BRACHYTHERAPY DOSE VERIFICATION USING GAFCHROMIC EBT3 FILM

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BRACHYTHERAPY DOSE VERIFICATION USING GAFCHROMIC EBT3 FILM

by

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Dissertation submitted in partial fulfilment of the requirement for the degree of Bachelor of Health Science (Honours)

(Medical Radiation)

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CERTIFICATE

This is to certify that the dissertation entitled BRACHYTHERAPY DOSE VERIFICATION USING GAFCHROMIC EBT3 FILM is the bona fide record of research work done by Ms NUR ALYA IRDINA ISMAIL during the period from September 2019 to August 2020 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 fulfilment for the degree of Bachelor of Health Science (Honours) (Medical Radiation).

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………………………

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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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NUR ALYA IRDINA ISMAIL

Date: ……………………..

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

%	Percentage
HDR	High dose rate
LDR	Low dose rate
PDR	Pulsed dose rate
cGy	Centigray
cm	Centimetre
mm	Milimetre
F	French
Gy	Gray
2D	Two-dimensional
3D	Three-dimensional
TPS	Treatment planning system
CT	Computed Tomography
MRI	Magnetic Resonance Imaging
TG-43	Task Group-43
AAPM	American Association of Physicists in Medicine
DD	Dose difference
DTA	Distance to Agreement
QC	Quality Control
QA	Quality Assurance
IMRT	Intensity Modulated Radiation Therapy
OD	Optical Density
dpi	Dots Per Inch
VMAT	Volumetric Modulated Radiation Therapy
MBDCA	Model-Based Dose Calculation Algorithms
DVH	Dose Volume Histogram
ALARA	As Low as Reasonably Achievable

ABSTRAK

Tujuan: Kajian ini membentangkan tentang penilaian analisis gamma dengan menggunakan filem Gafchromic EBT3 sebagai media dosimetrik untuk pengesahan dos bagi tiga pelan dos yang berlainan dalam aplikasi dos tinggi brakiterapi.

Kaedah: Sebelas kateter plastik Proguide 6F dilapisi dengan lapan kepingan fantom air pepejal yang ketebalan 1 cm dan dua kepingan fantom akrilik yang ketebalan 1 cm. Susun atur tersebut diimbas dengan pengimbas CT untuk tujuan pelan rawatan. Tiga pelan berbeza, pelan A (Kotak), pelan B (Endo) dan pelan C (Gyn) dirancang dan dikira dengan sistem perancangan rawatan brakiterapi Oncentra (TPS) dengan kedudukan dwell yang berbeza diaktifkan. Pengukuran dilakukan dengan penyinaran filem Gafchromic EBT3 yang diletakkan 1 cm di atas kateter untuk setiap pelan. Analisis gamma perisian Verisoft dengan kriteria kelulusan 3% perbezaan dos (DD), 3 mm jarak ke persetujuan (DTA) dan toleransi tahap 95% digunakan untuk membandingkan taburan dos antara data TPS dan data yang diukur dari filem EBT3.

Keputusan: Analisis gamma menunjukkan lebih daripada 90% titik yang dinilai telah memenuhi kriteria penerimaan untuk pelan A dan pelan B dengan kadar lulus 98.6% dan 96.7%. Pelan C yang memiliki bentuk penyebaran dos yang lebih kompleks menunjukkan persetujuan paling sedikit antara TPS dan data yang diukur dengan kadar lulus 67.4%.

Kesimpulan: Penilaian analisis gamma menunjukkan kesepakatan yang baik antara pembahagian dos yang dikira menggunakan TPS dan diukur dengan filem Gafchromic EBT3, justeru menunjukkan potensi yang bagus untuk penggunaan dosimetri filem dalam brakiterapi untuk pengesahan dos.

ABSTRACT

Purpose: This study presents an evaluation of gamma analysis of Gafchromic EBT3 films as dosimetric media for dose verification of three different planning of dose distribution in HDR brachytherapy environment.

Methods: Eleven of 6F of Proguide plastic catheters were sandwiched with eight slabs of 1 cm of Solid Water phantoms and two slabs of 1 cm customized acrylic phantoms. The set up was scanned by computed tomography (CT) for treatment planning purpose. Three different plan, plan A (Box), plan B (Endo) and plan C (Gyn) were planned and calculated with Oncentra brachytherapy treatment planning system (TPS) by different dwell positions activated. Measurements were conducted by irradiation of Gafchromic EBT3 film placed 1 cm above the catheters for each plan. Gamma analysis of Verisoft software with passing criteria of 3% of dose difference (DD), 3 mm of distance to agreement (DTA) and 95% level tolerance was used to compare the dose distributions between the TPS data and measured data from the EBT3 film.

Result: Gamma analysis demonstrated over 90% of evaluated points passed the criteria of acceptability for plan A and plan B with passing rate of 98.6% and 96.7% respectively. Plan C which more complex shape of dose distribution showed the least agreement between TPS and measured data with passing rate of 67.4%.

Conclusion: Gamma analysis evaluation showed good agreement between dose distributions calculated using TPS and measured by Gafchromic EBT3 films, thus showing the potential of using film dosimetry in brachytherapy for dose verification.

CHAPTER 1

INTRODUCTION

1.1 Background study

Brachytherapy is a term used to describe the short distance treatment of cancer or also known as internal radiotherapy with the use of radiation from small and encapsulated radionuclide sources. This type of treatment is given by placing sources directly into or near the target volume to be treated and it requires implantation of catheters to allow the radioactive sources into the patient through intracavitary, intraluminal or interstitial (needles) applicators. Brachytherapy sources can be permanently implanted or the delivery can be temporary with remote afterloading system where a mobile source is advanced from a sealed safe into the catheters and retracted back into the safe after completing the treatment. Besides, brachytherapy is also known for the steep dose fall off with increasing distance to the radioactive source (Tanderup *et al.*, 2017).

