DOSIMETRIC STUDY OF 3DCRT AND IMRT TECHNIQUES OF LOCALISED PROSTATE CANCER USING MALE PELVIC PHANTOM

NURSYATINA BINTI ABDUL RAOF

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by

NURSYATINA BINTI ABDUL RAOF

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LIST OF ABBREVIATIONS

AMDI	Advanced Medical and Dental Institute
CC	Collapsed cone
CT	Computed tomography
CTV	Clinical target volume
DCAT	Dynamic conformal arc therapy
DD	Dose difference
dMLC	Dynamic multi leaf collimator
DTA	Distance-to-agreement
DVH	Dose volume histogram
EBRT	External beam radiation therapy
EBT	External beam therapy
EBT2	External beam therapy 2
EBT3	External beam therapy 3
ECC	Element correction coefficient
ERT	External radiation therapy
GI	Gastro-intestinal
GPR	Gamma pass rate
Gy	Gray
GTV	Gross tumour volume
ICRU	International Commission on Radiation Units and Measurements
HU	Hounsfield unit
IG	Image guided

IMRT	Intensity modulated radiation therapy
LINAC	Linear accelerator
MC	Monte Carlo
MLC	Multi leaf collimator
MU	Monitor unit
MV	Mega voltage
NOD	Net optical density
OARs	Organs at risk
OD	Optical density
PDD	Percentage depth dose
PTV	Planning target volume
QA	Quality assurance
ROI	Region of interest
RT	Radiation therapy
RTOG	Radiation Therapy Oncology Group
SRS	Stereotactic radiosurgery
SRT	Stereotactic radiotherapy
SSD	Source to surface distance
STP	Standard pressure and temperature
TL	Thermoluminescence
TLD	Thermoluminescence dosimeter
TPS	Treatment planning system
USM	Universiti Sains Malaysia
UV	Ultra violet
VMAT	Volumetric modulated arc therapy

2D	Two dimensional
3D	Three dimensional
3DCRT	Three dimensional conformal radiation therapy

KAJIAN DOSIMETRI BAGI TEKNIK-TEKNIK 3DCRT DAN IMRT KE ATAS KANSER PROSTAT SETEMPAT MENGGUNAKAN FANTOM BAHAGIAN PELVIK LELAKI

ABSTRAK

Kawalan mutu bagi rawatan radioterapi merupakan keperluan asas bagi penentuan penyampaian dos. Justeru, keseluruhan proses rawatan telah dihasilkan semula menggunakan fantom bahagian pelvik lelaki. Teknik perancangan rawatan IMRT dan 3DCRT digunakan bagi kanser prostat setempat dengan tenaga foton 6 MV. Set data imej CT dari fantom yang direka khas bagi bahagian pelvik tersebut digunakan untuk menentukan sempadan geometri bagi prostat, rektum, pundi kencing dan kedua-dua femur. Pengukuran dos ke atas sasaran diperolehi daripada TLD dan filem EBT3 manakala dos pada organ-organ yang berisiko (OARs) diukur menggunakan TLD sahaja. Titik pengukuran dikenalpasti pada fantom untuk meletakkan 17 biji TLD pada sasaran iaitu prostat dan 83 biji pada OARs. Sekeping filem EBT3 diletakkan pada bahagian tengah dalam 31 keping Perspeks di mana sasaran berada. Teflon digunakan mewakili kedua-dua femur. Fantom ini telah berjaya direka bagi menggantikan bahagian pelvik lelaki. Semua TLD yang dikalibrasi memberikan nilai sisihan piawai dalam julat 0.04 – 0.38. Filem EBT3 memberikan tindak balas linear (R^2=0.9444 dari julat dos 0 cGy – 400 cGy. Penyampaian dos ke atas prostat sebagai sasaran (PTV) yang diukur menggunakan TLD adalah konsisten melalui pengiraan dos dalam perancangan 3DCRT dengan beza peratusan dari 0.24% hingga 4.61%. Sisihan piawai bagi nilai 5% pada PTV dan OARs menunjukkan tiada perbezaan signifikan antara pengiraan 3DCRT dan pengukuran TLD. Analisis gamma pada PTV menggunakan teknik IMRT

memberikan nilai 95% menggunakan filem EBT3. Oleh itu, fantom pelvik yang direka khas ini memenuhi kriteria asas bagi pengesahan dos ke atas PTV dengan teknik IMRT menggunakan filem EBT3 dan pengesahan dos ke atas PTV dan OARs dengan teknik 3DCRT menggunakan TLD.

DOSIMETRIC STUDY OF 3DCRT AND IMRT TECHNIQUES OF LOCALISED PROSTATE CANCER USING MALE PELVIC PHANTOM

ABSTRACT

Verification of dose delivery is a basic necessity of quality assurance in radiotherapy treatment. The entire treatment process was replicated with a constructed male pelvic phantom. Intensity modulated radiation therapy (IMRT) and three-dimensional conformal radiotherapy (3DCRT) treatment planning techniques were used for localised prostate cancer treatment using 6MV photon energy. A CT image of male pelvic region from custom made phantom was used to contour the prostate, rectum, bladder and both femoral head. Dose measurements to the target was obtained from the thermoluminescent dosimeters (TLDs) and Gafchromic external beam therapy (EBT3) film while OARs dose measured with TLDs only. Points of interest were identified in phantom for TLDs placement with seventeen (17) holes to the prostate and eighty-three (83) holes distributed among the OARs. A piece of EBT3 film was located at the center of 31 pieces of Perspex where the target was located. Teflon was used to construct both femoral head. The pelvic phantom has been successfully constructed to replicate male pelvic region. All calibrated TLD generated standard deviation in range 0.04 to 0.38. The EBT3 film displayed a linear response (R^2=0.9444) from dose range 0 cGy to 400 cGy. Dose delivery to the prostate volume or planning target volume (PTV) measured with TLDs was consistent with 3DCRT planned doses with percentage different from 0.24% to 4.61%. The standard error bar of 5% value on PTV and OARs showed no significant differences between 3DCRT calculation and TLD measurement. The gamma evaluation at PTV using IMRT technique was 95% using EBT3 film. Hence, this

new handmade pelvic phantom fulfilled the basic criteria for dosimetric verification to PTV with IMRT technique using EBT3 film and dosimetric verification to PTV and OARs with 3DCRT techniques using TLD.

