

**DETERMINATION OF THE COUCH TRANSMISSION FACTOR
AND ITS INCORPORATION IN TREATMENT PLANNING SYSTEM**

**IAN CHANZU
BSc (Moi)
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DECLARATION

This research project is my original work and has not been presented in any other institution for a degree award or other qualification.

CHANZU IAN

REG. NO. SPPV/05404P/2020

Signature _____ Date _____

This research project has been submitted with our approval as supervisors:

Signature _____ Date _____

PROF. JACKSON M. ODOTE

DEPARTMENT OF TECHNICAL AND APPLIED PHYSICS

THE TECHNICAL UNIVERSITY OF KENYA

Signature _____ Date _____

DR. JOASH ONGORI

DEPARTMENT OF TECHNICAL AND APPLIED PHYSICS

THE TECHNICAL UNIVERSITY OF KENYA

DEDICATION

I dedicate this work to my parents Mr Joash Konzolo and Mrs Mary Ngoya for the major and big sacrifices they made to support me towards the completion of my studies. May God, give you more life to enjoy the fruits of your labour through me.

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ABSTRACT

Treatment couch is an equipment used in the treatment of cancer patients. It is used to give comfort and support during treatment. This ensures good treatment outcome as the patient will be intact thereby maximizing the dose to the target while minimizing the dose to surrounding organs. In order to improve tumour dose coverage, more radiation beams are placed to come from different angles, others penetrating the couch before reaching the target. The treatment couch is made of carbon fibre thus making it radiotranslucent especially for the radiation beams penetrating through it before reaching the target. Research previously done, shows that the treatment couch causes poor dose distribution resulting to underdose. To solve this problem, the treatment Couch Transmission Factor (CTF) needs to be included in the Treatment Planning System (TPS) in order to compensate for the dose absorbed by the couch. This study investigated the CTF of the iBEAM evo treatment couch and virtual TPS couch model, and its incorporation in the Oncentra TPS. The study was carried out in three phases using a cylindrical CTDI phantom, ion chamber and a TPS generated virtual square phantom. Phases 1 and 2 gave an equal mean CTF of 1.00 for 6MV and 15MV while phase 3 gave a mean CTF of 0.97 for 6MV and 0.98 for 15MV. The highest deviations recorded between CTF values in phase 1 and phase 3 were at GAP 11 (-9.03%) for 6MV photon energy and GAP 4 (-4.96%) and GAP 11(-6.65%) for 15MV photon energy. The highest deviations recorded between CTF values in phase 2 and phase 3 were at 11 (-9.53%) for 6MV photon energies and 11 (-6.85%) for 15MV photon energy. The implication of these results was seen on the dose deviations between phases 1, 2 and phase 3 if the plans in the TPS could have been delivered. The highest recorded underdose was 12.71 monitor units in phase 2 at GAP 11(213.8°) and 10.63 monitor units in phase 1 at GAP 11 (213.8°) for 6MV, 7.02 monitor units in phase 1 and 7.97 monitor units in phase 2 for 15MV at GAP 11(213.8°). In conclusion, from this research done, the CTF is not incorporated in the TPS. However, further studies are recommended of the same when the CT couch attached on the CTDI scanned image is included in the external or body contour.

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LIST OF ABBREVIATIONS

AAPM	American Association of Physicists in Medicine.
AP	Anterior Posterior.
CT	Computed Tomography.
CTDI	Computed Tomography Dose Index.
CTF	Couch Transmission Factor.
DICOM	Digital Imaging and Communications in Medicine.
EBRT	External Beam Radiation Therapy.
GAP	Gantry Angle Position.
HU	Hounsfield Unit.
ICRU	International Commission on Radiological Units.
IGRT	Image Guided Radiation Therapy.
IMRT	Intensity Modulated Radiation Therapy.
LINAC	Linear Accelerator.
MeV	Mega Electron Volt.
MU	Monitor Units.
MV	Mega Voltage.
nC	Nano Coulomb
PA	Posterior Anterior.

SAD	Source to Axis Distance.
SOP	Standard Operating Protocols.
TG	Task Group.
VMAT	Volumetric Modulated Arc Therapy.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Wilhelm Roentgen discovered X-ray radiation in 1895 which has subsequently been widely applied to the treatment of cancers. At least two-thirds of cancer treatments in Western nations employ radiotherapy, which is the application of ionizing radiation to the treatment of cancerous and non-cancerous diseases (Chen and Kuo, 2017).

According to Podgorsak (2005), 50 years ago, technological advancement in radiotherapy was relatively slow, relying primarily on radiation X-ray generating tubes, Betatrons machines and van de Graaff type of generators. In 1950's, H.E. Johns' from Canada invented a teletherapy Cobalt-60 unit that provided an increased demand in the use of higher photon energies. This put the teletherapy cobalt-60 unit to be used for many years in radiotherapy. Medical LINACs were created concurrently, configured with electrons and photon megavoltage X-ray radiation of different energies which offered excellent use in radiotherapy.

The LINAC and teletherapy machines are used to perform most radiotherapy procedures. They are mounted isocentrically, such that the beam, couch and gantry axis rotation meet at a central position. This allows the machine's gantry to rotate around the patient at a fixed Source To Axis Distance of 100 cm for LINAC'S and 80 cm for Cobalt-60 teletherapy units minimizing chances of collision. LINAC energy ranges are 6MV, 15MV for photons and 6MeV, 9MeV, 12MeV, 15MeV for electrons. The main components of these external beam radiation treatment machines are: a radiation source; a gantry and gantry stand; a patient treatment couch; and a machine treatment console.

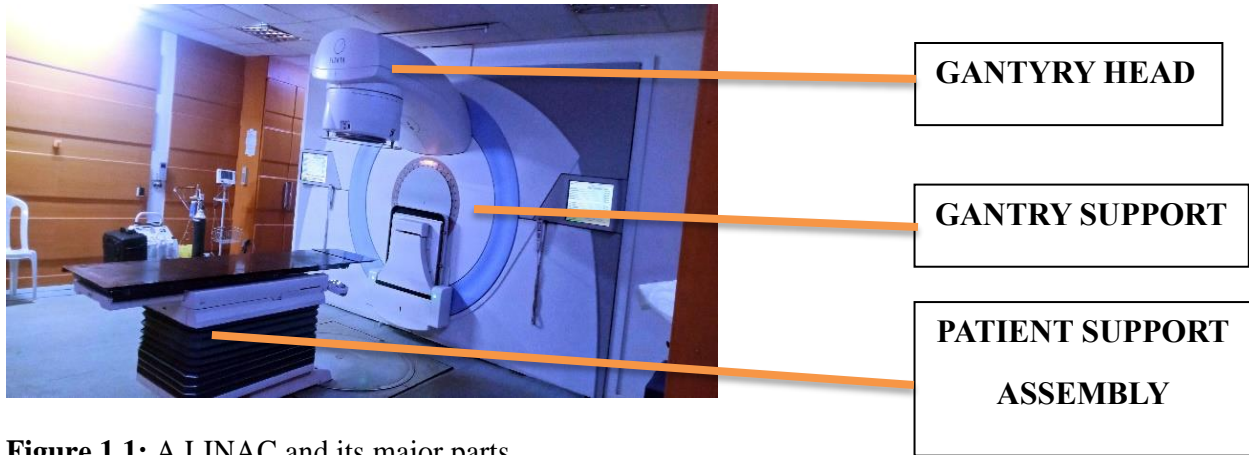


Figure 1.1: A LINAC and its major parts.