Due to the steep dose gradient that characterizes brachytherapy, it result in delivery of a high dose to the tumour within a short time and reduces the doses received by adjacent healthy tissues which decreases the risk of side effects. The possibility to deliver a higher dose per fraction within a short time decreasing the overall treatment time and consequently, allowing a more convenient treatment. However, geometrical uncertainties may be seriously affecting to the intended treatment especially on a given dose distribution due to the steep brachytherapy gradients. The disadvantage of brachytherapy is that can only be used in cases in which the tumour is well localized and relatively small. Statistically, about 10 – 20 % of all radiotherapy patients are treated with brachytherapy in a typical radiotherapy department (Podgorsak, 2005).

Remote afterloading system is an application of the As Low as Reasonably Achievable (ALARA) principle in radiation control. The replacing of manual afterloading to remote afterloading not only reduces the radiation exposure to personnel but also provides technical advantages, such as isodose distribution optimization, that improve patient care. Besides, remote afterloading promotes less probability of temporarily misplacing radioactive sources or actually losing sources, events that do occur with manual afterloading (Glasgow *et al.*, 1993).

Brachytherapy consists of several treatment delivery techniques which based on the delivering doses rates. Low dose-rate (LDR) brachytherapy uses an implanted source with dose rates around 0.4 – 2 Gy/h and delivers a dose of 40 to 60 centigrays (cGy) per hour over several days. High dose-rate (HDR) brachytherapy uses a traveling (stepping) source with dose rates up to 12 Gy/h at 1 cm from the source and delivers a dose greater than 100 cGy per minute for 5 to 30 minutes. Pulsed-dose-rate (PDR) brachytherapy uses a cable-driven source that delivering a dose of up to about 300 cGy per hour for about 10 to 30 minutes and repeated over several days (De La Puente and Azab, 2014). Dose rate is an important consideration in radiobiology of brachytherapy as increasing of dose rate increases biological effect when changing of dose rate for a particular technique (Hoskin and Coyle, 2011). LDR technique is increasingly being replaced by HDR technique, which offers of shorter treatment times, the ability to carry out dose optimization from the use of single stepping source technology and also the greater flexibility to be used for a much wider range of treatment sites. However, LDR technique are still a recognized standard treatment modality in the field of prostate brachytherapy, where small palladium-103 or iodine-125 seeds are permanently implanted into the organ (Lee, 2014).

Modern brachytherapy is increasingly based on remote afterloading (for HDR brachytherapy), the use of three-dimensional (3D) imaging and treatment planning system (TPS). The implementation of 3D imaging such as CT and MRI in brachytherapy has moved the field into an era of improved implant geometry and more frequent use of individualized adjusting approaches via dose optimization. Acquiring a 3D data imaging using CT or MRI has enabled more accurate planning and better dose determination to volumes of both the target and the organ at risk (OARs). Besides, the availability of 3D dose distributions has largely improved the understanding of the relation between dose and clinical effects, which allows for improved possibilities to handle treatments according to certain dose constraints in the balancing and prioritization between the target and OAR doses (Kertzscher *et al.*, 2014). From the 3D dose distribution, dose volume histogram (DVH) parameters can be obtained which quantify the absolute or relative amount of a certain volume irradiated to a certain dose. In this way, hot spots in OAR, or target periphery dose or central dose can be evaluated (Tanderup *et al.*, 2017).

Furthermore, with the dose optimization methods available, the reliability on TPS has increased and it becomes one of the important component in the radiation treatment process. However, one of the challenges involved in the implementation of a modern brachytherapy TPS into a clinical situation is verifying the dose calculation accuracy. The accuracy of dose calculation plays a vital role in the brachytherapy treatment planning because the given dose per fraction is very high and inaccuracies in the dose distribution may lead to the critical damage to normal tissues and incorrect target dosage. Dosimetric audit is required for the improvement of patient safety and to aid optimization of treatment. It is essential to reassure the validity of the treatment is being delivered in line with accepted standards and that delivered doses are as prescribed. Thus, the accuracy of TPS is of vital importance in treatment outcomes in brachytherapy (Palmer *et al.*, 2014).

Brachytherapy dose calculation are routinely calculated according to the Task Group 43 (TG-43 or TG-43U1) formalism recommended by the American Association of Physicists in Medicine (AAPM) which has been in clinical use for over 15 years. This formalism assumes that the patient consists entirely of water with uniform density (0.998 g cm^{-3}). However, this protocol ignores important factors that can impact dose distributions, such as tissue and applicator heterogeneities (atomic composition and density), finite patient dimensions and interseed attenuation (Famulari *et al.*, 2018). Most TPS used for treatment plan preparation are still based on the TG-43 recommendations. These algorithms and optimization routines have been verified by many authors in homogenous conditions. Recently, several model-based dose calculation algorithms (MBDCAs) recommended by the AAPM Task Group 186 (TG-186) have become available that provides guidance on the use of MBDCAs for brachytherapy dose calculations. It enhance the treatment planning relative to the implementation of the conventional TG-43 formalism by taking into consideration for individualized, patient-specific radiation scatter conditions, and the radiological effect of material heterogeneities that differing from water (Rivard *et al.*, 2010). In other words, because these recommendations deliver accurate tissue segmentation and take into account the elemental composition of the structure, their use continues to make inroads because they provide better accuracy in brachytherapy dosimetry. Therefore, reliable and repeatable methods of TPS verification are necessary for the clinical use of these new dose calculation methods (Zwierzchowski *et al*., 2017).

Self-developing dosimetry films have long been used to successfully verify dose distributions and their use has been well documented. Film dosimetry was developed into a powerful tool and easily available for radiotherapy treatment verification and quality assurance. However, this approach still needs to be customized especially in terms of its technical possibilities and brachytherapy TPS realization regime in particular facilities (Zwierzchowski *et al.*, 2016). Introduction of poly-diacetylene based radiochromic film (GAFCHROMIC^{TM}, International Specialty Products, Wayne, NJ) solved some of the problems associated with 2D radiation detectors. High spatial resolutions, weak energy dependence, near tissue equivalence, relatively insensitive to visible light and undergo colour change directly without chemical processing has made radiochromic film become an established dosimeter for radiotherapy dose measurements that primarily used to verify external beam dosimetry but recently it has also been recognized and widely used in brachytherapy applications (Devic, 2011). Lastly, film technology, scanning and analysis techniques have developed significantly and the latest Gafchromic EBT3 with multi-channel analysis is now recommend for accurate dose measurement in the last decade (Palmer *et al.*, 2013).