CHAPTER 1 - INTRODUCTION

1.1 Background

Prostate cancer ranks the most common cancer and the second most common cause of cancer death in men. Since most of the patients who were diagnosed with non-metastatic prostate cancer can survive longer than 10 years, the choice of radiation therapy (RT) techniques with minimised RT related toxicity is important for improving quality of life. As technology advances, new RT techniques have emerged and have been used in clinical practice. Three dimensional conformal radiation therapy (3DCRT) delivers a radiation dose conforming to the target volume of tumour. Thus, 3DCRT significantly increases the target dose while reducing the exposure of healthy tissue. RT techniques evolved to an advanced form of 3DCRT, intensity modulated radiation therapy (IMRT), which generates non-uniform fields to increase the radiation dose delivered to the intended target volume while potentially minimizing the irradiation to the organs at risk (Yu et al., 2016).

The most important aspect in radiotherapy treatment delivery is the accuracy of prescribed dose to the target volume with minimum damage to surrounding healthy tissues. There are many possibilities of errors from the first step of planning until treatment execution, hence accuracy of delivered dose cannot depend on treatment planning system (TPS) alone.

Instead of patients being utilised to correlate the dose absorption, a phantom material identical to human tissue is created for measuring the distribution of dose in radiotherapy. Initially, water phantom has been introduced for investigation of

dosimetry. However, it is not suitable and most of the time is not practical in clinical situations. Hence, Perspex has been used as a solid homogeneous phantoms (Faiz and Stathakis, 2010). The phantom is exposed to a set of patient data beam from treatment planning system to verify the actual measured dose and compare with the calculated dose. The phantom is anatomically realistic with radiologic properties that identical to real tissue concerned and allow many possibilities of measuring devices to be used to verify the dose. (Radaideh et al., 2012).

Thermoluminescent dosimeter (TLD) has been chosen in this study because it is more suited to a point dose measurement and the small size factor. Hence, it allows multiple points of measurement for more efficient reading statistically. While the EBT3 film high sensitivity to high energy is the factor it was selected for measuring the actual dose to the target for 3DCRT.

1.2 Research Problem

1.2.1 Rationale of Radiotherapy Dosimetry

Two aspects must be considered in order to achieve the aim of radiotherapy which are the accuracy and precision of dose to the tumour including the surrounding tissues and to the particular geometry of treatment delivery. Hence, for a successful radiotherapy plan to be achieved, the requirement of an adequate coverage to the tumour with the prescribed dose and the best possible beam geometry is very much important. The assurance of accuracy for dose delivery will not be successful with the treatment planning system (TPS) due to possibilities in inducing errors from the beginning of the simulations procedure to the treatment delivery. Furthermore, the precision of data input related to dosimetry from calibration contribute the errors

too. Therefore, multiple sources that generate uncertainties of radiotherapy procedure must be considered.

1.2.2 Problem Statements

Recently, there is an advance paradigm shifting for radiation therapy treatment in prostate cancer. The three dimensional conformal radiation therapy (3DCRT) conventionally used in various shapes are formed to limit dose to the normal tissues. Although this approach improved the dose conformity and dose escalation, there were limitations in dose sparing to immediate adjacent OARs such as rectum and bladder. IMRT expanded from 3DCRT. Instead of using fixed radiation portals, computer software is introduced and dynamic field is created for optimisation of the modulated intensity of the beam. As the result, three dimensional dose volume which is more conform to the target with steep dose gradients between surrounding normal structures. Hence, IMRT creates better conformity to the target and reduce the dose to OARs compare to 3DCRT. Studies shown increases of late toxicities contributed from the higher doses to the rectum and bladder. In any radiation therapy technique, the important target remains in optimising the minimal dose to both OARs. These dose distribution enhancements on conformity of the radiation to the target directed to the significant utilisation of IMRT for prostate cancer. The percentage expanded from <5 % to >95 % of external beam cases between 2000 and 2008 in men older than 65 years (Martin et al., 2014).

In spite of this outstanding minimisations in dose and volume to normal structures using IMRT, this vigorous analysis of 3DCRT and IMRT revealed no difference in patient-reported bowel, bladder, or sexual functions for similar doses delivered to

the prostate and proximal seminal vesicles with IMRT compared with 3DCRT delivered either to the prostate and proximal seminal vesicles or to the prostate alone (Bruner et al., 2015).

Hence, 3DCRT technique is still worth treatment in most localised prostate cancer although it is conventional and more advanced techniques have been approached. The consequences of this directed the studies on issues of dosimetry related.

In this study, TLD and EBT3 film were chosen as the radiation dosimeters. The small size of TLD is suited for point dose measurement in high gradient region. In addition its sensitivity to the low dose level made it suitable for measurement of dose to PTV and OARs with 3DCRT. The same measurement using TLD was not implemented for IMRT because of the time constraint during this study. Only EBT3 film was used to measure the PTV dose with IMRT technique. This due to the sensitivity of the film to high energy dose so that the verification of dose to PTV is convincing using the phantom.

1.3 Objectives of Research

1.3.1 To fabricate prostate treatment verification phantom having Malaysian body size

1.3.2 To verify Treatment Planning System (TPS) dose calculation at the planning target volume (PTV) with TLD measurements in 3DCRT irradiation technique

1.3.3 To compare the doses at the OARs with the TPS calculations in 3DCRT irradiation technique using TLD

1.3.4 To verify TPS dose calculations at the PTV with EBT3 film measurements in 3DCRT and IMRT irradiation technique

1.4 Scope and Limitations of Research

A set of CT data was utilised for delineation of important structures – prostate, rectum, bladder and both femoral head. An image was chosen as a reference to represent overall standard size of Malaysian male pelvic region. Dose measurements to the target and organ at risk (OARs) were obtained from the thermoluminescent dosimeters (TLD) and gafchromic external beam therapy EBT3 films. Dosimetric interest points were located on the specific organs for TLD chips placement. Prostate as the PTV is allocated with seventeen (17) holes to place the TLDs while another eighty three (83) holes were distributed among the OARs. A piece of EBT3 film was located at the centre of the 31 pieces of Perspex where the PTV was located. Teflon was used to construct both femoral head. However, these materials were not accurately reflects the real density of soft tissues.

A computerized treatment planning on the phantom was calculated using Monaco 5.11 treatment planning system (TPS). Collapsed Cone and Monte Carlo algorithms were used in this TPS. This study focuses on 3DCRT and IMRT techniques using TLD and EBT3 film. The 3DCRT technique using TLD and EBT3 film whereas IMRT technique using only EBT3 film. This is due to the time consuming on using TLD and Linear Accelerator (Linac) for IMRT technique. The limitation in EBT3 film was the low sensitivity of the film for low dose range. Hence, OARs dose for IMRT technique cannot be completed and compared with the 3DCRT technique using film.