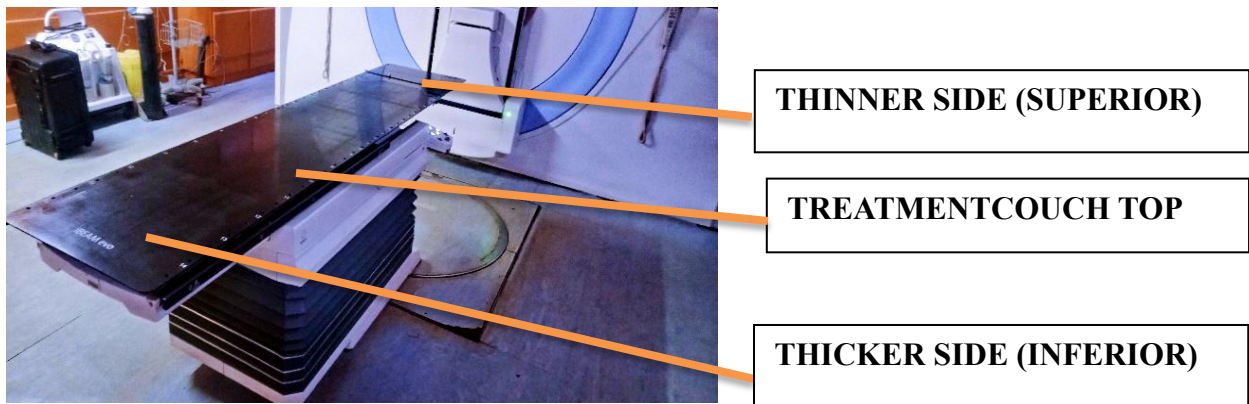


Figure 1.2: Patient support assembly.

During radiotherapy, the machine’s gantry rotates around a patient positioned on the treatment couch while delivering radiation to the targeted site. Patient on treatment couch must be still so that the main goal of radiotherapy can be achieved, which is to maximize radiation dose to the target while minimizing dose to normal organs. To minimize skin toxicity and beam attenuation during conventional radiation, treatment couches were constructed of a "tennis-racket kind”. This kind of treatment couches experienced sagging on the area with the tennis racket material depending on the patient's weight and duration of usage, since they were not strong and rigid enough to provide support. This decreased the precision and accuracy of patient positioning for treatment.

As a consequence of their sagging nature, they were replaced by carbon fibre couch tops which have a “high rigidity” ability, “better tensile strength”, allows “minimal bending” when loaded, high specific strength, high beam transmission, strong and light in weight (Rall,2016). The rigidity and strength of a carbon fibre couch are provided by compressed foam sandwiched in a carbon fibre shell. The carbon fibre couch tops are supported by frames. According to Meyer et al. (2001), for each type of treatment couch, the configuration of the supporting frames differs, resulting in an intersection of varying degrees of freedom.

1.1.1 Standard treatment couch

This couch has a traditional design with a frame beneath the couch top that provides support to the patient. It has two different frame spine sides, centrally and laterally and a removable tennis racket and flat panel supports where the posterior and posterior oblique beams pass through. This couch can be found on the Elekta and ZXT of Siemens' standard therapy couch. The supports at the centre are made up of carbon fibre materials so that the attenuation of the beam can be reduced (Meyer et al. 2001).

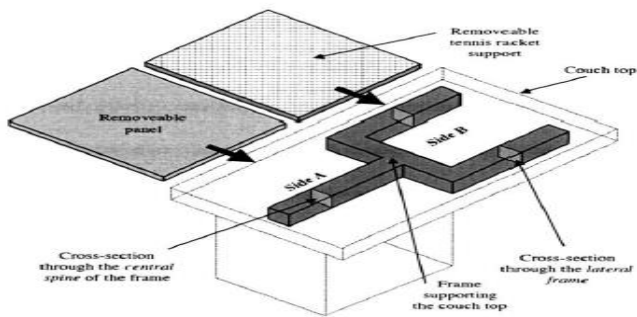


Figure 1.3: Diagram of a standard treatment couch (Meyer et al. 2001).

1.1.2 Variable standard treatment couch

This couch is made up of a carbon fibre couch top and a removable tennis racket material top supported by sliding rails. The rails can be continuously moved in the left and right directions. An excellent representation of this type of couch is the “Varian Exact”. This helps to move the rails out of the beam path in some oblique angles (Meyer et al. 2001).

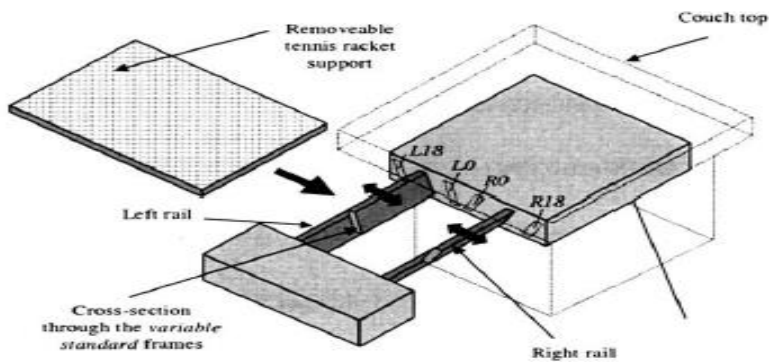


Figure 1.4: A variable standard treatment couch (Meyer et al. 2001).

1.1.3 C-arm treatment couch

This couch consists of a main panel which is fixed with a tennis racket portion. Two shaped c-arm rails are mounted beneath the “tennis racket” part so as to rotate around the fixed axis. The c-arm rails can be rotated separately to move out of the beam's path. This treatment couch design was applied to the Elekta couch (Meyer et al. 2001).

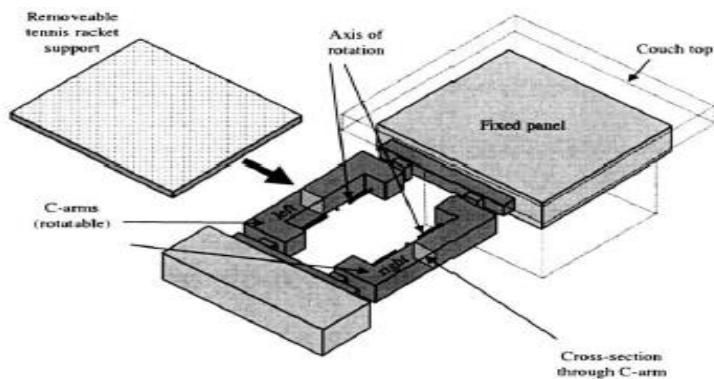


Figure 1.5: A c-arm treatment couch (Meyer et al. 2001).

1.2 TREATMENT PLANNING

Treatment planning has advanced from 2-dimensional and 3-dimensional planning to more elaborate techniques such as intensity-modulated radiation therapy and volumetric modulated arc therapy with the incorporation of image guidance. The more advanced the treatment, the more precise, accurate and conformal it is. Long ago, treatment planning was done manually, but with the introduction of computers, dose calculation algorithms software were developed that aided in treatment planning.

The most and accurate optimal plan design depends mostly on beam incidence freedom that is achieved through couch, collimator and gantry movements' combination. With this freedom of degrees, the probability of the beam reaching the patient without passing through the couch is minimal. This results to a poor dose distribution within the target. The impact of its effect will depend on the treatment type, photon energy, treatment field size, and number of beams passing through the couch. There are clinical situations where the radiation beams will intersect the treatment couch for instance when utilizing the four-field box technique (see figure 1.6) for the pelvic case irradiation, AP/PA for the spine or lungs, brain IMRT, prostate IMRT and head/neck IMRT.

All beams penetrating the couch will reduce the dose supplied to the tumour about 2-5% (Olch et al. 2014). This necessitates the inclusion of the couch in dose calculations, either in the TPS or manual calculations. Inclusion of the treatment couch in the computerized planning system can be done in two ways. The first method involves integrating a scanned CT scan image of the treatment couch into the TPS patient collected dataset using registration-based modules or software. The second method involves creating a TPS model of the scanned CT image and then incorporates it as a DICOM radiotherapy structure. The two strategies will compensate for the

absorbed radiation by the treatment couch. No matter how small the radiation dose is, its clinical significance to the patient is large.