1.2 Problem Statement

In the last few years, numerous of commercial detectors and phantoms have been specifically developed to verify dose distributions in external beam radiotherapy, due to the acceptance of intensity modulated radiotherapy (IMRT) and volumetric modulated radiotherapy (VMAT) techniques. These active detectors may conveniently be adopted for dosimetric audit. However, there have been no similar commercial developments for brachytherapy (Palmer, 2015). Besides, the introduction of new dose calculation methods implemented in TG-186 that provide greater accuracy in brachytherapy dosimetry and the physical processes of modern brachytherapy equipment to calculate and delivers treatment is relatively simple as the dose calculation is solely depends on the treatment planning system (TPS), but this does not mean that dosimetric audit is without complexity. This concern raises the significance of having dosimetric systems that are able to measure the dose precisely to confirm that the intended dose is delivered to the patient. However, the current recommended quality control measures are limited to basic functions of the delivery system. Although well-type ionisation chambers have been adopted for source strength determination, and commonly TLDs have been used for point dose measurements, but still there is no clear consensus on techniques for verification of dose distribution measurement in brachytherapy (Yoosuf *et al*,. 2018). Hence, there is a need for more accurate verification of dose calculation.

As the assurance of the delivery system of the brachytherapy unit, the dose calculation from the TPS need to be verify prior to the treatment in order to achieve the potential benefit to the patient. Therefore, the problem that need to solve in this study is to know the percentage difference between the calculated and measured dose by using the same method for the IMRT pre-treatment quality assurance. In this study, Gafchromic EBT3 were used to verify the dose distribution from TPS. Data obtained from EBT3 film and TPS were imported into gamma analysis software (Verisoft) to compare the results. Since there is no general rules for gamma analysis in brachytherapy dosimetry, American Association of Physicists in Medicine (AAPM) TG-119 recommendations of gamma analyse for IMRT which is 3% dose difference and 3 mm distance to agreement (DTA), with 90% of acceptance is referred.

1.3 Objective

1.3.1 General Objective

To evaluate the brachytherapy dose verification using Gafchromic EBT3 film.

1.3.2 Specific Objective

- To study the dosimetric performance of Gafchromic EBT3 film in dose verification of brachytherapy.
- To study the relationship between the dose distributions calculated using TPS and the doses measured by Gafchromic EBT3 film by gamma analysis method.

- To compare the dose distribution of three different treatment planning.

1.4 Significance of study

In this study, analytical investigation using Gafchromic EBT3 film was performed for verification of dose distributions by the TG-43 based TPS with gamma analysis (Verisoft). This perspective is done to evaluate the effectiveness of EBT3 film as a relative dosimeter for brachytherapy dose verification using gamma analysis. Different plans was generated through Oncentra Brachytherapy treatment planning in order to provide a better understanding about the dose verification. Therefore, this study may improve the efficacy of dose verification in brachytherapy and the aims of radiotherapy in treating cancer with optimum delivery system can be achieve.

CHAPTER 2

LITERATURE REVIEW

This chapter review the literature related to the use of Gafchromic film to verify the dose distributions from treatment planning system (TPS) of brachytherapy. High dose rate (HDR) brachytherapy has proven to be a highly successful radiation treatment in the management of different types of cancers with the innovation and advancement in treatment techniques, imaging technology and 3-dimensional (3D) TPS. The brachytherapy TPS become one of the important component in the radiation treatment process and its implementation into a clinical environment is challenging especially in verification of dose calculation accuracy. Accurate confirmation of dose distributions actually delivered by treatment equipment is crucial to confirm the intended prescribed radiation treatment is achieved. The excellent spatial resolution combined with near tissue equivalence and self-developing properties of Gafchromic film make it particularly attractive and has potential for brachytherapy dose measurement (Palmer *et al.*, 2013).

Besides, the use of Gafchromic EBT3 film to verify dose distributions in brachytherapy with the application of gamma evaluation method had been proven. The method is often used in IMRT-based dose evaluation that quantify differences between two dose distributions; one is calculated by the TPS while another one measured by appropriate quality assurance tool. Then, a passing rate criterion are established that determines a particular number of evaluation points satisfy a combined dose difference (DD) and distance-to-agreement (DTA) threshold (Asgharizadeh *et al.*, 2015). However, the gamma evaluation method is done in software and although the method is commonly used in external beam therapy, but recently, its application are accepted in brachytherapy.

From the study conducted by Palmer *et al* in 2013, the highlight of the study is to investigate the potential for EBT3 multi-channel dosimetry to be used for commissioning and routine quality assurance of advanced brachytherapy techniques where two test cases were studied; film-array measurements in the vicinity of a clinical treatment applicator and pseudo-clinical Solid Water test block measurements. According to the study, Gafchromic EBT3 film and multi-channel analysis has been successfully applied to measure dose distributions in the vicinity of isolated HDR brachytherapy sources, treatment applicators, and QC test situations. Agreement has been demonstrated with Monte Carlo radial dose and with TPS calculations. Besides, 2D local gamma analysis (FilmQAPro software) is found as a useful method to compare planned intended dose distributions with that actually delivered by the HDR treatment unit as the results obtained shows there is a good agreement between TPS calculations of dose distributions and film dose measurements with gamma passing rates at 3% (local)/3 mm exceeding 96% in all cases and generally exceeding 99%.