The target and the OARs for TLD placement was only 8 mm from the surface of the Perspex. A uniform structure of target and OARs were created upon contouring whereas in reality the tumour and OARs was not in the uniform structure. The number of TLDs on each dosimetric region of interest were decided base on the maximum TLDs that can fit the area. This limitation directed the study to focus only in a single plane on the isocentre of the beams. Point dose was read on the isocentre slice.

The prescription of the plan was prescribed for 6000 cGy in 20 fractions with the arrangement of six beams criss-cross and intersect within prostate, behind the bladder and in front of the rectum. The beam arrangement decision was based on the conformity of dose to the PTV which is referred to 95% of dose distribution cover 95% of target volume. The OARs dose constraints was referred to Radiation Therapy Oncology Group (RTOG) 0415 protocol and was implemented in Radiotherapy Unit, Advanced Medical and Dental Institute (AMDI), Universiti Sains Malaysia (USM).

Dose calculation to PTV and OARs must be validated by measuring the delivered dose to the phantom and compared to the calculated dose by the TPS. OARs dosimetric measurement have not been studied previously using Perspex phantom and new detectors. This research will create the Perspex board as a humanoid male pelvic area to study the dose distribution in the PTV as well as in the OARs.

The TLDs and EBT3 films were placed on the phantom and are irradiated with 6 MV photon by Linac. TLDs were analysed 24 hours post irradiation using Harshaw 3500 TLD Reader. The TLDs reading obtained is a signal in charge unit (Coulomb).

Therefore it was converted to dose unit by cross calibration technique with each TLDs calibration value. The EBT3 film was analysed using the Verisoft software.

1.5 Thesis Overview

Chapter One contains the background, research objectives, scope and limitations of the research. Theory and literature review, especially on 3DCRT and IMRT techniques, TLD and EBT3 film are described in Chapter Two. Chapter Three focuses on the materials used in the research and approached methodology. Chapter Four indicates the results achieved and further discussions. Chapter Five concludes and proposes the enhancements for future works.

CHAPTER 2 - THEORY AND LITERATURE REVIEW

2.1 Introduction

3DCRT and IMRT improve the biochemical outcome in patients with favourable, intermediate and unfavourable risk prostate cancer. IMRT is associated with minimal rectal and bladder toxicity. However both treatments delivered high conformity of dose to the target. The critical contribution of 3DCRT and IMRT in the modern management of prostate cancer appears to be reduction of the volume of the anterior rectal wall included in the planned target volume carried to high radiation doses. IMRT requires more specific tasks as it needs expertise skills, specific delineation of organs and complicated quality assurance (QA) efforts. In prostate cancer, escalation of dose has been restricted by the toxicity of healthy tissues especially in the rectum and bladder. Since the prostate was sandwiched between the rectum and bladder, the organ motion was the main aspect to be minimized during the treatment. Due to the motion on prostate and other sensitive internal organs, the positioning of the original planning on CT images may vary during the radiotherapy treatment. This prostate motion have been studied by Fung et al., 2005 and revealed a predominant shift of prostate from the position on CT planning in the superior-posterior direction, with an average closer to the superior axis. Thus margin to CTV has been recommended. Although major shifting can occur in certain cases, Wang et al., 2007 has discovered that the motion of the prostate was within 1 cm provided the proper instructions to patients for full bladder preparation is given. Thus, the uncertainty for inadequate dose area during the treatment can be minimised.

3DCRT dose distribution is uniform on the planning target volume (PTV) and no rapid fall-off existed near the PTV edge compared to IMRT. The anterior rectal wall or the bladder base is comprised in volume during the irradiation in 3DCRT. The organ motion and isocentre realignment on dose received to both prostate and OARs can be different in both techniques (Wang et al., 2007).

Harrison et al., 2011 manufactured a coronal slice pelvic phantom for auditing purpose. The dimension of the phantom is 22 cm height at mid-point and 31.5 cm width at superior end with 18.4 kg weight of fully assembled phantom. The phantom with tissue equivalent materials was tested for dose distribution study for prostate and rectal cancer treatment case. It compares planned and measured doses under 3D conformal plans. The methodology involved loading the phantom with TLD for dose measurement. The measured point doses taken from average of three TLD disks placed at the measurement point. The standard deviations for the first 19 measurements indicated statistical reproducibility of the measurements of within ±3%. The TLDs in position 20 at a low dose region and consequently the statistical variation of the measurement was large in comparison to the dose received. The average standard deviation across the measurements taken was 1.5%. The agreement between the measurement points and the predicted points indicate the delivery of the prescribed treatment is accurate to within 3% for measurement points.

The Hounsfield unit (HU) scale is a linear transformation of the original linear attenuation coefficient measurement into one in which the radiodensity of distilled water at standard pressure and temperature (STP) is defined as zero Hounsfield units (HU), while the radiodensity of air at STP is defined as -1000 HU.

The construction of the images scanned in the CT modality is made after processing the information captured by a set of detectors in order to define the attenuation coefficient generated by each row that cross the object. This object is discretised on voxels. The grey level that will colour each voxel is representative of the ability of photon interaction with each voxels crossed. It will depend on the linear attenuation coefficient of the tissues. These values of attenuation are regulated in a pattern that has water as a reference to a zero change in 1000 to -1000, or -500 to 500, where the minimum of the scale is the air (-1000) and the maximum is given by the absorption of metal (+1000). The scale of the numerical representation of the absorption promoted by each voxel is called Hounsfield unit. Latter, the values on Hounsfield scale is correlated to the 256 grey scale. In this grey scale, the bone is white, the grey water medium is to HU equal zero, the metal bright white (+1000) and the black air (-1000) (De Matos and De Campos, 2009).

By modifying the level and extent of the colour window (shades of grey), the grey scale represents an adaptation in the anatomical exploration of the object, which shows greater contrast with an organ or tissue without being hidden by other tissues that have characteristics of absorption similar. The air, which is the least absorbent, will be an end of the scale and means a mitigation contrast. The most absorbent is on the other end of the scale of mitigation. Pure water is considered the middle of the scale and sets the value of zero attenuation in Hounsfield scale. Since most tissues that comprise the human body have a large amount of water, these tissues do not show great variation in absorption with the exception of bone tissue. Thus to obtain the contrast between the soft tissue is common to use the grey scale values ranging only from -1000 to +1000 allowing more stress these tissues, however the bone

tissue that are more saturated absorbent appear in white losing the contrast (De Matos and De Campos, 2009).

In this study, Perspex with density 1.18 g/cm3 was used to construct the phantom as it has the identical density to the tissue in human body (Radaideh et al., 2012). Perspex slabs were cut and constructed to represent the model of a patient's pelvic region and represent the soft tissues. Teflon with density 2.2 g/cm3 was used to represent both femoral heads.