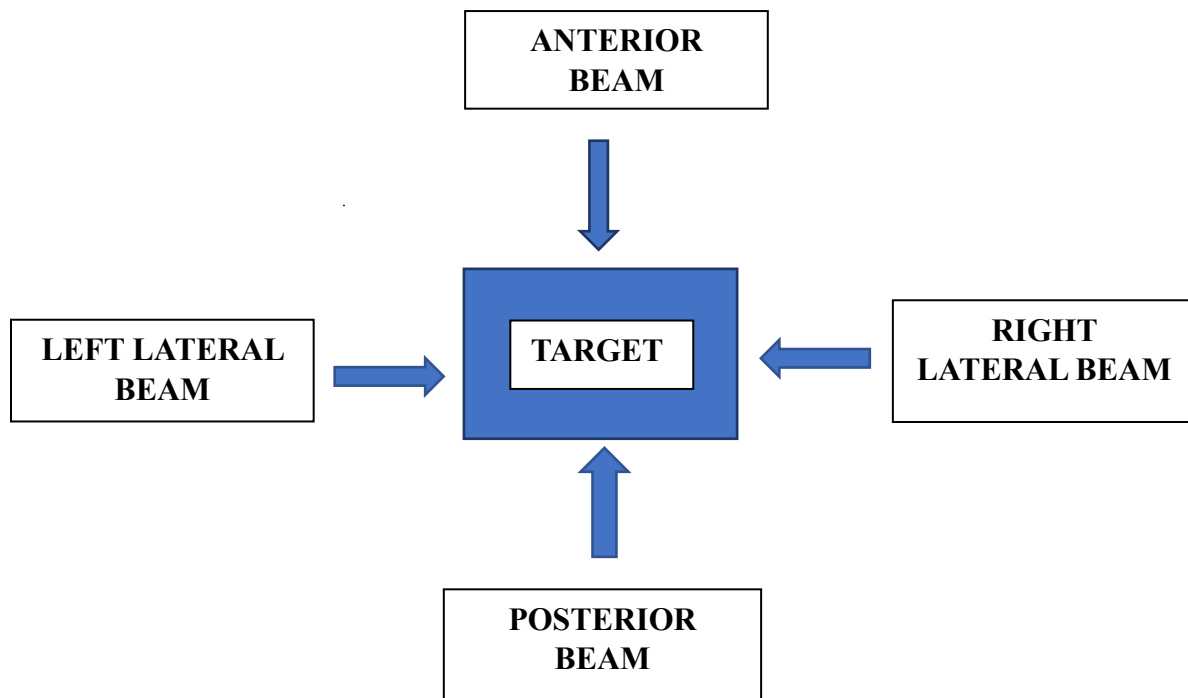


Figure 1.6: Schematic representation of a four field or box technique.

1.3 STATEMENT OF THE PROBLEM

Cancer recurrences are one of the major problems affecting the oncology or cancer department in the whole world. According to Weisman et al., (1985), a larger percent of cancer patients, after treatment, have metastases to other body organs or recurrences of the same tumour type. Some go back for retreatment, and others fail due to financial issues or due to pain and discomfort. These can be attributed to many factors. Since the oncology department is a multidisciplinary team, everyone in the department has a role to play in ensuring such scenarios don't happen. Starting all the way with the oncologist, whose job is to prescribe the appropriate radiation dose and also ensure target delineation, is accurately done, capturing the primary plus any residual disease. On the other hand, medical physicists in charge of the treatment planning should ensure prescribed dose to the target is delivered in practice, therefore evaluating the treatment process in addition guaranteeing software and hardware are working properly and in an optimal state. Finally, radiation therapists should ensure safe and accurate patient positioning for accurate treatment dose delivery.

When every step of the radiation treatments is performed carefully, the chance for recurrences can be minimized. One important aspect of planning process that can affect treatment planning accuracy is related to the treatment couch. After commissioning, the immobilization device and Treatment Planning System Quality Assurance are rarely done to ascertain the accuracy of dose delivery. For effective tumour coverage, beams are placed in several directions to treat the tumour fully. According to TG 176 report by Olch et al. (2014), beams penetrating the couch before reaching the tumour have an effect on the tumour dose coverage, which will attenuate the radiation dose, reducing the tumour dose. This underdose of targets leads to recurrence issues.

More so, computers installed with the treatment planning software can crash or breakdown. The software can also crash due to computer virus infections. This might delay the treatment of patients due to the lack of a TPS, and more so because the manufacturers of the software are not in the country. Since radiotherapy has evolved from 1D, whereby plans used to be made without computers and a good prognosis was made, in such scenarios, a 2D treatment plan can be made and dose calculated manually. If this Couch Transmission Factor was not known since it existed in the computer, the manual dose calculation would not factor it in, leading to an underdose of the patient, especially when treating using posterior (see figure 1.6) and posterior oblique beams.

In the literature, most researchers have put much concentration on the Eclipse software and Monaco software but little research has been done on the CTF of the Oncentra TPS and how it has been incorporated in the system. Therefore the goal of this study is to evaluate the incorporation on the treatment Couch Transmission Factor in the Oncentra TPS.

1.4 OBJECTIVES

1.3.1 General Objective

- a) The aim of this research project is to determine a CTF of iBEAM evo treatment couch and evaluate how it has been incorporated in the Oncentra TPS.

1.3.2 Specific Objective

- a) To determine the couch transmission factor in three phases.
- b) To perform a comparison between the three couch transmission factors.
- c) To perform a dosimetric comparison in calculation of dose using the determined couch transmission factor.

1.5 RESEARCH QUESTIONS

- a) In which way is the CTF of the patient treatment couch incorporated in the Oncentra TPS?
- b) What CTF error margins does the patient treatment couch incur when compared to the CT couch and the Oncentra treatment Planning couch model?
- c) How does change in the gantry angles affect the CTF of the beam penetrating through the patient treatment couch?

1.6 JUSTIFICATION

Radiotherapy requires a safe and effective administration of high dose which conforms to a precisely defined tumour volume. Patients in radiotherapy are not treated suspended in air; rather they lie on a treatment couch for immobilization and comfort ability during treatment. In conventional radiotherapy, some machines used the carbon fibre couch, while others used the tennis racket couch top. The Equinox cobalt-60 machine, which used racket tennis, and the Bherbhatron cobalt-60, which used a carbon fibre couch top, are two examples. Irrespective of the difference in couch top materials, the formula used to calculate the dose incorporated other factors (collimator scatter factor, phantom scatter factor, wedge factor, tray factor, and output factors) that are in the beam paths, neglecting the couch factor.

In modern radiotherapy, the introduction of computers resulted in the development of TPS, which makes use of algorithms to calculate doses in both homogenous and inhomogeneous media. The treatment couch is incorporated into this TPS to compensate for the attenuated radiation dose in the couch. This couch factor especially on the perpendicular beams should be indicated in the department's Standard Operating Protocols to be used in manual dose calculations in case the TPS fails or for quick emergency treatment procedures. Due to

advancement in treatment techniques, the gantry rotates in clockwise and ant-clockwise direction delivering radiation to the target in order to achieve a highly conformal and good radiation dose distribution inside the tumour volume. To achieve this, in some cases the beam angles will intersect the couch posteriorly.

In 2014, AAPM recommended in TG 176 report by Olch et al. (2014), that the treatment immobilization devices and patient treatment couch tops to be incorporated in TPS due to their dosimetric effects to the patient. Dosimetric impacts of these devices include surface dose increase, tumour under dose and affected dose distribution. All other output factors are always accounted for in manual and in the TPS calculations, but the treatment couch factor is mostly overlooked because it's thought to be close to negligible. Differences in the treatment couches, treatment machine units, TPS, couch factors however small, are studied in various different researches as reported from TG 176 report.

