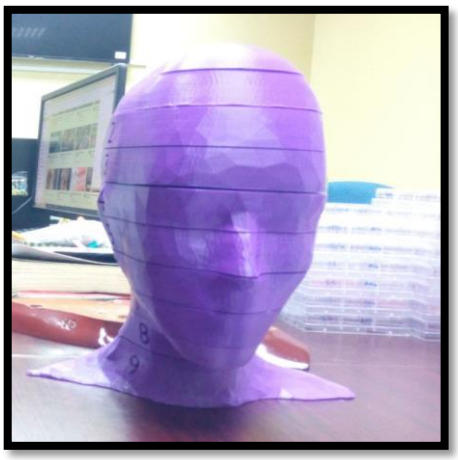

Figure 3. 4: 3D-printed PLA head phantom

In this study, 3D-printed head phantom was made from polylactic acid (PLA). The phantom was printed by My Vista Cube 200 3D printer. The head phantom was constructed based on RANDO head phantom model. PLA has physical density of 1.2 g/cm^3 and electron density of 3.38×10^{23} electrons/cm^3 (Burleson et al., 2015). However, its physical properties is not identical to water. The phantom consist of eleven slices same as the RANDO head phantom. Density filling for the 3D printed model was 100 %. It was printed using fused deposition method (FDM).

3.1.6 Gafchromic EBT 3 Film

The film used in this study was Gafchromic EBT 3 whereby the sheet of films were cut according to the size of the slab of head and neck phantom. 4 sheets of films were used to be irradiated with 6 MV photon beam by using Siemens Primus Linear Accelerator. Each sheet were placed between slab 1 and 2, slab 2 and 3, slab 3 and 4 as well as between slab 4 and 5. The purpose of this film is to verify dose distribution in radiotherapy. Gafchromic EBT 3 film has identical composition and thickness of both polyester layers that sandwiched the active layer. The identical thickness of both polyester layers make EBT 3 film more advantage compared EBT 2 film. Due to the same thickness of polyester layers, EBT 3 film has symmetrical structure that enable both sides of film

to be used. This can avoid the potential errors in optical density measurement (Valeria et al, 2003). In addition, this identical layers are significant to this film because it helps to avoid Newton's ring during film scanning.

Figure 3. 5: Gafchromic EBT3 film

3.1.7 EPSON flatbed scanner (Expression 10000 XL)

EPSON flatbed scanner (Expression 10000 XL) is used as the film scanner for the film dosimetry in this study. This is one type of model scanner that can be used for image analysis and were recommended by International Specialty Products (ISP) for dosimetry purposes. In addition, this film scanner is operated along with one unit of computer installed with software which is Verisoft version 5.1. This software provides services such as film scanning and film calibration. Figure 3.7 shows EPSON flatbed scanner.

Figure 3. 6: EPSON flatbed scanner (Expression 10000 XL)

3.1.8 PTW Verisoft Software

PTW Verisoft is a gamma analysis based software used in radiotherapy for IMRT plan verification (Pathak et al., 2015). The IMRT delivery quality assurance involves dose delivery of plan created in TPS to a phantom. Then, the 2D dose distribution calculated by the TPS was compared with the dose measured using 2D-array from LINAC.

Verisoft software was used to compare gamma distribution for calculated dose (cGy) using TPS and measured dose using Gafchromic EBT 3 film. It was used to calculate percentage of pixels passing criteria. Parameters of distance to agreement (DTA) and dose difference (DD) are selected for comparison of dose distribution. The software supports gamma evaluation method that determine the passing rate for each measured plan.

3.2 METHODS

3.2.1 Phantom scanning

Computed Tomography (CT) images of the RANDO phantom head and neck phantom was obtained using Philips Brilliance Big Bore CT simulator. The CT scanning conditions were as follows; slice thickness: 3 mm, peak voltage: 120 kVp, current: 30 mA, window width: 1500, window level: -500 and field of view (FOV): -244.90 mm for RANDO phantom. From the CT images, regions of interest (ROIs) were selected. The average CT number were calculated. Immobilization device such as Head rest ‘B’ and 4 cm ‘poly’ were used to enhance reproducibility of patient positioning during treatment. However, during the study, the CT-simulator machine broke down when the PLA head and neck phantom was scheduled to be scanned. This situation indirectly interrupts the process of data collection.