2.2 Thermoluminescent Dosimeter

A thermoluminescent dosimeter, or TLD, is a type of radiation dosimeter. TLD requires some characteristics such as wide interval and high sensitivity of TLD in which the luminescence intensity is linear with absorbed dose and high TL signal per unit absorbed dose. In addition TLD is able to preserve information for a long time. Another characteristic is the one isolated peak of TL curve. Heating procedure will be complicated if several peaks exist. A strong physical, stable on chemical and resist with radiation should be the important characteristics of TL dosimetry material (McKeever et al., 1995). These requirements should be satisfied in a high-quality TL dosimeter. However, the requirements cannot be fulfilled all the time, mainly the small fading condition (Kortov, 2007). In addition the small size of TLD made it suited for point dose measurement especially in high gradient region. Hence, it is suitable for 3DCRT dosimetric verification. The standard deviation (σ) is the uncertainty of dose distribution across the phantom. The standard uncertainty in each TLD measurement is $\leq$ 3% (Howell et al., 2010). However, Radaideh et al., 2012 discovered that the standard deviations of TLD 100 was 3-5% for dose delivered from 100 cGy – 500 cGy. TLD response also not depend on dose rate.

TLD has become a compatible dosimeter due to various advantages it offers such as it is reusable, cost effective, stable in long intervals and unaffected by moderate environmental changes. In this study, TLD was chosen due to its size which makes it possible to be placed in the phantom. TLDs were reusable dosimeters, hence annealing process should be done after every single irradiation. Such dosimeters can be placed in a phantom without causing a major perturbation of the electron fluence. They require no direct connection or leads to the read-out instrument, which adds to their attractiveness (Klevenhagen, 1985).

2.3 Gafchromic External Beam Therapy 3 (EBT3) Film Characteristics

Nowadays, a new generation of radiochromic film, EBT3 which is an important tool for verification of high dose radiation therapy such as IMRT has been introduced. The most important EBT3 characteristics were the response at high-dose levels, scanner orientation sensitivity and post irradiation coloration, energy and dose rate dependence, and orientation dependence with respect to film side (Borca et al., 2013). EBT3 has a special polyester substrate that prevents the formation of Newton's Rings interference patterns in images acquired using flatbed scanners. The response to high dose levels made it suitable for dose verification to target in this study. Also the structure of EBT3 film is symmetric and eliminates the need of keeping track of which side of the film was placed on the scanner.

The gafchromic film dosimetry was widely used for external beam therapy. The high spatial resolution, weak energy dependence and tissue equivalence properties of this film were suitable for intensity modulated radiation therapy (IMRT) (Fiandra et al., 2006). Gafchromic film also has minimal field size effects and therefore superior to be used for calibration purposes (Cheung et al., 2006).

The use of the EBT3 film with the phantom is to verify the calculated dose distribution by the TPS. The standard deviation between measurement and TPS for phantom was 3.9% to 4.7% (Mitillo et al., 2016).

2.4 Linear Accelerators (Linac)

Photons in EBRT are generated in Linac. The following section describes the photon generation and the beam shaping in the treatment head. The different components in a treatment head can be seen in Figure 2.1.

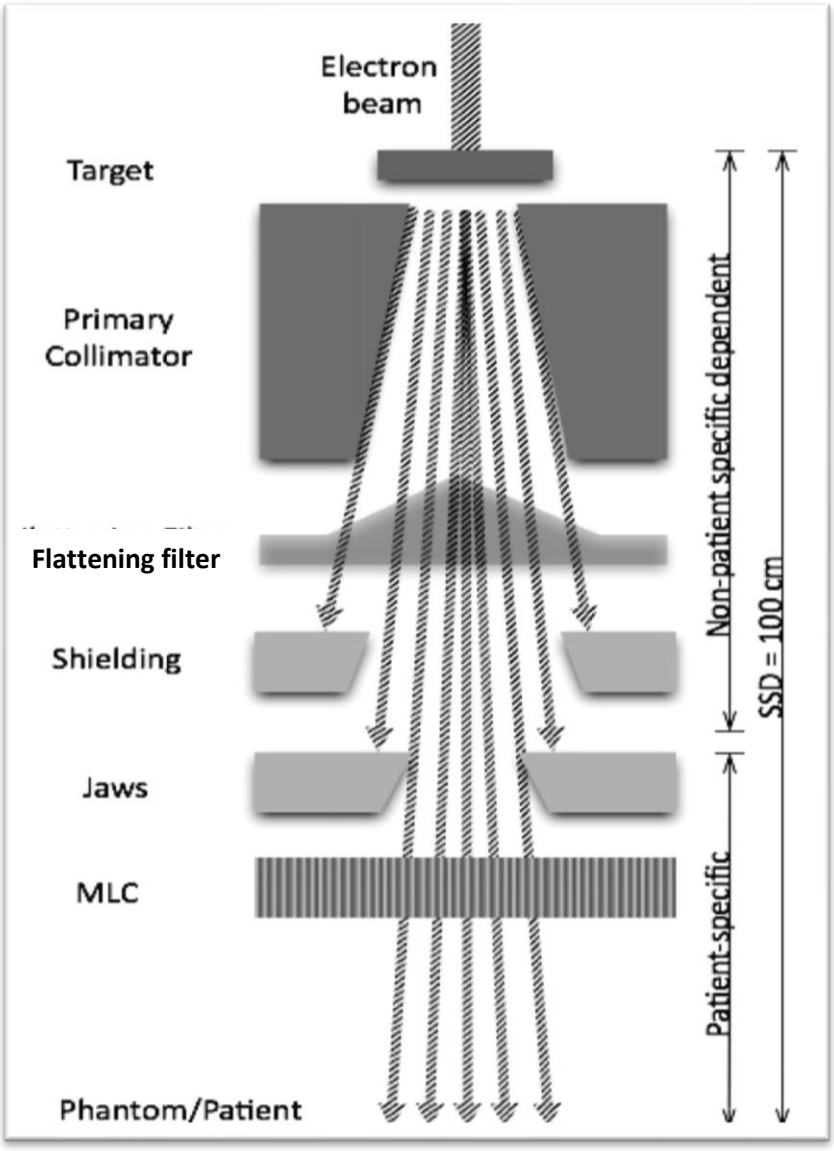


Figure 2.1: The different components in the linear accelerator treatment head (Mayles et al., 2007)

The photons are produced by focusing accelerated electrons on a metal target. The electrons are generated by an electron gun. The electron gun consists of a filament that upon heating and within electrostatic field releases electrons. The amount of current supplied to the filament regulates the electron fluence in the Linac and thereby the fluence of photons. The accelerated electrons strike the metal target and produce photons. The aims of the photon production are high bremsstrahlung production, high mean energy, small source size, a large angular distribution and a low electron contamination.