It's recommended in every cancer centre to perform quality assurance regularly and determine a factor that matches their specific TPS. Thus far modelling of the Linac treatment couch has been done at Pinnacle TPS, Eclipse TPS, Monaco TPS and CMS Xio by the manufacturer's attenuation profile of the different couches. From the modelling, effective methods have been suggested to incorporate the treatment couch. Some institutions utilize the Oncentra TPS where it is necessary to model the LINAC treatment couch into this TPS so as to reduce the effects stated above. This can have an effect on the dose being delivered as reported by Olch et al. (2014) on the "dosimetric effects caused by immobilization devices".

CHAPTER TWO

LITERATURE REVIEW

This section provides the literature review for the determination of treatment couch transmission factor and its incorporation in the Treatment Planning System (TPS). Patient treatment couch is an essential component of external radiation treatment. It provides support to the patient while in the treatment position, and it may also be used to immobilize the patient to ensure accurate and reproducible treatment delivery. However, the presence of patient treatment couch may also cause radiation beam attenuation, resulting in a reduction in the delivered dose. Therefore, it is necessary to account for radiation beam attenuation caused by patient treatment couch in the TPS. This is typically done by incorporating a treatment couch transmission factor into the TPS. From TG 176 report, by Olch et al. (2014), several researchers have investigated the dose attenuation for various types of treatment couches and treatment machines. An iBEAM evo treatment couch showed an attenuation of up to 2.7% at 0° and 4.6% at 50° for 6MV photon energy.

2.1 RADIATION INTERACTION WITH MATTER

X-Ray radiation is generated through the interaction of high energy electrons with high atomic number material. The photons created will transfer their energy to electrons in matter that will deposit absorbed dose in the patient (Palmer, 2013). In radiotherapy, radiation is used to treat cancer and other medical conditions. The interaction of radiation with matter is an important aspect of radiotherapy, as it determines how the radiation will affect the patient's body. There are several different ways that radiation can interact with matter. Photoelectric effect occurs when a photon (a particle of radiation) gets absorbed after interacting with an inner shell electron. During this process a photo-electron will be ejected from the atom leaving a vacancy in the shell

that is filled when an electron from a higher level drops. Characteristic x-rays or an Auger electron can be emitted subsequently. Compton scattering that occurs when a photon interacts with an outer shell electron and is scattered, causing it to lose some of its energy. Pair production can take place when a high-energy photon interacts with an atomic nucleus and creates a positron and electron (Sprawls, 2012). A photon interaction is a prerequisite of photons being individual units of energy. As radiation traverses through matter, it can be transmitted thus following no interaction, absorbed by depositing its energy, or scattered after interaction as shown in figure 2.1 below.

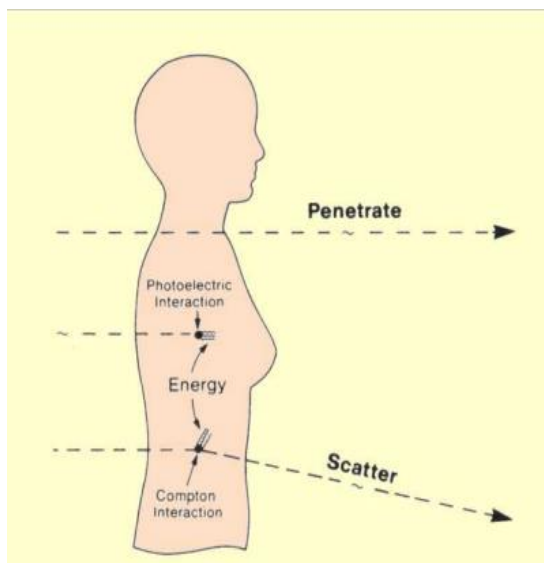


Figure 2.1: Radiation interactions with matter in human body (Sprawls, 2012).

When charged particles, such as electrons, alpha particles and protons, move through matter, they are capable of causing ionization through collisions. They are referred to as directly ionizing radiation, provided they possess adequate kinetic energy (Khan et al. 2014). Typically, a multitude of photons with varying energies comprise an x-ray radiation beam that is generated from a target or a gamma-ray beam emanating from a source. Notably, attenuation takes place in

the process of penetration of radiation through matter. According to Fraass et al. (2019), when an x-ray beam passes through matter, its intensity may decrease due to attenuation. Attenuation can result from either absorption or scatter of photons within the beam, and may vary depending on factors such as the beam's energy and the nuclear atomic number (Z) of the absorber. Figure 2.2 below illustrates the attenuation characteristics of a photon beam as it passes through matter. In a narrow-beam geometry specific setup, a detector is placed at a distance fixed from the source of radiation, beyond an absorber's range to avoid scatter, with the aim of measuring only the primary photons that passed through the absorber. This means that any photon that undergoes scatter due to the absorber is not intended to be detected in this setup.

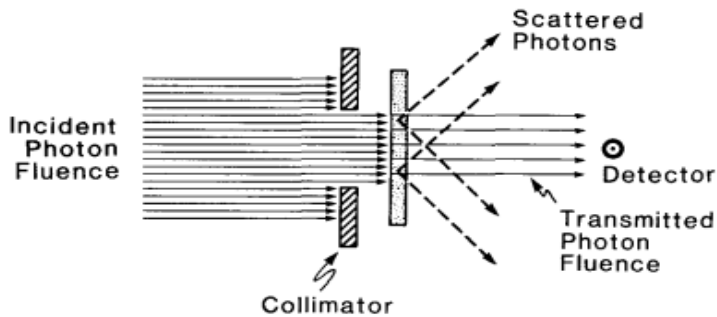


Figure 2.2: Experimental arrangements for studying narrow-beam attenuation through an absorber (Fraass et al. 2019).

The concept of beam attenuation is significant in this study as it explains the impact of a carbon fibre patient treatment couch in attenuation and also dose build-up of various x-ray energies. Carbon fibre has a lower atomic number than other materials commonly used in treatment couches, such as metal or plastic. This lower atomic number means that carbon fibre is more effective at attenuating lower-energy photons, such as those used in imaging, while having less

effect on higher-energy photons used for treatment. This lowers the build-up of radiation passing through the patient treatment couch, which can lead to more accurate and precise dose delivered to the tumour volume reducing skin dose. By optimizing treatment couch design and using appropriate materials, radiation therapists can improve treatment quality and reduce the risk of side effects.

A study performed by Wilson et al. (2011) on the impact of the Varian Exact™ carbon fibre treatment couch on dose build up and radiation beam attenuation argued that carbon fibre is perceived as essentially radio-translucent. Nevertheless, studies previously done disagree with this perception especially for oblique gantry angles of incidence. Wilson et al. (2011) further investigated the radiation beam attenuation and build-up surface dose improvement feature of the Varian Exact™ carbon fibre insert treatment couch. They found a notable correlation between the angle of incidence and attenuation, leading to reductions in phantom doses of up to 6% for 6MV photon energy and 4% for 15 MV photon energy. These findings suggest that the energy of the radiation beam has an impact on the degree of attenuation. Figure 2.3 below illustrates the dose attenuation experimental setup.