In the year of 2013, a study done by Palmer *et al* in brachytherapy applicator dosimetry (BRAD) test object was presented for dosimetric audit in comparing planned and delivered dose distributions around any ovoid or ring and intrauterine (IU) clinical treatment applicator for HDR brachytherapy for cervix cancer. The BRAD test object consists of a near full-scatter water tank with applicator and film supports constructed with Solid Water. In the BRAD test object, one EBT3 Gafchromic film of dimensions 100 × 120 mm was positioned and precisely held on each of four orthogonal planes crossing the IU tube of the clinical treatment applicator, which intended to sample the dose distributions in the high-risk clinical target volume such as points A and B, bladder, rectum and sigmoid. Gamma analysis method was then used to compare the RTDose grid with measured multi-channel film dose maps. According to the results from two pilot audits presented in this study, using of two sources (Ir-192 and Co-60 HDR), it demonstrated an excellent agreement with a mean gamma passing rate of 98.6% by using criteria of 3% local normalization and 3 mm distance to agreement (DTA). Besides, the mean DTA between prescribed dose and measured film dose at point A was 1.2 mm as an acceptable limit of 3.0 mm DTA is suggested. Therefore, the results presented in this study have shown that the use of EBT3 Gafchromic film with multi-channel analysis for dose measurements have the potential to successfully used for the measurement of dose distributions in HDR brachytherapy.

In 2014, Palmer *et al* conducted a study to evaluate the triple-channel dosimetry in clinical brachytherapy (a typical cervix treatment) dose distributions using EBT3 film, reported that the gamma passing rates exceeding 90% for triple-channel dosimetry but the passing rate reduced to exceeding 37% for single-channel dosimetry at criteria 3% local normalization and 2 mm distance to agreement, over a region of interest of 105 x 80 mm which is equivalent to 0.3 to 13 Gy dose range. The study also stated that the Gafchromic EBT3 film and a flatbed scanner is an applicable method for brachytherapy dosimetry, and uncertainties may be reduced with triple-channel dosimetry and specific film processing methodologies.

Also in 2014, a study conducted by Palmer *et al* presented a novel approach with the use of TPS DICOM RTDose file export to compare planned dose distribution with measured dose distribution using Gafchromic EBT3 films that placed around clinical brachytherapy treatment applicators. Gamma evaluation method was used to compare the dose distributions. Meanwhile for dose difference and distance to agreement were determined at prescription Point A. According to the study, accurate film dosimetry was achieved using a glass compression plate at scanning to ensure physically-flat films, simultaneous scanning of known dose films with measurement films, and triple-channel dosimetric analysis. As for the results, the mean gamma pass rate of RTDose compared to film-measured dose distributions was 98.1% at 3% (local), 2 mm criteria and the mean distance to agreement was 0.6 mm. As shielding not accounted for in TPS, the mean dose difference, measured to planned, at Point A was -0.5% for plastic treatment applicators and -2.4% for metal applicators. However, the study stated that the needs to develop brachytherapy QA to include full-system verification of agreement between planned and delivered dose distributions can be achieve by using advanced film dosimetry and gamma comparison to DICOM RTDose files as the finding of the study has been demonstrated that this novel approach is suitable to fulfil this need.

In 2015, a retrospective dosimetry study was conducted by Asgharizadeh *et al* to test a patient-specific quality assurance system for preoperative endorectal brachytherapy that used the latest EBT3 Gafchromic film. A solid water phantom with an intracavitary mold applicator positioned at its centre was used to compare the calculated-to-measured dose distributions. Two EBT3 films were positioned 2 cm and 5 cm above the centre of the applicator within the phantom and the idea is to study the behaviour of the quality assurance system in low and high dose gradient regions. As for the result which is based on gamma evaluation method, this study stated that the measured dose distributions with criteria of 3%, 3 mm barely passed the test as it showed 95% passing pixels in low dose gradient region. However, in the high dose gradient region, a more rigid condition could be established. It is because the average for 15 patient plan used for the criteria of 2%, 3 mm and 3%, 2 mm with gamma function calculated using normalization to the same absolute dose value in both measured (using triple channel method) and calculated dose distributions, and matrix sizes rescaled to match lower resolution (calculated dose image) showed more than 95% pixels passing. Besides, this study also described that the EBT3

Gafchromic film can be used as a patient-specific quality assurance tool although it still needs to be justified.

In addition, there is a study about verification of calculation algorithm used in TPS for shielded vaginal applicators that based on film dosimetry method. The study conducted by Zwierzchowski *et al* in 2016 were performed by using standard vaginal cylinders of three different diameters (25 mm, 35 mm, and 40 mm) in the water phantom and measurements were performed without any shields and with three shields combination. According to the result, the study reported that gamma analysis (Verisoft software) showed a good agreement between the dose distributions calculated using TPS and measured by Gafchromic films as the gamma passing rates are over 90% of analysed points which meets the gamma criteria of 3%, 3 mm. Thus, it increase the viability of using film dosimetry in brachytherapy.

On the other side of year 2016, a study about dosimetric assessment of two HDR brachytherapy applicators which is cylindrical and flat applicators were 3D printed with acrylonitrile butadiene styrene (ABS) at different infill percentage was conducted by Ricotti *et al* demonstrated the use of EBT3 Gafchromic film as the dosimetric media to measure the depth dose profiles and superficial dose distribution due to the dosimetric consequences of varying the applicator's density by adjusting the printing infill percentage. Dose distributions were then compared to those obtained with a commercial superficial applicator. However, based on the result obtained, the study reported that the measured dose distributions turned out to be in agreement with the ones measured with the reference commercial applicator with overall gamma passing rate greater than 94% with 3% dose difference criteria, 3 mm distance-to-agreement criteria and 10% dose threshold. Although the 3D printing techniques requires further assessment for clinical application, but still the finding of this study regarding the use of EBT3 films as the dosimetric media is possible in brachytherapy.