The target consists of metal with high atomic number, Z, to get a high production rate of bremsstrahlung since it is proportional to the atomic number of the target to the power of two. However, a very high atomic number material decreases the amount of bremsstrahlung in the forward direction while a very thick target leads to low photon fluence due to self-attenuation. These are often achieved with a Tungsten target with a thickness of one third of the electron range. The photons produced in the target are then collimated in the primary collimator (Mayles et al., 2007).

After the primary collimator, the photons pass through a flattening filter to make the beam intensity uniform across the field. This is achieved by designing flattening filters that have a material with a high atomic number in the centre and a material with a low atomic number in the periphery. The use of flattening filters leads to more electron contamination and a decreased photon beam fluence. The beam is further collimated by the secondary collimator before it reaches the patient.

The photon energy fluence is affected by the inverse-square law as well as attenuation and scattering of the photon beam inside the patient. The representation

of dose distribution can be divided into different categories. Depth dose curves are dose distributions along a line parallel to the beam propagation direction. Lateral dose curves are dose distributions along a line perpendicular to the beam propagation direction at a certain depth (Mayles et al., 2007).

One of the contributors to the surface dose is scattered photons from collimators, flattening filters and air in the beam line. A second contributor to the surface dose is backscattered photons from the patient. A third contributor is high-energy electrons produced by interactions in the beam line. The surface dose decreases for higher photon energies. Following the surface dose is a build-up region. This is due to the relatively long ranged secondary electrons created at the patient surface. The maximum dose is reached at the end of the build-up region. The depth at which the maximum dose occurs depends on the energy and the field size of the beam. The maximum dose occurs at deeper depths for increased photon energies. Depending on the density of the material behind the patient the exit dose may have a build-up region or build-down region due to a decreased or increased amount of backscattered electrons (Mayles et al., 2007).

Areas of interest in a lateral dose curve include the central region, the penumbra region and the umbra region. The central region is the portion of the beam from the central axis within 1 cm to 1.5 cm of the geometric field edges. The penumbra region is defined as the integral from 20% of the maximum dose to 80% of the maximum dose. This integral should ideally be close to zero to optimise the beam shape at the field edges. Three main processes create the penumbra region. A geometrical spread of intensity at the field edges is seen since the source is of finite size. Scatter in the patient blurs the edges of the field. Finally, there is a possibility

of transmission through the collimators which also contributes to the penumbra. The umbra region defines the dose outside the target volume.

2.5 Treatment Planning System

3D treatment planning utilises state of the art imaging techniques for tumour and organs at risk visualisation, novel algorithms for accurate dose calculation and optimisation to generate a conformal dose distribution around the tumour while maximally sparing the surrounding normal tissues. In order to ensure the quality of treatment delivery, proper patient immobilisation, multi leaf collimator and electronic portal imaging device are used to reduce treatment discrepancies. The reduced volume of normal tissues inside the treatment area will decrease the chances of toxicity or the treatment side effects, allow dose escalation hence improve local tumour control.

The inverse method for was first suggested by Brahme, 1988 and confirmed later by many investigators (Goitein, 1990, Holmes and Mackie 1993, Mohan et al., 1994) who clearly revealed that beams with intensity modulation can generate a more conform dose distributions to an irregular target shapes and proposed inverse planning algorithms, optimisation methods and treatment delivery systems for a various tumour sites.

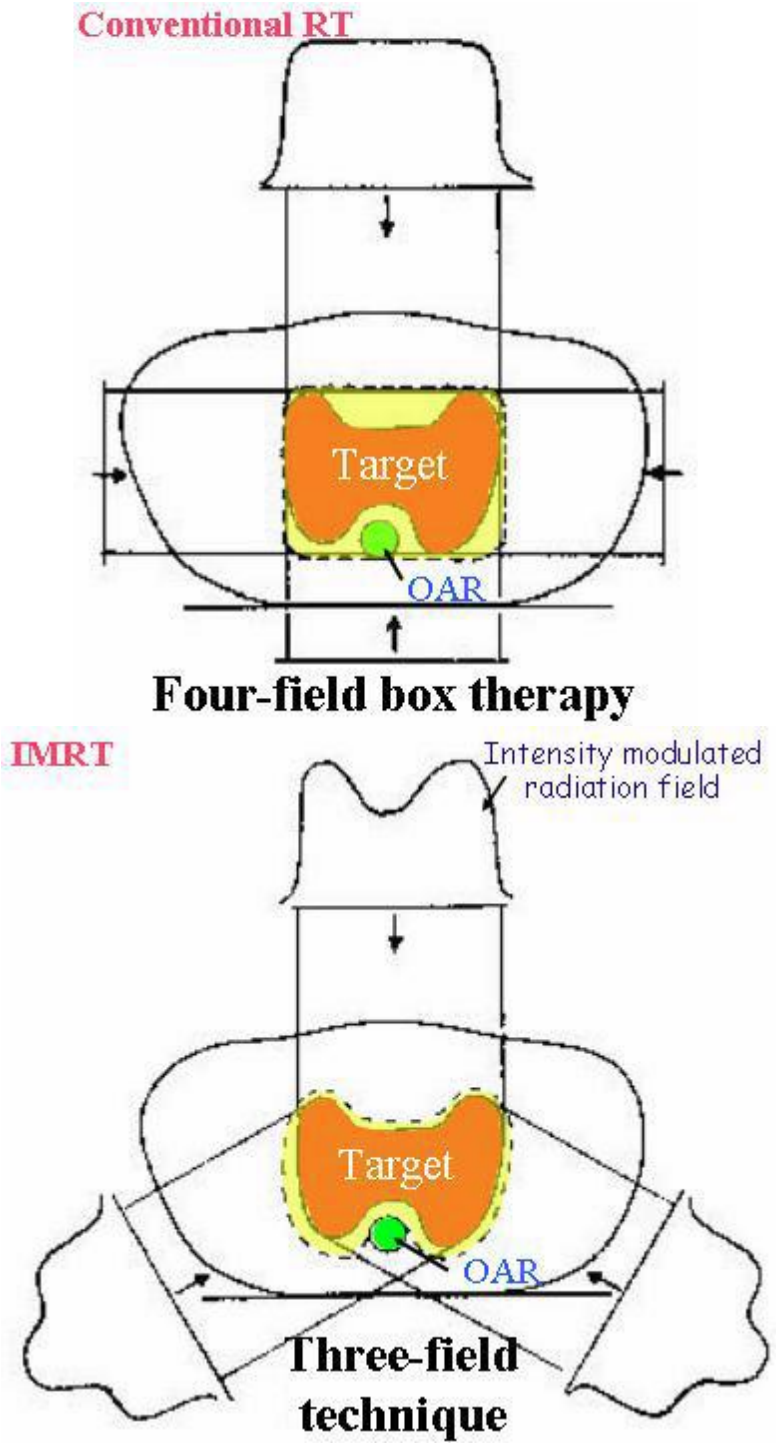


Figure 2.2: Comparison of the dose conformity around the target between conventional radiation therapy (RT) and IMRT. a) A four-field box technique with conventional radiation therapy. b) A three-field technique with IMRT showing the non-uniform energy fluence from each field. (Brahme, 1988)