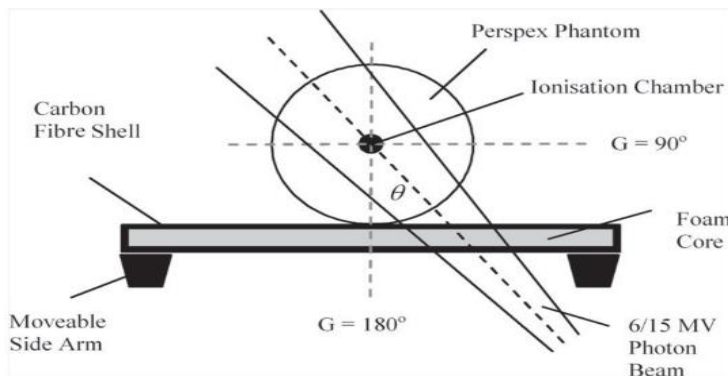


Figure 2.3: Schematic illustrations for beam attenuation measurement (Wilson et al. 2011).

Wilson et al. (2011) reported that it might not be suitable to account for the treatment couch attenuation in all beam geometries using hand calculations, as a TPS has the ability to model the couch with accurate dose calculation algorithms to do that. They further recommended extensive work to investigate the impact of neglecting treatment couch attenuation on radiation clinical treatments.

2.2 INTRODUCTION TO TREATMENT PLANNING SYSTEM

Recently, radiotherapy treatment techniques and planning modalities have rapidly developed. According to Zhang et al. (2017), the approach to radiation treatment has shifted from using a single field treatment radiation beam to using multiple fields' radiation beams or arc treatments. The use of IMRT has increased the number of radiation beam fields used for delivering treatment leading to a significant impact in patient treatment couches. This is especially true as VMAT plans have become the centrepiece of treatment (Zhang et al. 2017). As a result, there is a greater demand for delivering accuracy. Zhang et al. (2017) reported that the pencil beam algorithm and convolution algorithms are not able to accurately and precisely calculate treatment couch attenuation in all movable gantry angles.

Zhang et al. (2017) also reported that while Monte Carlo dose algorithms have improved the dosimetric accuracy of VMAT treatments in radiation therapy, it can be compromised if the couch is excluded from the treatment planning process. They evaluated the effect of patient treatment couch on radiation output delivery by incorporating two different treatment couch models (model A uniform couch and two-component couch model B) into the Monaco TPS. The objective was to determine which model more accurately quantified the influence of the couch on radiation dose. They found that Model A outperformed Model B by exhibiting fewer deviations from measurements and better resistance to changes in dose grid resolution. Based on

these results, Zhang et al. (2017) recommended that the couch Model A be introduced systematically into clinical practice. These results are applicable to the “Elekta iBEAM evo Extension 415” couch, and the techniques employed can be used in other treatment couch models.

Wagner and Vorwerk (2011) further investigated the accurate modelling of the parameters of patient treatment couch in the Eclipse treatment planning software. Here, The Varian Exact Type Treatment Couch comprises of a carbon couch top that is 25 mm in length with two movable rails 85 mm in length. To simulate the treatment couch in TPS, Wagner & Vorwerk (2011) suggested that the Hounsfield Units of each component should be adjusted. The treatment couch attenuation was measured using both high and low x-ray photon energies on a Clinac 2300 C/D machine and Eclipse TPS was used to calculate the treatment couch attenuation model using HU values of different sets. A comparison was then made between the calculated and measured and attenuations. Wagner and Vorwerk (2011) found that the HU values that showed the least deviation of the measured and calculated attenuation of patient treatment couch were -750 HU for carbon plate, -995 HU for carbon plate filling and 225 HU for rails. Treatment couch attenuation varied with the changes in gantry angle, with the largest value of attenuation occurring at the area of rails beneath the couch, as expected. They concluded that to accurately model Varian Exact type of Treatment Couch in Eclipse TPS, it is necessary to adjust the HU values as follows: -750 HU for carbon plate, -995 HU for carbon plate filling and 225 HU for rails. These HU values can then be incorporated in TPS to be used for high and low photon x-ray energies. By using accurate and correct HU values, patient treatment couch can be modelled correctly in Eclipse TPS.

2.3 COUCH

2.3.1 Treatment Couch

The couch to be used is an iBEAM evo couch (See Figure 1.2). It consists of two parts; head and neck extension which are the superior thinner side of the couch towards the gantry side and the thoracic, abdominal pelvic extension which is the inferior thicker side away from the gantry. The head and neck extension is used for positioning and immobilizing head and neck tumours while the rest of the tumours are done using the thoracic, abdominal pelvic extension. The thicker part with dimensions of $200 \times 53 \times 5 \text{ cm}^3$ is the longest in length and is supported by non-metallic rails while thinner part with dimensions of $41.5 \times 53 \times 2 \text{ cm}^3$ is the shortest. The couch top material consists of a low-density foam material sandwiched in between two carbon fibre shell layers of thickness 1.2 mm (Kong et al. 2022).

The iBEAM evo couch (See Figure 1.6) can support a maximum of 220 kg on the thicker side and 40kg on the thinner side. At the interphase between the extensions, we have strong solid carbon fibres which should be avoided during treatment because it will attenuate more doses to the patient that is not accounted in the TPS. During maintenance, it is recommended to use isopropanol or soapy water for cleaning. Abrasive detergents like aerosol sprays or corrosive agents for cleaning should not be used for cleaning as they will temper with the original physical properties of the carbon fibre material. The dosimetric properties of the head and neck extension have been proven to be 1.5% and 1.3% attenuation respectively for 6MV and 15MV energies (https://www.orfit.com/app/uploads/50220_PDF.pdf). On the other hand the dosimetric properties of the thoracic, abdominal pelvic couch top was proven to be 2.4% and 1.9% respectively from 6MV and 10MV energies ([https://ecatalog.elekta.com/oncology/ibeam\(r\)-evo-couchtop/products/0/20368/22373/20231/ibeam\(R\)-evo-couchtop.aspx](https://ecatalog.elekta.com/oncology/ibeam(r)-evo-couchtop/products/0/20368/22373/20231/ibeam(R)-evo-couchtop.aspx)).

2.3.2 CT Couch

The couch used for CT simulation is an IGRT couch from Siemens Company. It's made of 100% carbon fibre material of thickness ~ 2mm sandwiching a layer of foam. It has a length of 230 cm, width of 50 cm, and thickness varies from 11.3 cm at the couch tip to 12.7cm at the inferior edge of the couch. It has a maximum capacity of patient load of about 227kg. Its attenuation dosimetric properties are 3.1% and 2.0 %, respectively, for 6MV and 15 MV at 180 ° gantry angle and 4.4% and 3.0 %, respectively for 6MV and 15MV photon energies at 225 ° gantry angle (Spezi et al. 2007).

2.4 COUCH INCLUSION IN THE TPS

The couch top has been taken into consideration in the treatment planning procedure using two separate strategies. The first incorporates a CT image scan of the treatment couch into the treatment planning system. Fusion modules from the TPS, external software, or internally built software are then used to insert the scanned treatment couch top into the patient's CT data collection (Olch et al. 2014).

The second method is all about manual or automatic contouring of the couch. This works well if the institution uses the same type of couch for both treatment and simulation. An alternative to this is to create a couch-top drawing in the TPS in a simulated patient image data set and then attach a DICOM radiotherapy structure set containing this drawing. Each couch top used in the cancer centre can be secured to the same structure set and then copied to the real patient image set during planning. This will successfully provide a couch-top system for insertion into the real patient data set from a library of couches (Olch et al. 2014).

For regularly incident beams passing through the middle uniform region of carbon fibre couch tops, attenuation is around 2%; for extremely oblique rays, attenuation is approximately 6%; and for denser sections, attenuation can be as high as 17%. When the attenuation was about 10%, this approach demonstrated a reduction of up to 1.8% (Olch et al. 2014).

CHAPTER THREE

METHODOLOGY

In modelling the treatment couch in the TPS, there are two methods that can be used (Olch et al. 2014). The methods are described in the literature review (chapter 2, section 2.4) of which they are practically possible and approachable giving an attenuation of close to 1%.