Also in 2016, a new multi-channel inflatable applicator for esophageal HDR has been developed and tested in a simple water phantom by Zhao *et al*. The purpose of the study is to characterize the dose distribution of the new multi-channel esophageal applicator for brachytherapy HDR treatment, and particularly to study the effect of the presence of air or water in the applicator's expansion balloon. Oncentra (Elekta) planning system based on TG43 formalism were used in this study with 400 cGy was prescribed to a plane 1cm away from the applicator. Planar dose distributions were then measured for that plane and one next to the applicator using Gafchromic EBT3 film. Film and TPS generated dose distributions of film were then sent for gamma analysis evaluation. According to the results reported by the study, it showed that film dose measurement of the air-inflated applicator is lower than the TPS calculated dose with only 80.8% of the pixels passed the gamma criteria (3%/3mm). While for the water-inflated applicator, the measured film dose is fairly close to the TPS calculated dose (typically within <3%) with 99.84% of the pixels passed the gamma criteria (3%/3mm). Although one of the film dose measurement have shown lower passing rate of gamma analysis, it does not means that the potential of Gafchromic film as a film dosimetry in brachytherapy should be negligible.

According to a study by Zwierzchowski *et al* in 2017, two treatment plans were prepared for evaluation purposes with standard CT/MRI ring applicator sets were used. Ring applicators with 26 and 30 mm diameters and a 60 mm intra-uterine tube with 60º angle were used for the verification and Gafchromic films were used as the dosimetric media. The study reported that gamma analysis (OMNI Pro I'mRT software) showed that average gamma ranged for the 26 mm and 30 mm rings ranged respectively from 0.1 to

0.44 and from 0.1 to 0.27. Besides, it showed 99% of the measured points corresponded with the calculated data for both cases and thus the results met the 3%, 3 mm and a level of 95% criteria that recommended by the AAPM TG-119. As the analysis showed excellent agreement between the dose distributions calculated with the TPS and the doses measured by Gafchromic films, this finding confirms again the viability of using film dosimetry in brachytherapy as an easily repeatable and fast methods for commissioning procedures for brachytherapy TPS prior treatments are needed.

In recent year of 2018, there is a study with the aim to verify the dosimetric accuracy of two-dimensional (2D) *in vivo* rectal dosimetry using an endorectal balloon (ERB) with unfoldable EBT3 films for HDR brachytherapy for cervical cancer. The study by Jeang *et al* were performed which involved patient-specific quality assurance (pQA) tests in 20 patient plans using an Ir-192 remote afterloading system and a water-filled cervical phantom with the ERB. The dose distributions measured in ERBs were then compared with those of the treatment plans by using gamma analysis (OmniPro-ImRT) software. According to the results reported in the study, the absolute dose profiles measured by the ERBs were in good agreement with those of treatment plans as the global gamma passing rates were 96–100% and 91–100% over 20 pQAs using the criteria of 3%/3 mm and 3%/2 mm, respectively, with a 30% low-dose threshold. Besides, the dose-volume histograms of the rectal wall that obtained from the measured dose distributions showed small volume differences which is less than 2% on average from the patients' plans over the entire dose interval. Furthermore, the objective of this study was accomplished with the use of ERB and EBT3 Gafchromic films because it was effective and thus it might be clinically relevant for HDR brachytherapy for cervical and prostate cancers to monitor treatment accuracy and consistency.

Lastly, based on review of all the studies stated in this chapter, they showed that the possibility of using Gafchromic EBT3 film as a dosimetric media for measurement of dose distributions in brachytherapy along with the use of gamma evaluation methods is highly possible and further assessment should be considered in order to establish a fast, reliable and repeatable methods for verification of dose calculation from TPS prior treatments delivery.

CHAPTER 3

MATERIALS & METHODS

3.1 MATERIALS

This chapter explains on the materials and experimental method used for verifying the dose distribution from Treatment Planning System (TPS) by using gamma analysis. The experimental methods were divided into several sections. The first section describes the simulation of the experimental setup using CT simulator and then followed by treatment planning for three different plans using Oncentra Treatment Planning Software. Next, the third section describes the irradiation process by High Dose Rate (HDR) Iridium-192 afterloading system and also the steps to obtain Gamma analysis from Gafchromic EBT3 film data is explained.

3.1.1 CT Simulation of phantom

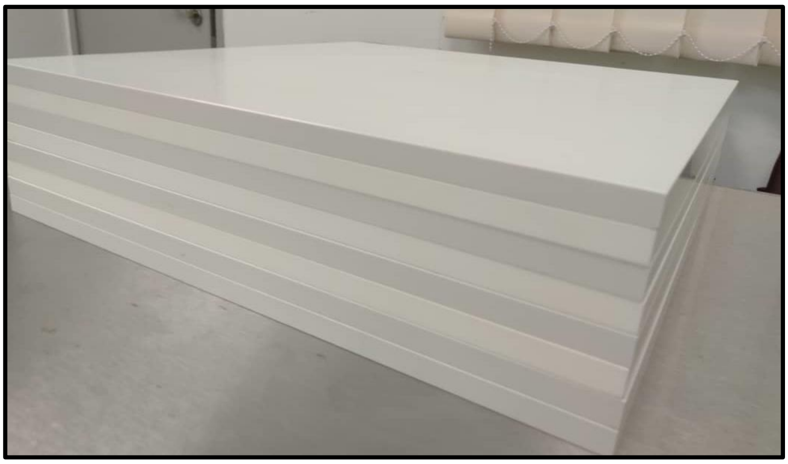
3.1.1.1 Solid Water Phantom

Experiment was conducted using of total 8 slab of water equivalent Solid Water phantoms of 1 cm thick with 30 x 30 cm dimensions. A 6 cm Solid Water phantoms for backscatter was placed on bottom side and another 2 cm was placed on upper side of the measurement assembly.