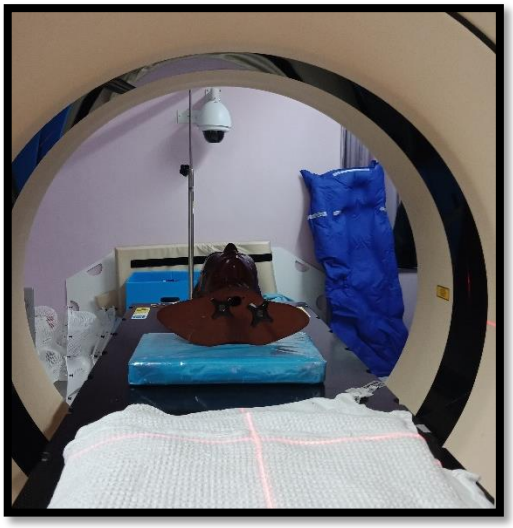

Figure 3. 7: Set-up of phantom scanning

3.2.2 3-Dimensional (3D) Treatment Planning System

Oncentra Treatment Planning System (TPS) was used for 3D treatment planning of the head phantoms. The phantom images obtained from CT simulator were exported to Oncentra TPS. Whole brain was contoured as regions of interest (ROI). In addition, organ at risk involved such as eyes, optic nerve and spinal cord as well as skin were contoured using Oncentra TPS tools. After contouring, two-parallel opposed lateral beam were applied. The isocenter point was positioned at the center of the beam behind the eyes at x, y and z were at 0.20 cm, -2.10 cm and -4.13 cm respectively. Whole brain regions where the doses were calculated by treatment planning system and compared to the dose measured on the film. The dose prescribed was 2000 cGy for 5 fractions using 6 MV photon beam. The SAD was determined at 94 cm. Collapse Cone algorithm was used for both plans of RANDO model and 3D printed model. Image of contouring, beam modelling and dose distribution using the Oncentra TPS is shown in Figure 3.8.

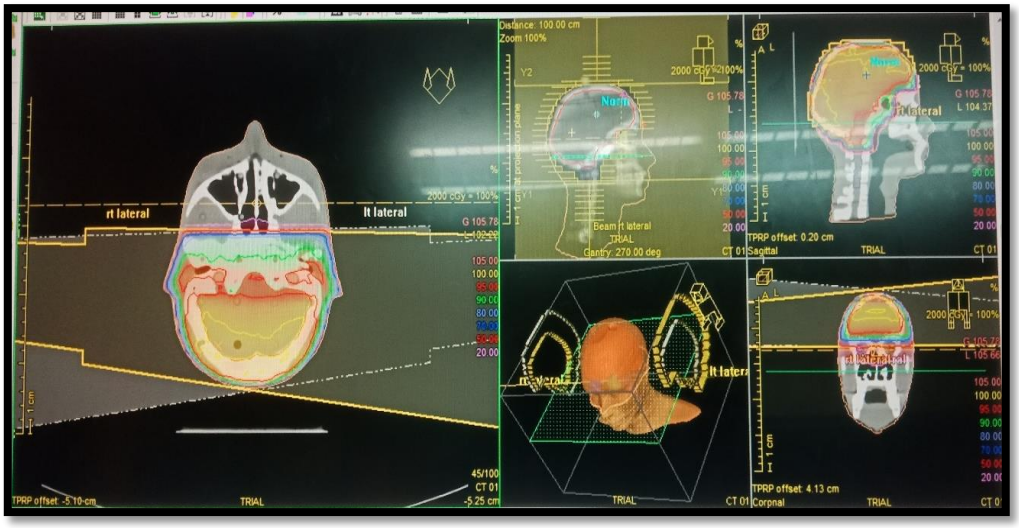

Figure 3. 8: Treatment Planning System (TPS)

3.2.3 Film calibration

For EBT3 calibration films, each film of 3.0 × 3.0 cm^2 was irradiated with 6 MV photon beam by using Siemen Primus linear accelerator. Each film was irradiated with the standard field size of 10 × 10 cm^2 at 1.5 cm depth with 100 cm SSD in solid water phantom. To generate calibration curve, the films were irradiated with dose prescription of 0 cGy to 600 cGy; 0, 100, 200, 300, 400, 500 and 600 cGy. Three measurements were performed for reproducibility purpose for each dose step of photon. The schematic diagram for film calibration set-up was shown in Figure 3.10.