For this research a different approach was used to verify the incorporation of the treatment couch factor in the Oncentra treatment planning system. The approach used was in three phases. The materials that were used are listed below.

3.1 MATERIALS.

3.1.1 Machine.

The treatment machine that was used is an Elekta Synergy Version S (See figure 1.1) configured with 6MV and 15MV photon energies and 6MeV, 9MeV, 12MeV and 15MeV electron energies. The energies used were 6MV and 15MV photon energies.

3.1.2 Couch.

The couch that was used in phase three was an iBEAM evo couch (See Figure 1.2) and an IGRT CT couch in phase one alongside the Somatom confidence CT machine.

3.1.3 Phantom.

The phantom used in phase 1 and phase 3 was a cylindrical CTDI phantom (See Figure 3.1). It consists of two parts. A small cylinder of diameter 16 cm in the inner side and larger hollow cylinder of diameter 32 cm on the outward side. The material of the phantom is a poly methyl methacrylate of density 1.19g/cm³ which is tissue equivalent. The phantom has alignment marks laterally and anteriorly with ion chamber grooves. It has a weight of 19.9kg.

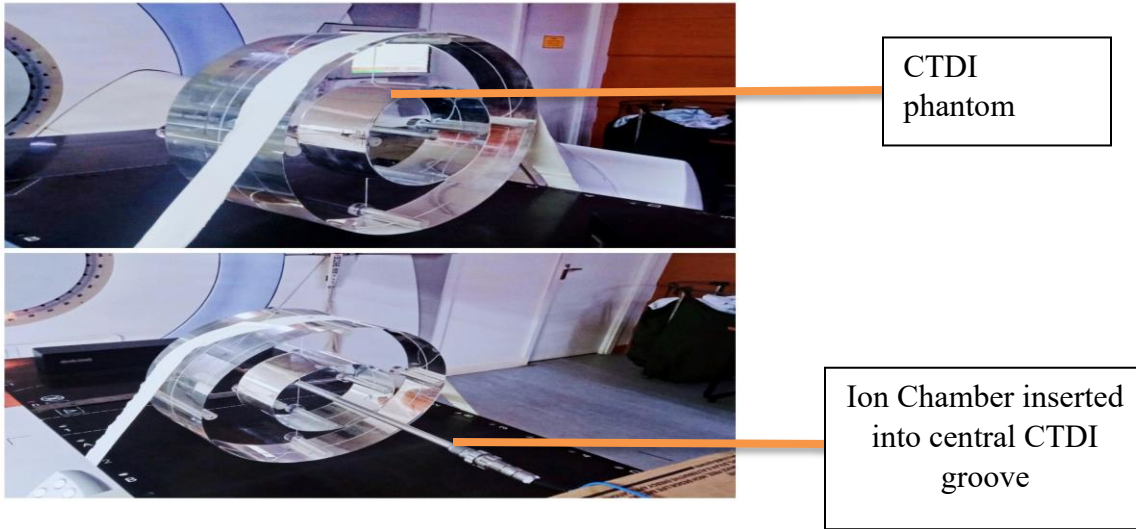


Figure 3.1: A CTDI cylindrical phantom.

3.1.4 Electrometer.

The electrometer used to record the measurements was a PTW Unidos E (See Figure 3.2). It was set at a voltage of 100V. Zeroing of the electrometer was done after every measurement.



Figure 3.2: A PTW Unidos electrometer.

3.1.5 Ion chamber/connecting cable.

A 0.6 cm³ PMMA/AI, type 30010 cylindrical farmer ion chamber was used in taking measurements with an approximately 20 meter BNC cable (See Figure 3.3) enclosed through the wall connecting the ion chamber with the electrometer outside the treatment room.

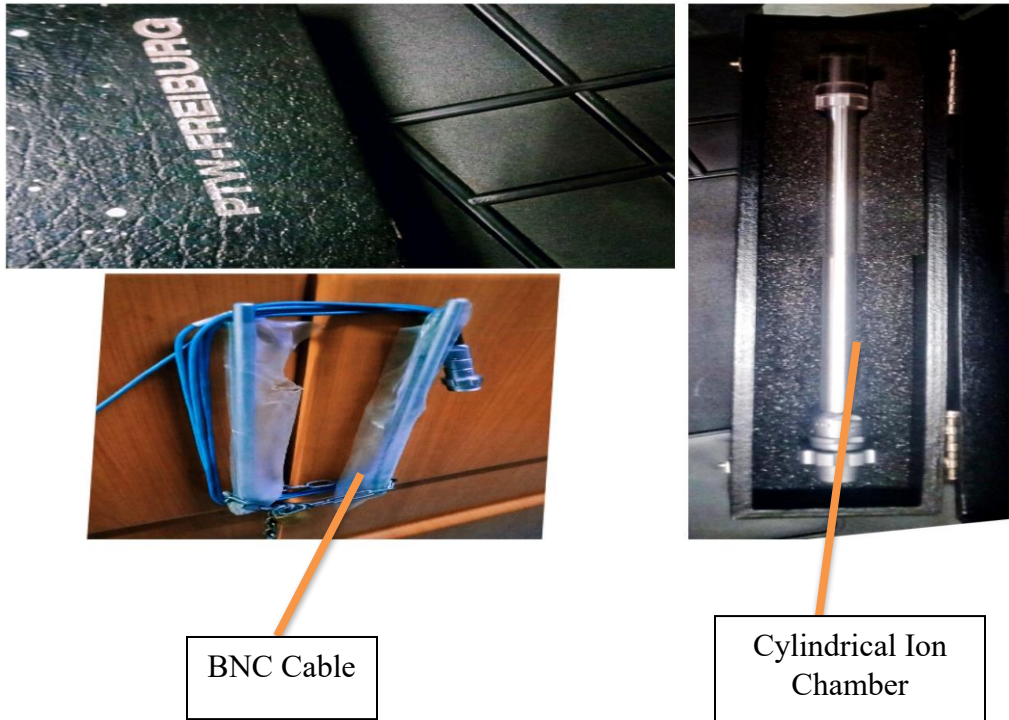


Figure 3.3: An Ion chamber and BNC connecting cable.

3.1.6 Treatment planning system

On the TPS computer, an Oncentra treatment planning software (See Figure 3.4) was used. This software uses convolution collapsed cone and pencil beam dose calculation algorithms. For this research the convolution collapsed cone algorithm was used in dose calculations.