3.1.1.2 Customized Acrylic Phantom

The customized acrylic phantom by Dr. Mohd Zahri Abdul Aziz (unpublished work) consists of two slabs of acrylic phantom of 1 cm thick with eleven of 6F size of Proguide plastic catheters that placed between the gap of the two slabs. The dimension of the phantom is 30 x 32 cm. The plastic catheter is a closed-ended catheter that used to connect to the afterloader which delivers the prescribed radiation dose to the target area.

a)



b)

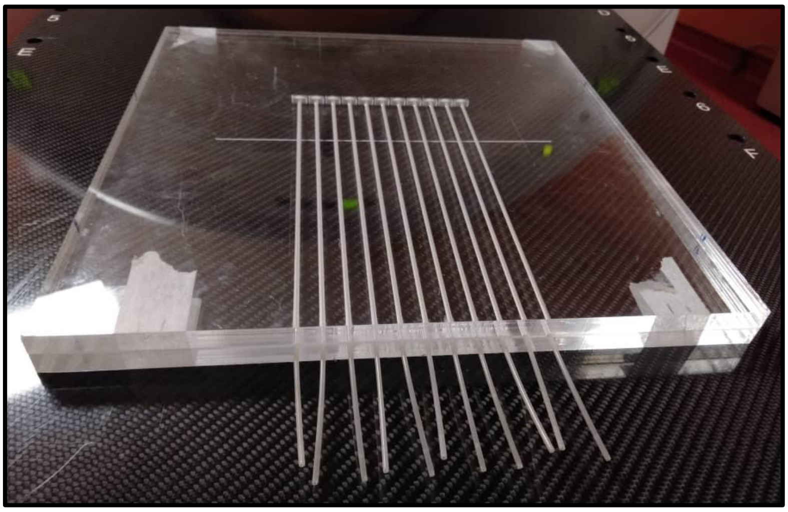


Figure 3.1 a) 8 cm of Solid Water phantom; **b)** 2 cm of customized acrylic phantom and 11 Proguide plastic catheters.

3.1.1.3 CT-Simulator

Toshiba Aquilion LB CT-Simulator in Advanced Medical and Dental Institute (AMDI) was used to scan the phantom setup during simulation process. This modality offers high quality of CT images as it is equipped with 90 cm large of bore size which provides good coverage of a setup and its 70 cm diagnostic field of view (FOV) that ensure superior image quality. Besides, this CT-simulator are able to double the number of slices to 32 per rotation without increasing radiation delivered to the patient and thus minimised the process of providing information with a reconstruction of up to 22 images per second of 0.5 mm images.

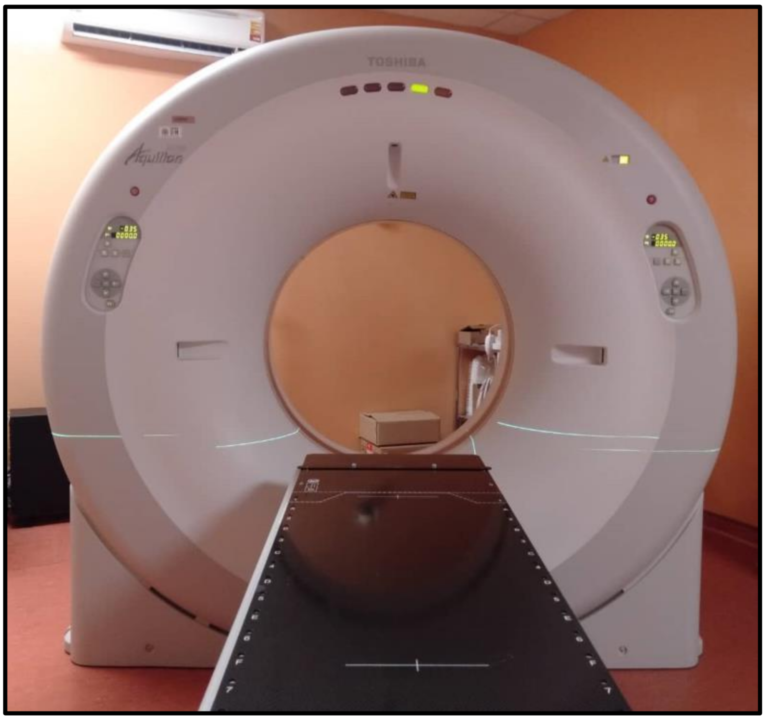


Figure 3.2 Toshiba Aquilion LB CT-Simulator installed in AMDI.

3.1.2 Treatment Planning System (TPS) using CT imaging acquisition

Treatment planning software which is Oncentra Brachytherapy was used in treatment planning by importing the CT images to the software.

3.1.2.1 Oncentra Treatment Planning Software

Oncentra Brachytherapy software is a software that offers a variety of useful tools that facilitate many of the challenging clinical tasks for planning, such as contouring and image reconstruction, as well as rapid planning calculations with dose and dose volume histogram (DVH) analysis. It helps in accelerate workflow and optimizes the planning accuracy for wide varieties of clinical HDR treatments. The dose calculation algorithm is based on the TG-43 recommendations published by the AAPM workgroup that calculate the deposition of dose around the source in a finite radius sphere of water. This software basically utilise the pre-calculated dose distributions of the source position and time which provide fast and practical plan. Besides, treatment plan objective can be achieved as the presence of DVH allows for instant visual plan evaluation adjustment and also the treatment file in this software can be transferred to the afterloader control station for speedy delivery.