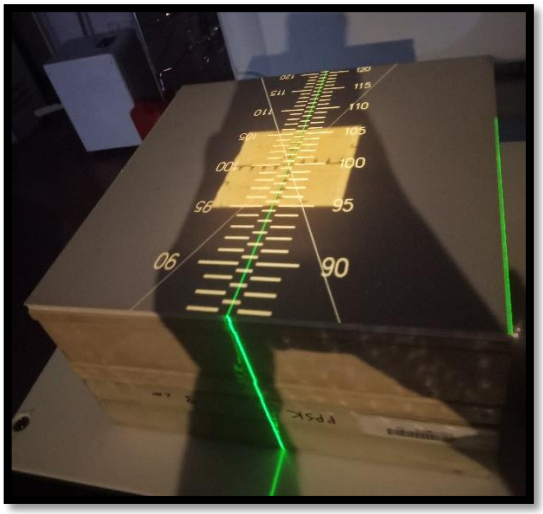

Figure 3. 9: Set up of EBT 3 film calibration

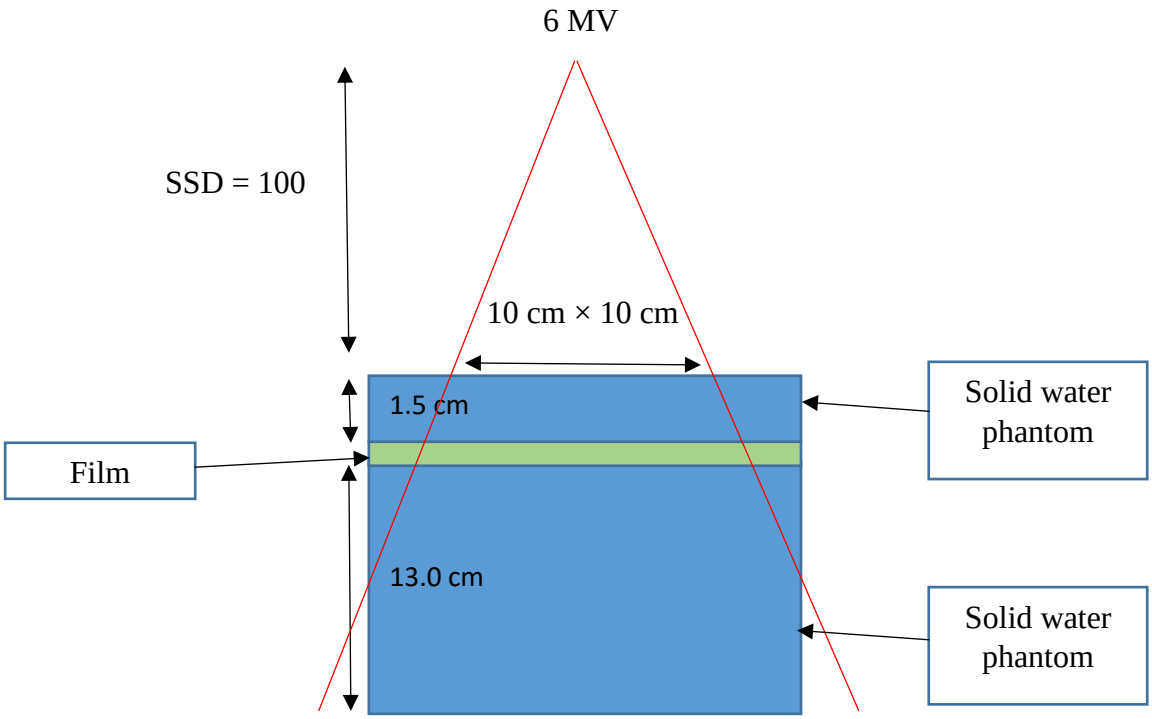

Figure 3. 10: Diagram of set-up of EBT 3 film in standard condition

3.2.4 Film scanning

To ensure the darkening of the film to be stable, the film should be scanned 24 ± 4 hours after irradiation. Irradiated films were scanned by EPSON 10000 XL flatbed scanner with reflection mode that associated with EPSON Verisoft Software version 5.1. Preview scan was conducted before saving the image as (.tiff) file format.