Intensity modulated radiation therapy (IMRT) was first proposed in 1982 (Bortfeld, 2006). The main advantage of IMRT over 3DCRT is that IMRT can produce a more conform dose distribution around the target. It also minimise the dose to the OARs. (Figure 2.2). IMRT introduced the non-uniform photon fluence from multiple equally spaced beams around the patient to achieve better dose conformance around the tumour. This leads to a possible disadvantage of IMRT which is more normal tissues of the patient will be irradiated to the unnecessary doses. The irregular treatment fields will be shaped by the MLC as showed in Figure 2.3.

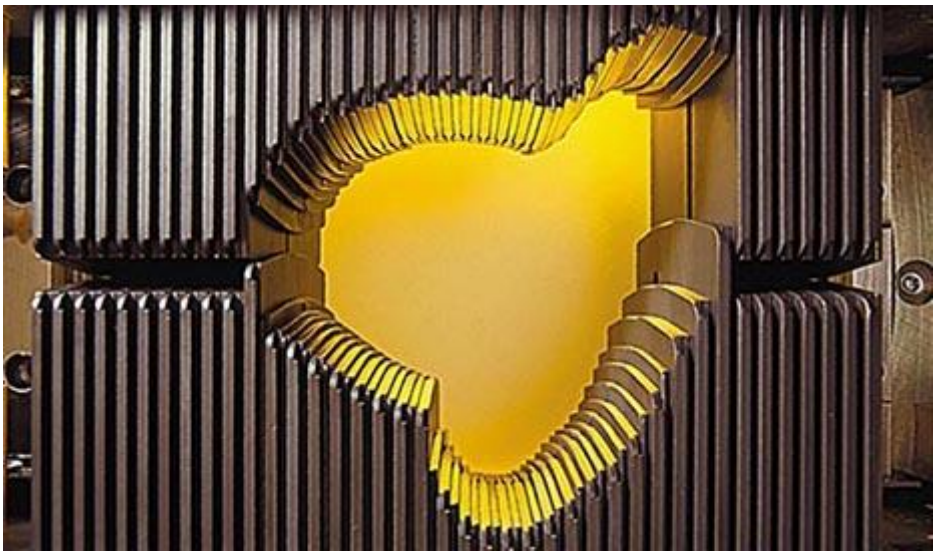


Figure 2.3: The multi leaf collimator (MLC) leaves that can form irregular shapes which can better match the target. (Kremer, 2014)

2.6 Theory of Dose Algorithms

In modern radiation therapy the planning process that requires simulations of dose distributions (3DCRT and IMRT) is compulsory. One clinically used dose calculation algorithm for photons is called the Collapsed Cone (CC) and Monte Carlo (MC) dose algorithms.

2.6.1 Monte Carlo Dose Calculation Algorithm

Monte Carlo (MC) simulation is based on a statistical model that calculates the dose distribution given a limited set of particle interaction types and their probabilities. For the system to be useful in radiotherapy, it must meet several criteria of which the energy deposition is a part. It must also accurately characterize the Linac's radiation production, its beam modulation and account for patient contours and inhomogeneities. Treatment aids are accurately modelled. The algorithm uses transmission filters through which MC tracking does not occur when the jaws/MLCs are modelled. The algorithm tracks particles from source to end.

2.6.2 Collapsed Cone Dose Calculation Algorithm

The CC dose algorithm calculates dose with known approximations such as the no kernel tilt approximation. The kernels represent the transport of energy or dose from an interaction point and are pre-calculated with MC simulations. The MC based dose calculation uses statistical methods to calculate dose.

Dose can be reported as dose-to-water or dose-to-medium. The traditional method in radiation therapy is to report dose as dose-to-water and thereby treat all materials as water with different densities (Ma and Jinsheng, 2011). Dose-to-water can be explained as the dose deposited to a specific point if an infinitesimal volume of tissue is replaced with an infinitesimal volume of water. The CC dose algorithm

calculates dose as dose-to-medium and later converts it to dose to-water. The reasons for reporting dose-to-water are due to a tradition (benchmark) and it is said to be clinically relevant since the radiation sensitive parts of the cell are surrounded by water (Siebers et al., 2000).

CC algorithm in Monaco 5.11 is a fluence based algorithm. Radiation scatter from primary collimator, flattening filter, secondary collimator, wedge and backscatter to monitor chamber are modelled. After the energy fluence is known, dose is calculated by mean of a Monte Carlo point Kernel based algorithm, calculating dose to medium as default and taking into account tilt kernel effect. Dose calculation through convolution is facilitated using the CC approximation. The calculation is made to the actual medium itself, rather than the dose to a Bragg-Gray water cavity. For the CC calculations, a regular 3D dose grid is defined from the density matrix geometry by choosing the voxel midpoints. A ray trace is performed to each of these points to determine the amount of radiant energy released in each voxel from the incident beam. Both the modulated direct energy fluence and the head scatter energy fluence are considered (Monaco 5.00 Training Guide, 2015).

CHAPTER 3 - MATERIALS AND METHODS

This study has been carried out at Radiotherapy Unit, AMDI, USM. Linear Accelerator (Elekta, Crawley, West Sussex, UK), Computed Tomography (CT) Scanner (Toshiba, Tochigi-Ken, Japan), TLD Reader (Thermo Fisher Scientific, Ohio, USA), Treatment Planning System (TPS) (Monaco 5.11, Crawley, West Sussex, UK) and Oncology Information System (OIS), Mosaiq were used in this study. TLD100 (Thermo Fisher Scientific, Ohio, USA) and EBT3 gafchromic film (Ashland, Bridgewater, US) were used as the dosimeters to compare the actual dose to PTV and OARs between measurement and the calculated one by the TPS.

The male pelvic phantom is irradiated using an Elekta Synergy Platform Linac with dual energies 6 MV and 10 MV (Figure 3.1). The accelerator has 80 leaf pairs with projected width of 0.5 cm at isocentre. While the Toshiba Aquilion CT Scanner was used to scan the phantom as showed in Figure 3.2.