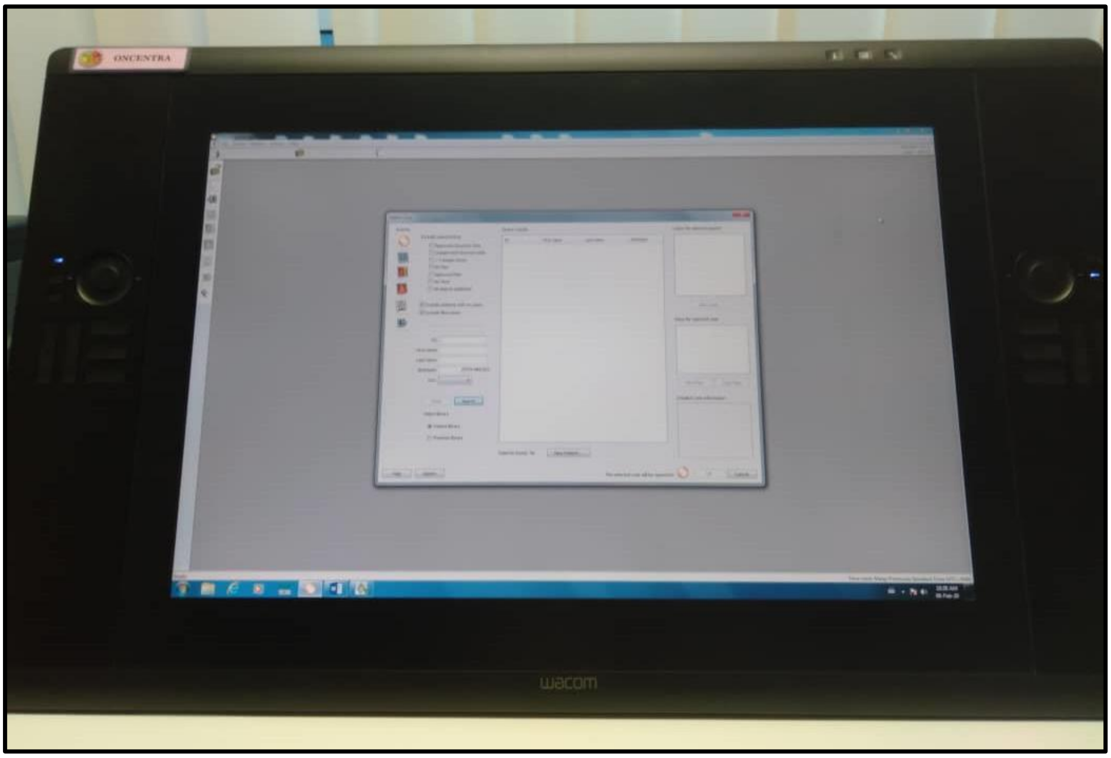


Figure 3.3 Oncentra treatment planning software available in AMDI.

3.1.3 Irradiation with HDR-Brachytherapy

The materials that was used during the irradiation with HDR-Brachytherapy are listed in following subsections.

3.1.3.1 High Dose Rate (HDR) Remote Afterloader

High Dose Rate (HDR) refers to the delivery of a high dose of radiation in a relatively short time and dose rate that greater than 12 Gy/hr while the remote afterloader is a modality that automatically administer the radioactive source which is in capsule form, from the tungsten shielded safe directly to the target area which is controlled by the remote-control system at the control console.

In this study, experiment was conducted using a Nucletron microSelectron V3-High Dose Rate (HDR) Iridium-192 afterloading system in AMDI. The HDR unit uses a radioactive Iridium-192 source, with half-life of approximately 74 days. Due to the short half-life, the source needs to be replaced every three to four months in order to maintain an acceptable treatment time. The source used is a small line source attached to the end of a flexible drive cable which is also called as source wire.

The HDR remote afterloader is equipped with 30 selectable channels and indexer system that drives the source to the treatment positions (dwell position) with irradiation time (dwell time) through a connecter called as transfer tube or transfer guide into a catheter or an applicator that implanted in the patient. The source is then was retracts back into its shielded container before continue to the next channel and the process is repeated until all the planned channels have been exposed as planned. Before the active source wire is proceed for treatment, a dummy wire is activated to verify the pathway is clear from any obstruction.

With the availability of the remote afterloader system, it helps to deliver HDR brachytherapy more precisely and safely in minimising the direct contact with the radioactive source and unnecessary radiation exposure to the personnel and precisely.

3.1.3.2 Transfer tube

Transfer tube or transfer guide is a flexible tube which is a crucial component in HDR remote afterloading system as it is used to connect the catheters or applicators implanted in the patient to the afterloader. The tip of the tube is labelled with a number which indicates the connected channel number. In this study, 11 transfer tube of 6F size were used corresponds to the number of catheter used.