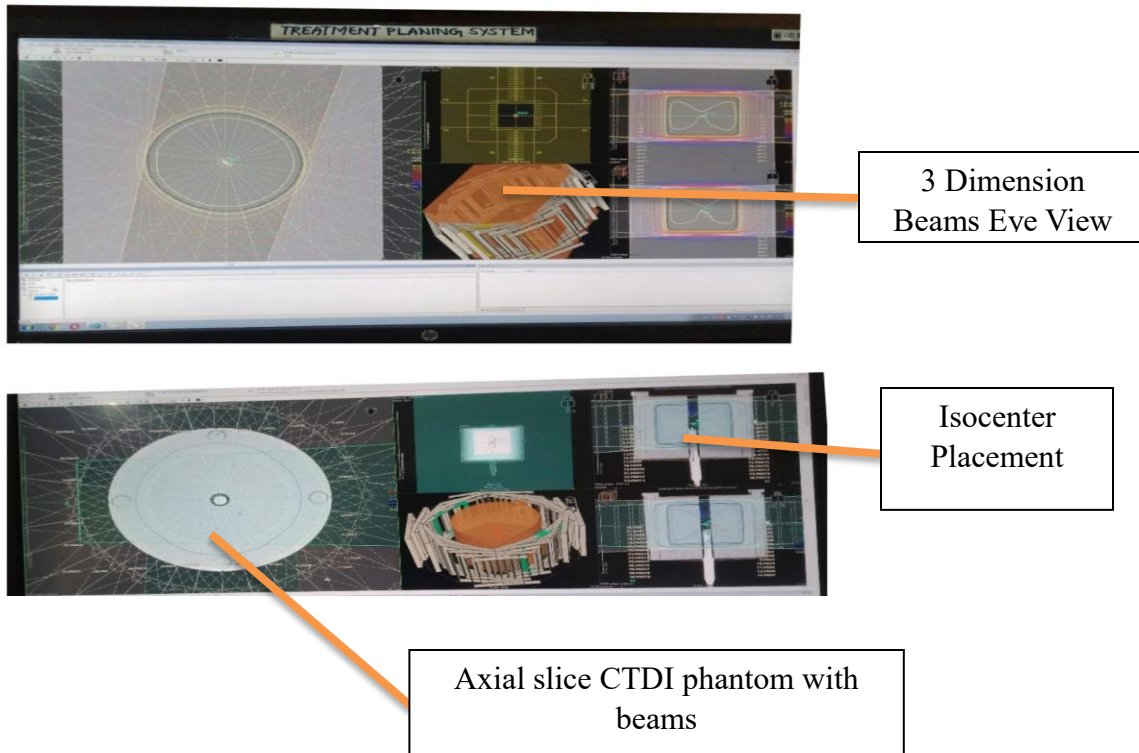


Figure 3.4: Oncentra Treatment Planning System display.

3.2 EXPERIMENTAL SETUP

The experiment to determine the Couch Transmission Factor (CTF) was carried out in three phases as described briefly hereafter.

3.2.1 Phase 1

In this phase, two procedures were involved; CT scanning and treatment Planning. The couch transmission factor modelled in the Treatment Planning System (TPS) was investigated with the CTDI phantom CT scan image attached to the CT scan couch.

3.2.1.1 CT scanning

The uniform CTDI phantom was positioned accurately on the Somatom Confidence CT scan machine IGRT couch using the external lasers. The phantom was strapped to prevent any motion caused by couch movement during scanning. Using the external lasers, alignment marks on the phantom were matched (See Figure 3.5).

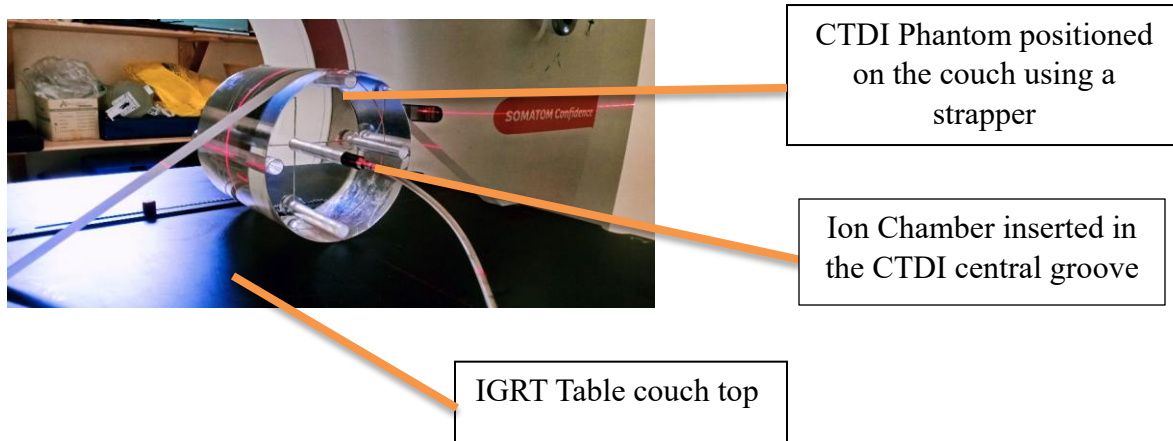


Figure 3.5: CTDI phantom positioning.

The scanning length covered the whole phantom without leaving part of it outside the field (See Figure 3.6). In the central part of the phantom, inside the central hollow groove, a 0.6 cm³ cylindrical ion chamber was inserted. This was useful in the planning process by normalizing the dose at the centre of the active volume of the ion chamber. The position of the middle active volume ion chamber to the inferior edge of the CTDI phantom was taken into consideration and marked as position A. This helped to maintain the position when placing the ion chamber during the next phase.

A CT scan topogram was taken first. The phantom scan topogram was shaped to the required size, and the scanning proceeded on as shown in Figure 3.7. The images were checked for any artefacts then exported to the Oncentra TPS.

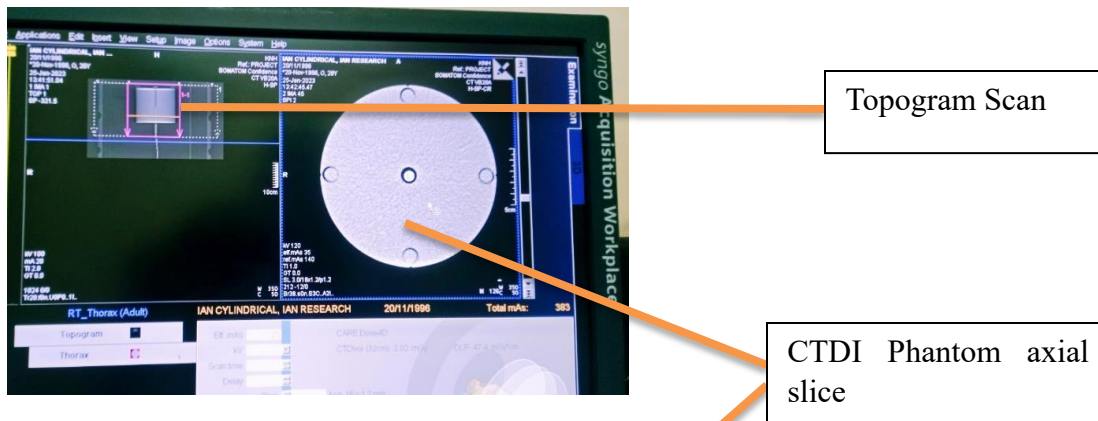


Figure 3.6: Topogram scan.

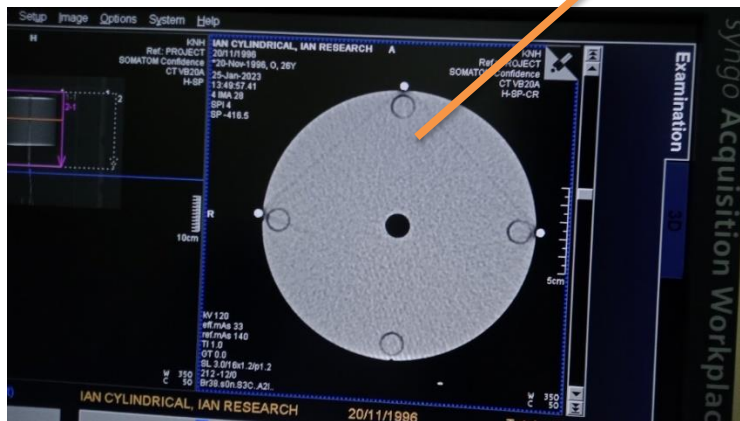


Figure 3.7: CTDI CT scan image before export to Oncentra.

3.2.1.2 Treatment Planning

The images imported on the Oncentra TPS were registered and assigned an ID as follows: Name – Ian Cylindrical, Ian and the Radiation ID – 20/11/1996. On the Contouring section, an external contour of the body of the phantom was made excluding the CT couch as it is done during contouring for real patient CT scan images. An isocentre was placed at the measured position A as in the CT scan procedure which was at a depth of 8 cm from the surface of the phantom. This was determined to be a source-surface-distance (SSD) of 92 cm. (See Figure 3.8).