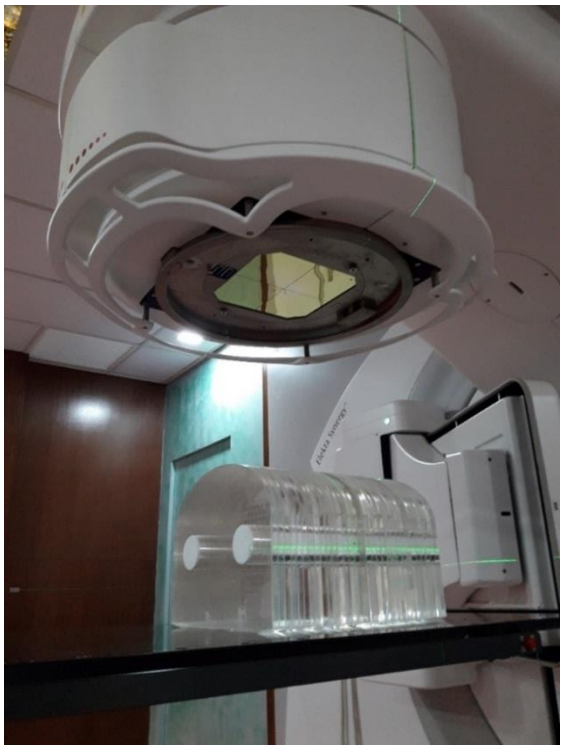


Figure 3.1: The Elekta Synergy Platform linear accelerator used in this study

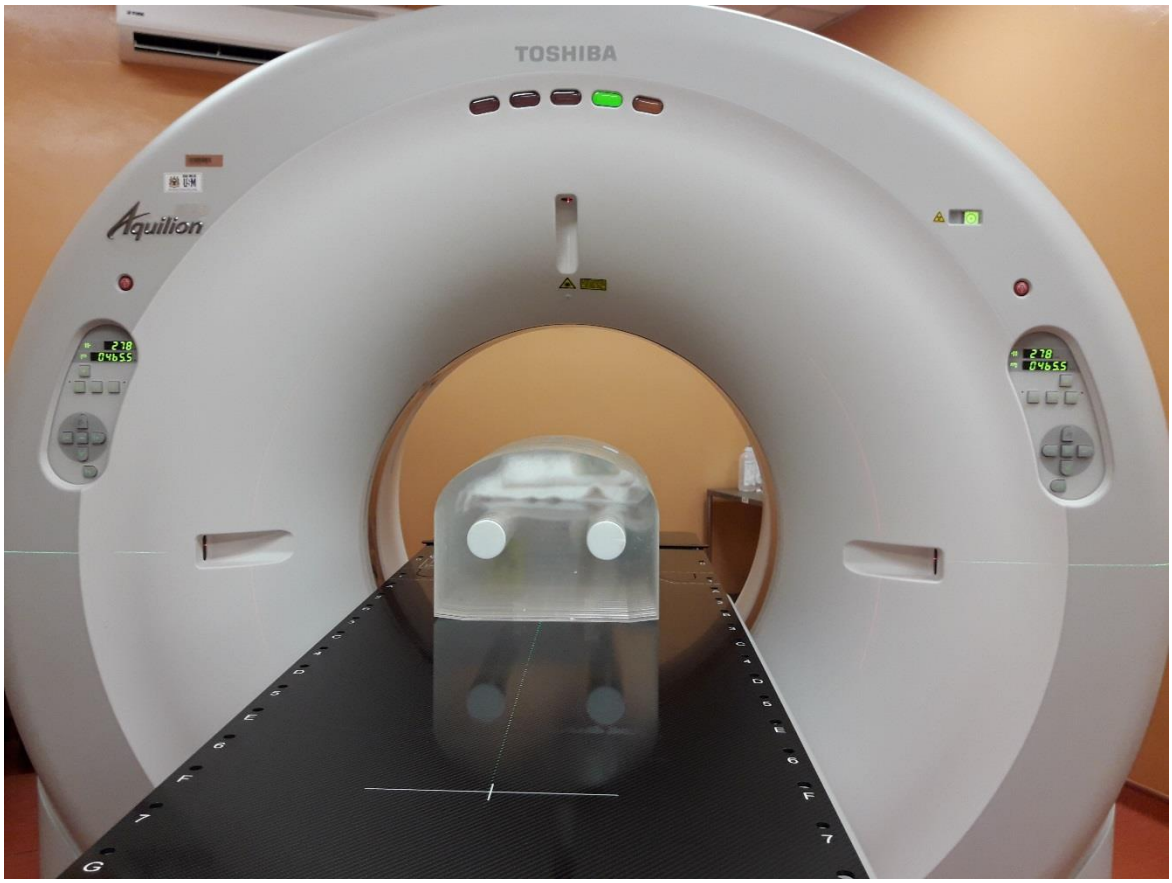
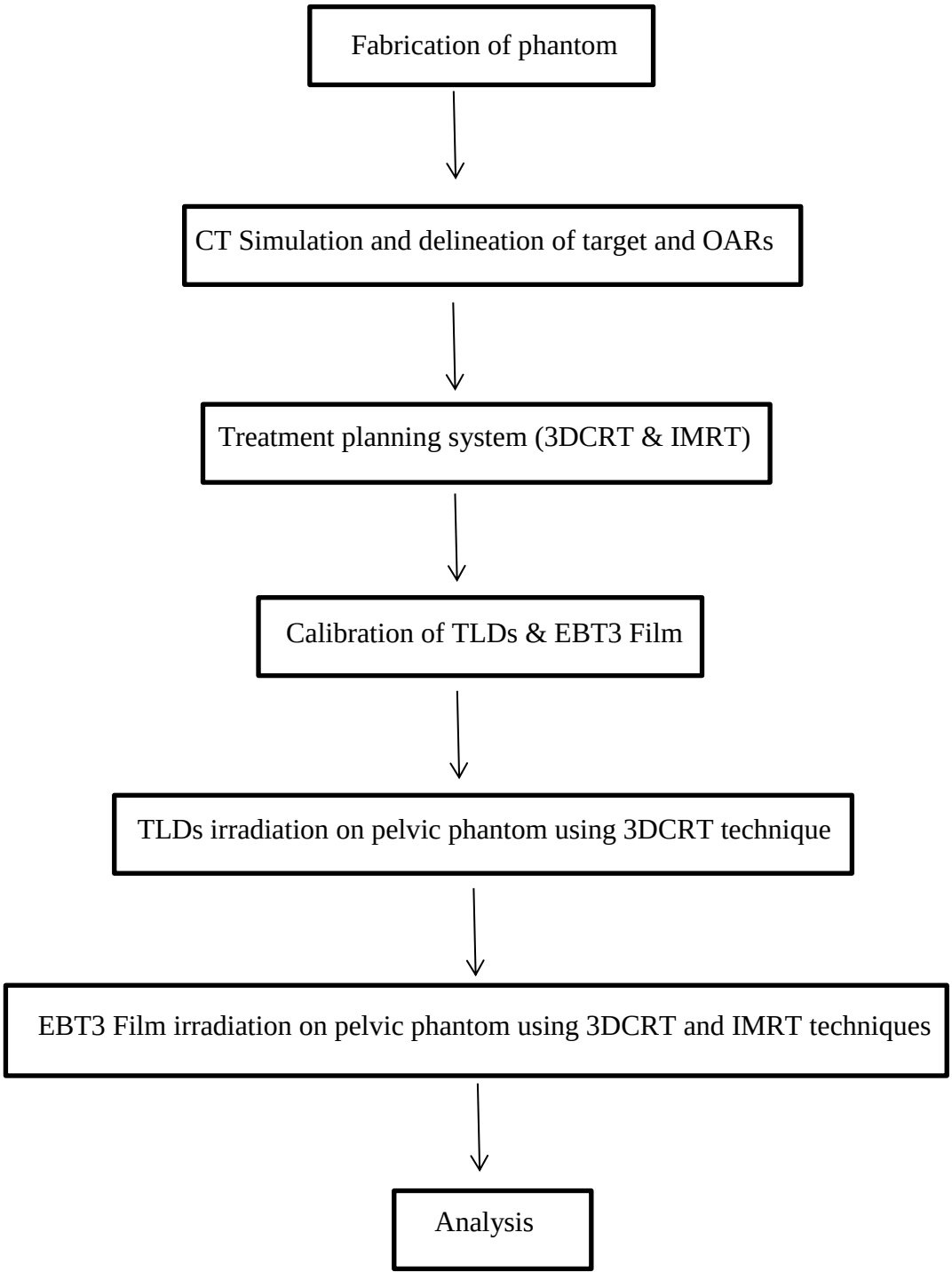