Figure 3. 11: Procedure of film scanning

3.2.5 Film analysis

After the scanning process, the films were analysed. For each calibrated scanned film, pixel values were taken. Each pixel values was read by a point of interest (POI). The readings for all pixel values were then saved in a table as references to determine the Net Optical Density (OD). According to Devic et al., 2004, the net OD was calculated by using formula in Equation (1):

Net Optical Density (OD) = OD exposed –OD unexposed

$$= \log_{10} \frac{(unexposed\ pixel\ values)}{(exposed\ pixel\ values)}$$

Equation (1)

The unexposed pixel value was the pixel values of unexposed film, whereas the exposed pixel values was the pixel values for exposed film. The calibration curve was plotted in which the net OD values are against prescribed dose (cGy). A positive linear correlation curve was obtained as shown in Figure 4.1. Table A.1 shows the readings for film calibration. Figure 3. 12 shows the procedure of analysis of the EBT 3 film.

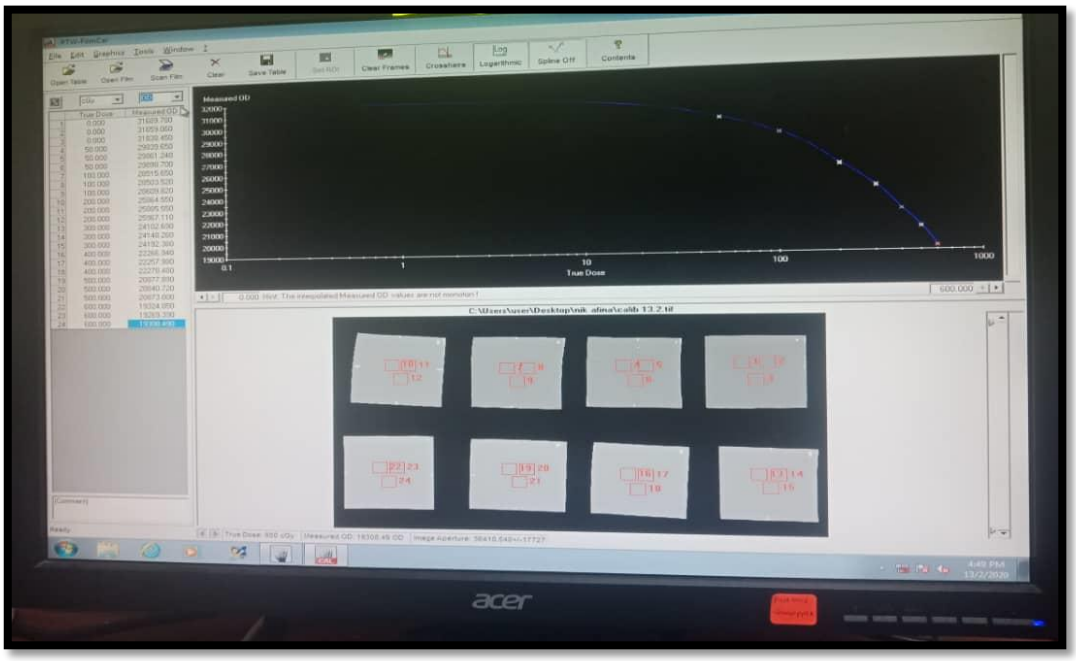

Figure 3. 12: Procedure of analysis of the EBT 3 film.

3.2.6 Irradiation of film

The approved treatment plan was then exported to ARIA, the report and verification patient information system. In this system, the treatment fields were prepared as planned. 4 sheets of cut films were irradiated with 6 MV photon beam by using Siemens Primus Linear Accelerator. Each sheet were placed between slab 1 and 2, slab 2 and 3, slab 3 and 4 as well as between slab 4 and 5. Each film were irradiated based on the planned target volume which are based on multi-leaf collimator set according to the plan done on Oncentra TPS. The on-coach set-up of film is shown in Figure B.1 and Figure B.2. Figure 3.13 shows ARIA, the report and verification patient information system.