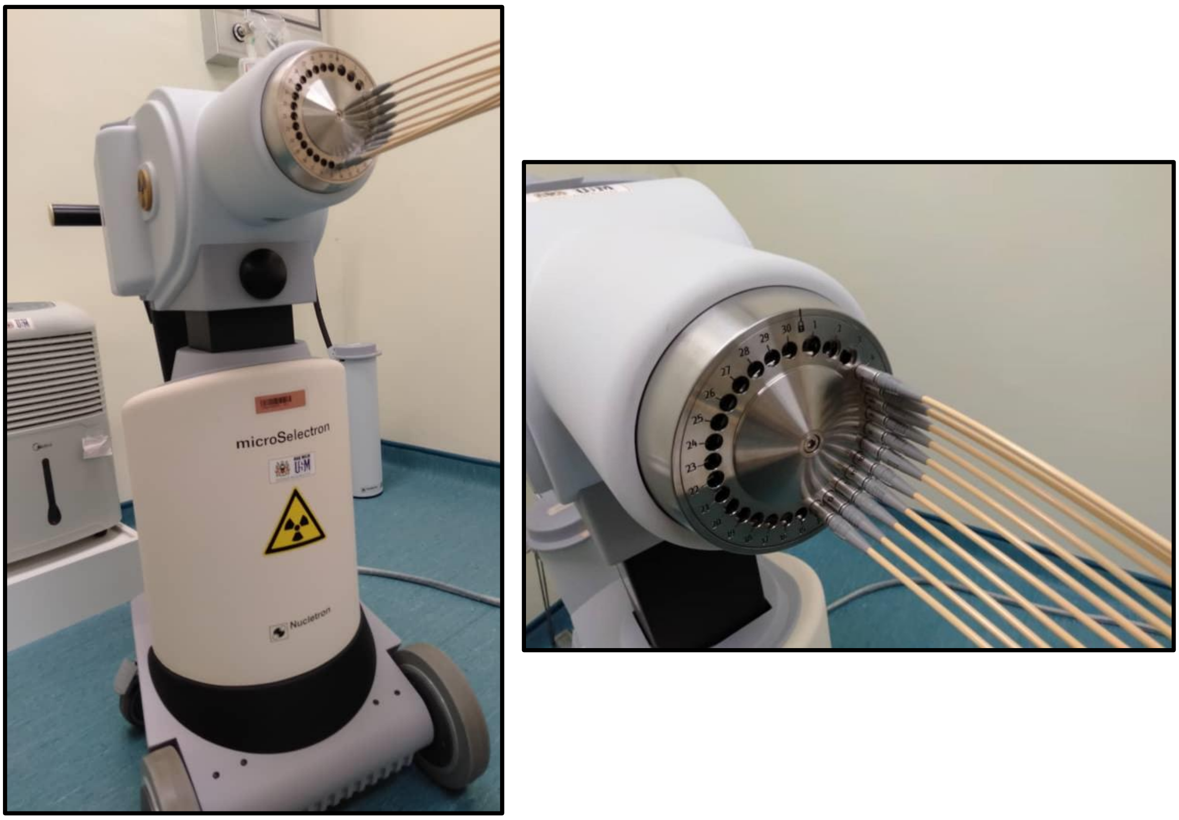


Figure 3.4 Nucletron microSelectron V3-High Dose Rate (HDR) Iridium-192 afterloading system installed in AMDI with indexer connected to 6F size of transfer tubes.

3.1.3.3 Gafchromic EBT3 Film

The film used in this study was GAFCHROMIC EBT3 (Lot #: 03071601), with sheet dimensions of 20.3 × 25.4 cm^2. Gafchromic EBT3 film is a self-developing film, composed of an active layer with 26-28 mm thickness laminated between two 125 mm matte polyester layers. The total film thickness is approximately 0.28 mm. EBT3 film provides greater confidence that neither side of the film is affected differently by exposure or scanning as the polyester lamination is symmetrical. Microscopic silica spheres that contain in polyester surface eliminating the formation of Newton's Rings interference patterns in images acquired during scanning proses. The film has a near water-equivalent effective and energy-independent dose response. The dynamic dose range of the film is from 0.1 Gy up to 10 Gy and thus make it suitable for high-energy photon measurement.

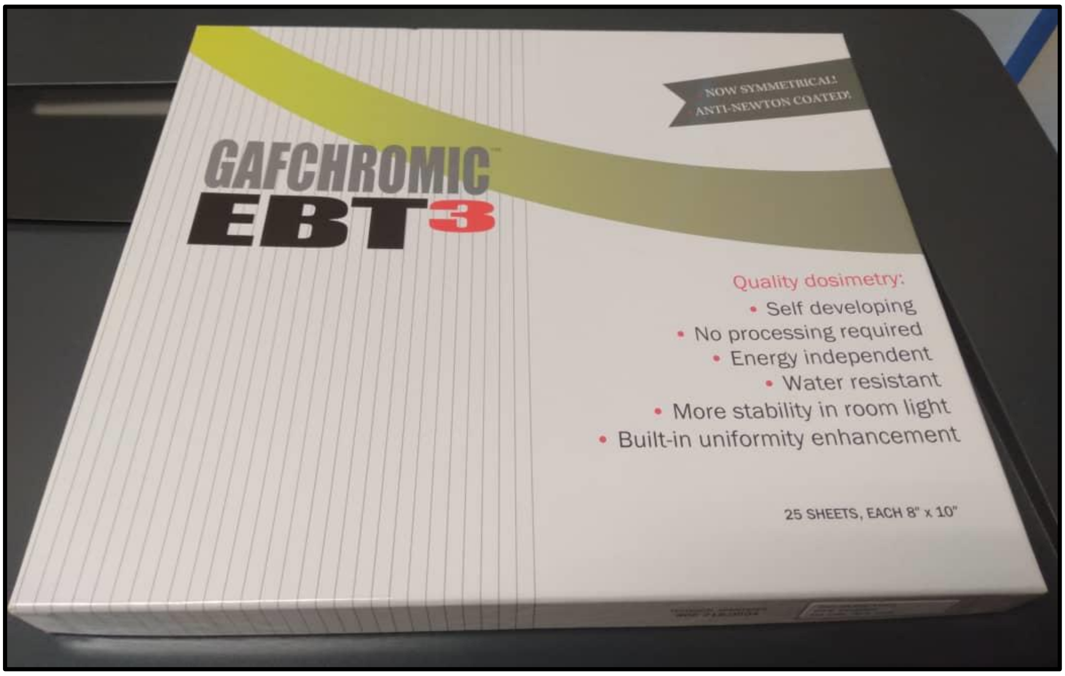


Figure 3.5 Gafchromic EBT3 film from a single batch.

3.1.3.4 Epson Expression 11000 XL Flatbed scanner

An Epson Expression 11000 XL Flatbed scanner was used to scan film that has been irradiated in this study. With the maximum scanning area of 310 mm x 437 mm, scanning resolution of 2400 dpi x 4800 dpi, and 3.8 Dmax plus 48-bit colour, the scanner offers almost everything require for professional-quality of large format scanning size.

The output format of this scanner can be saved in JPEG, PDF or TIFF. As for this study, the output format used is in uncompressed tagged image file format (TIFF). One Hi-speed USB port is used as the interface and the light source used by the scanner is Xenon gas fluorescent lamp.

Figure 3.6 Epson Expression 11000 XL Flatbed Scanner in AMDI.

3.1.3.5 PTW Verisoft software

PTW Verisoft is a gamma analysis based software commonly used in radiotherapy for pre-treatment verification of IMRT plans created in TPS. Gamma analysis functions to evaluate the coincidence between the calculated and measured dose distributions by utilizing the percent dose difference (DD) and distance to agreement (DTA). Previous study proven the useful of gamma tool in the quantitative comparison two-dimensional dose distributions (Low *et al*., 2003). The Verisoft software assists physicists in grid, and the data analysis software. It is therefore virtually impossible to provide general recommendations applicable for all situations (Pathak et al., 2015).

In this study, the Verisoft verification software is used to compare gamma distribution for calculated dose (cGy) using TPS and measured dose using films. This is to find out what percent of pixels passing rate of certain criteria with three different planning are performed for the comparison between measured dose from HDR brachytherapy unit and calculated dose from TPS.

Figure 3.7 PTW Verisoft software available in AMDI.