Figure 3.2: The Toshiba Aquilion computed tomography scanner used to scan the male pelvic phantom

3.1 Flowchart of Methodology



3.1.1 Phantom Construction

The CT scanned image of 1 cm slice thickness of a medium built male with prostate cancer was used to fabricate the actual size pelvic area of Malaysian patient

containing the organs of prostate, rectum and bladder. One piece of the Perspex was constructed with holes for TLDs placement and meant for the centre of the phantom.

TLDs and EBT3 gafchromic films were located at the centre of the phantom. The phantom tomographic view was illustrated as in Figure 3.3 and data corresponded to dimension of related body parts was arranged as in Table 3.1.

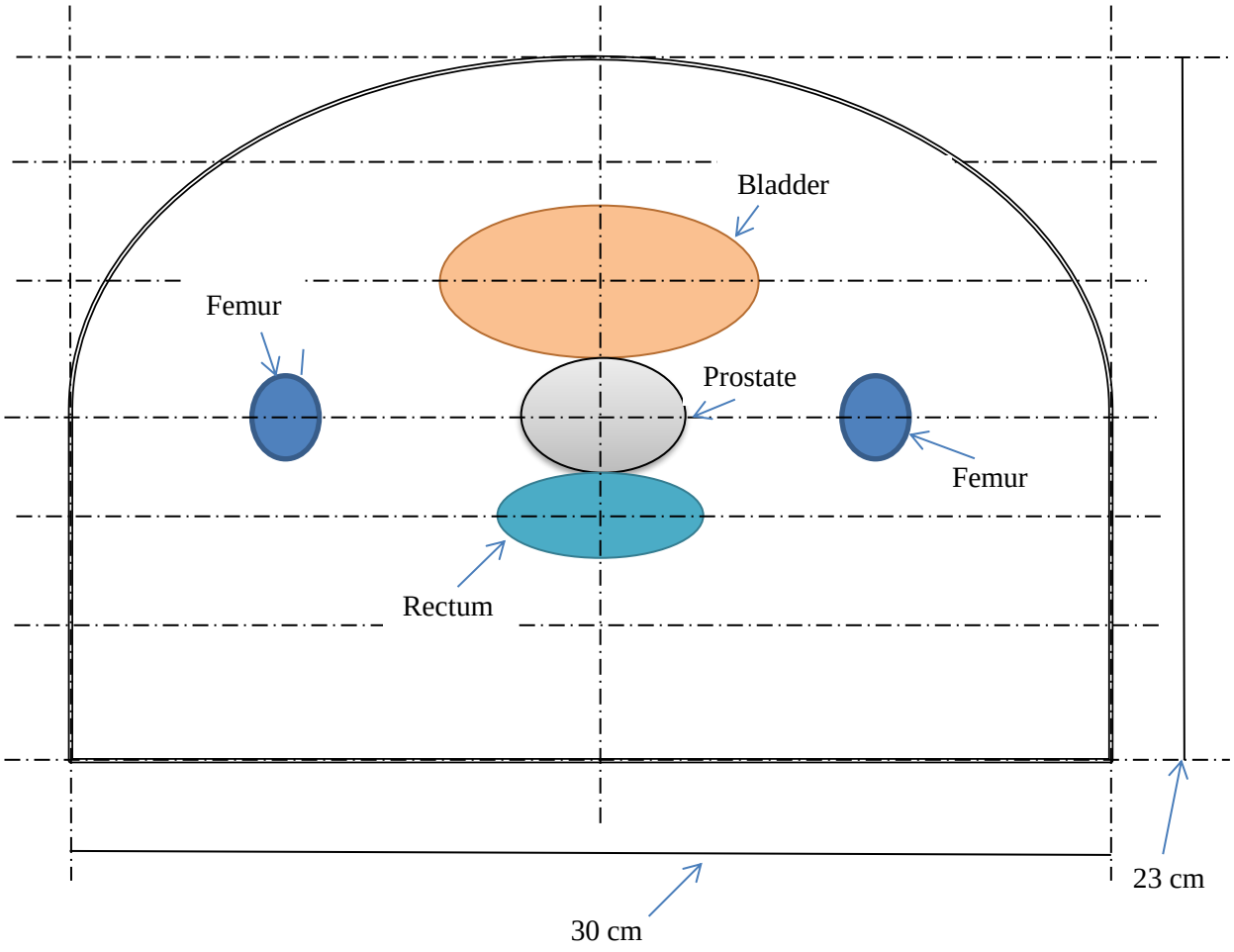


Figure 3.3: A cross sectional image on PTV and OARs