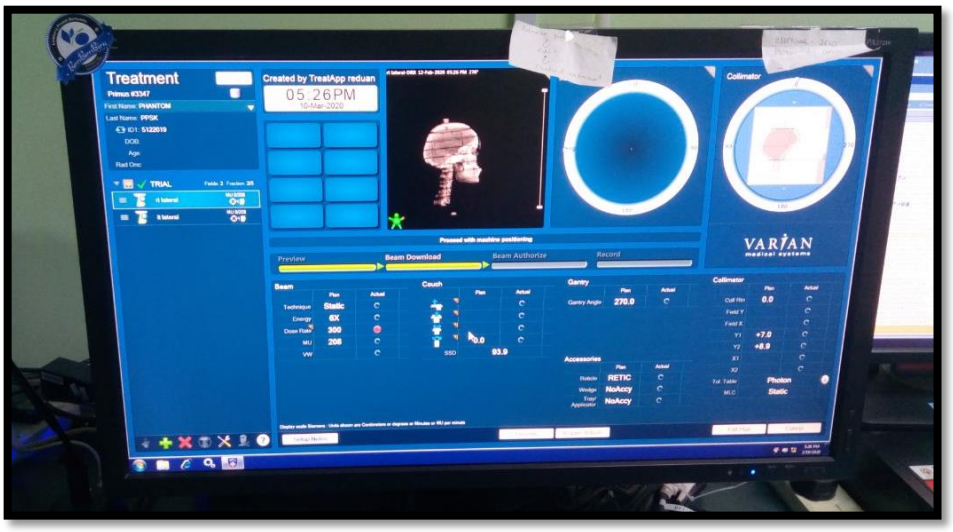

Figure 3. 13: ARIA, the report and verification patient information system.

3.2.7 Film scanning of measured film

24 hours after irradiation of the film, the film must be scanned and analysed. In this study, the Gafchromic EBT 3 film was cut according to the phantom's shape. The films were scanned by EPSON 10000 XL flatbed scanner. After scanning the film, the images of the scanned films were saved in computer that is connected to the scanner. After that, the dose of irradiated films measured were compared with the planned dose by the treatment planning system by using Verisoft Software version 5.1.

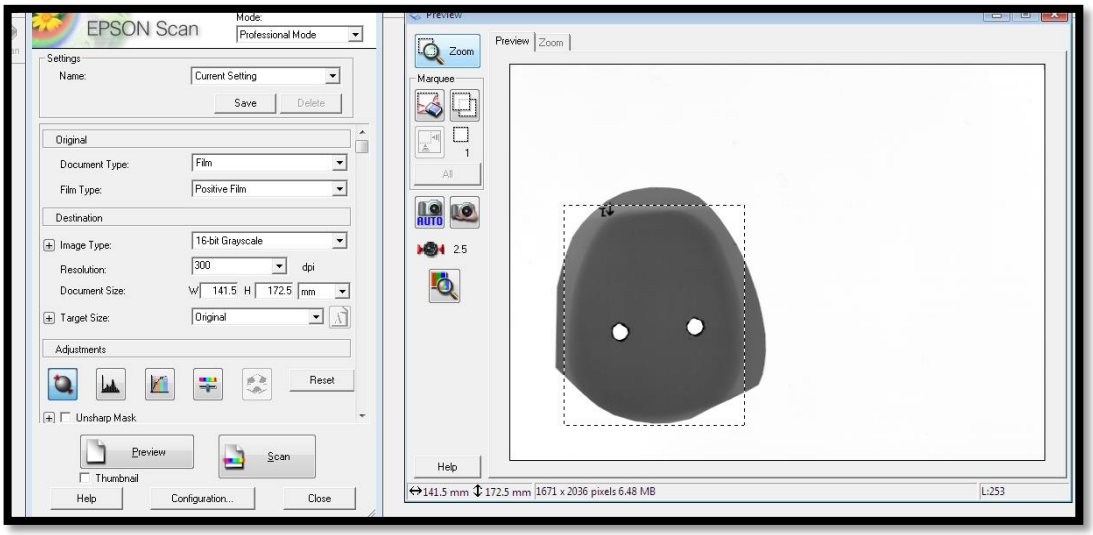

Figure 3. 14: Procedure of film scanning

3.2.8 Dose verification using Verisoft Software

The TPS generated plans were exported to the Verisoft Software version 5.1 to compare the measured doses by the films with the planned dose by the TPS. The dose distribution calculated by the TPS was imported to the upper part while the bottom part imported the data obtained by the measured films.

The transaxial view was selected for comparing the dose distributions between the planned dose by the TPS and measured dose by the film. Same slice of calculated doses and measured doses were compared. With marker as reference, the slice position for slice 1, slice 2, slice 3 and slice 4 are + 15 mm, - 9 mm, -34 mm and -59 mm respectively. AAPM (American Association of Physicist in Medicine) TG-119 recommendations for Gamma analysis in IMRT (3 % and 3 mm, with a level of 90 % for acceptance) was used in this procedure.

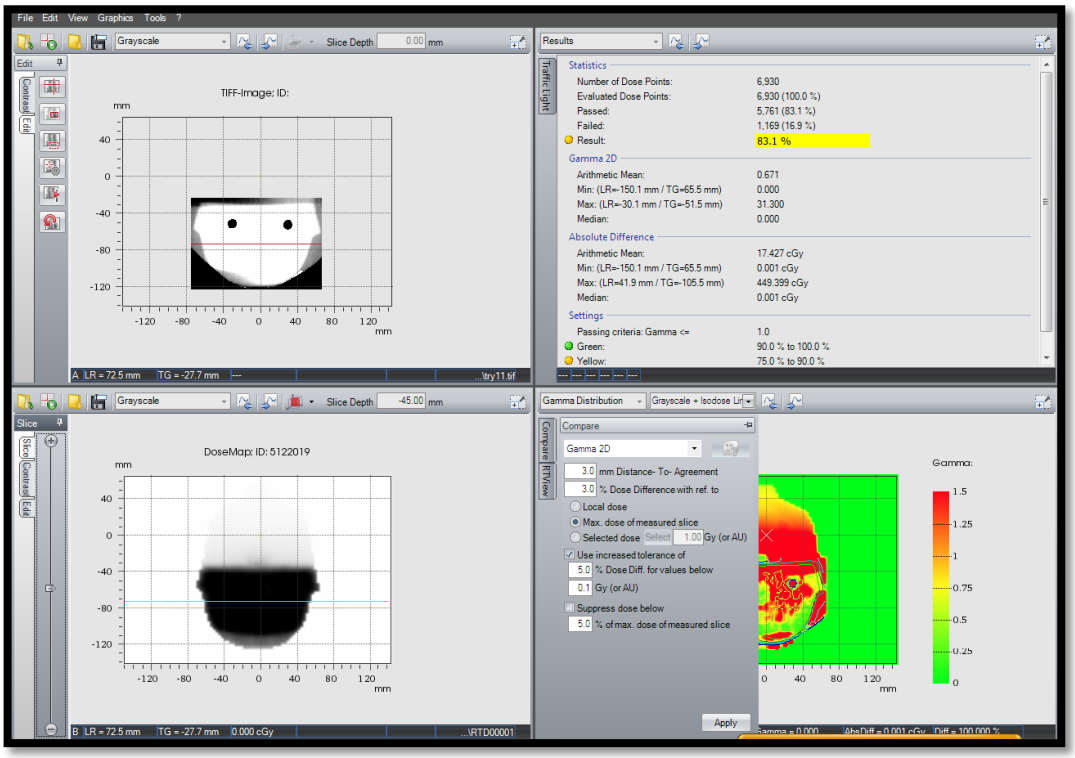

Figure 3. 15: Gamma analysis using Verisoft software

3.2.9 Summary of work flow

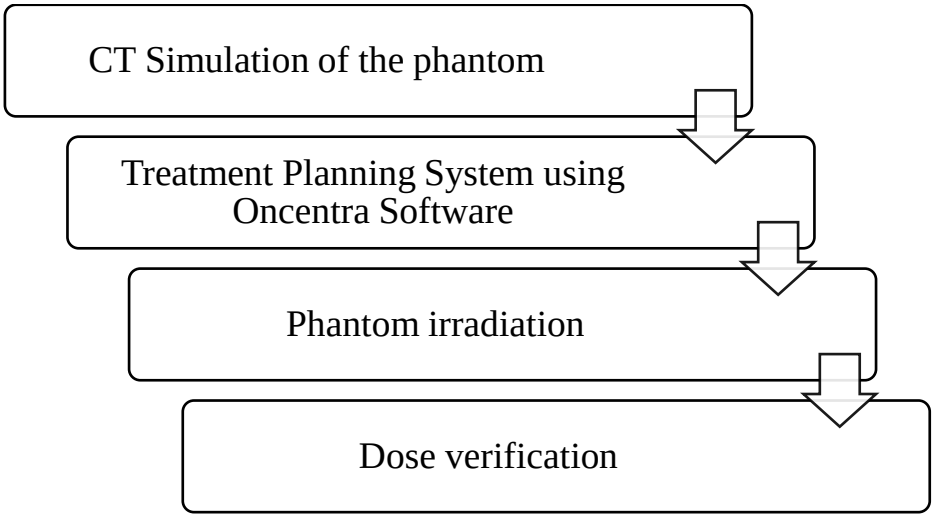

Figure 3. 16: Flow chart of methodology in this study