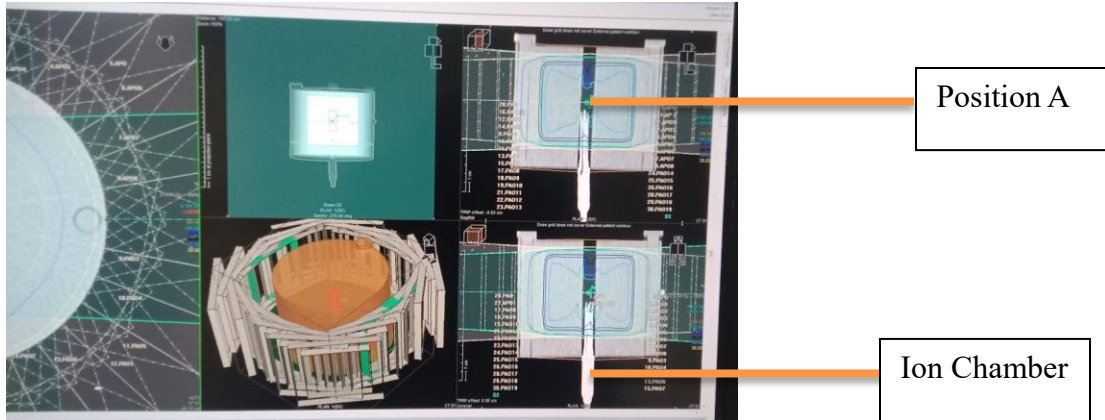


Figure 3.8: Setting the isocentre and beam placement on the CTDI phantom in Oncentra TPS.

Beams were placed at an interval of 11.25° gantry angle starting from 0° to 348.25° gantry angles. The dose was calculated using the collapsed convolution cone dose calculation algorithm (See Figure 3.9).

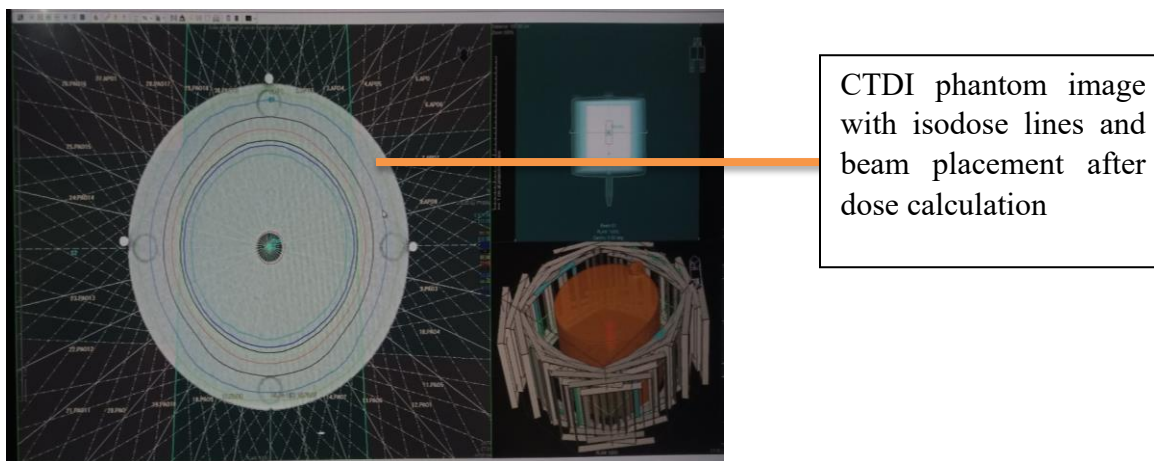



Figure 3.9: Beam geometry orientation on the CTDI phantom.

Data was then collected from the treatment printout preview window as shown in Figure 3.10 for each field in monitor units. The planning parameters used were: Photon energies of 6MV and 15MV, field size of 10cm × 10 cm, and 100 monitor units.

Print Preview

Zoom In 130 % Zoom Out Print



Patient name	PHANTOM, IAN	Sex	Male
Patient ID	RT 20/11/1996		
Birth date	01 Jan 1996		
Case	2D		
Plan	PLAN 2 (15K)	Treatment position	HFS
Saved	04 Mar 2023 18:28:45 by Brian	Dose calculated	Yes
Printed	02 May 2023 08:12:54 by Brian	Optimized	No
Time zone	E. Africa Standard Time (UTC+3:00)	Plan intent	Curative

Treatment Printout

Beam Information

All coordinates in the IEC 61217 system, origin at TPRP (REF SLICE).
The TPRP has coordinates X=0.04 cm Y=10.00 cm Z=1.44 cm relative to the origin of the original DICOM patient coordinate system.

Beam	1. PA1	2. PA2	3. PA3	4. PA4	5. PA5	6. PA6
Beam number	1	2	3	4	5	6
Treatment unit	Sinergy	Sinergy	Sinergy	Sinergy	Sinergy	Sinergy
Radiation type	PHOTON	PHOTON	PHOTON	PHOTON	PHOTON	PHOTON
Energy	15 MV	15 MV	15 MV	15 MV	15 MV	15 MV
Fraction Group Number	1	1	1	1	1	1
Number of Fractions	6	6	6	6	6	6
MU or min / Fraction	111.03	113.00	116.96	122.78	116.12	112.33

	(FX)	(FY)	(FX)	(FY)	(FX)	(FY)	(FX)	(FY)	(FX)	(FY)	(FX)	(FY)
FX (cm)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
FY (cm)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
X1 (cm)	(X1)	-5.00	(X1)	-5.00	(X1)	-5.00	(X1)	-5.00	(X1)	-5.00	(X1)	-5.00
X2 (cm)	(X2)	5.00	(X2)	5.00	(X2)	5.00	(X2)	5.00	(X2)	5.00	(X2)	5.00
Y1 (cm)	(Y1)	-5.00	(Y1)	-5.00	(Y1)	-5.00	(Y1)	-5.00	(Y1)	-5.00	(Y1)	-5.00
Y2 (cm)	(Y2)	5.00	(Y2)	5.00	(Y2)	5.00	(Y2)	5.00	(Y2)	5.00	(Y2)	5.00
MLC	MLCX	MLCX	MLCX	MLCX	MLCX	MLCX	MLCX	MLCX	MLCX	MLCX	MLCX	MLCX

Isocenter X (cm)	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
Isocenter Y (cm)	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Isocenter Z (cm)	-1.38	-1.38	-1.38	-1.38	-1.38	-1.38	-1.38
Table Top Lateral (cm)	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Table Top Longitudinal (cm)	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00	-10.00
Table Top Vertical (cm)	1.38	1.38	1.38	1.38	1.38	1.38	1.38
SSD (cm)	89.72	89.09	87.87	85.98	88.08	89.27	
Depth of isocenter (cm)	10.28	10.91	12.13	14.02	11.92	10.73	
Gantry (degrees)	191.30	202.50	213.80	225.00	236.30	247.50	
Gantry Arc Direction							
Collimator (degrees)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Couch (degrees)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Algorithm	CC	CC	CC	CC	CC	CC	CC
Number of Histograms							
Inhomogeneity correction	On	On	On	On	On	On	On
Bolus							
Bolus ID							

Continued

Figure 3.10: Data display on the Treatment printout preview window for phase 1.

3.2.2 Phase 2

In this particular phase the Oncentra treatment planning system was used to investigate the couch transmission factor of the couch model configured in the Treatment Planning System (TPS) with the virtual phantom image created from the TPS itself.

On the Oncentra TPS, a virtual square phantom of 20 cm × 20 cm × 20 cm was created (see Figure 3.11). A vertical and horizontal measurement of approximately 10 cm depth was noted and an isocentre placed at that point. This same point was used as the dose normalization point of that plan

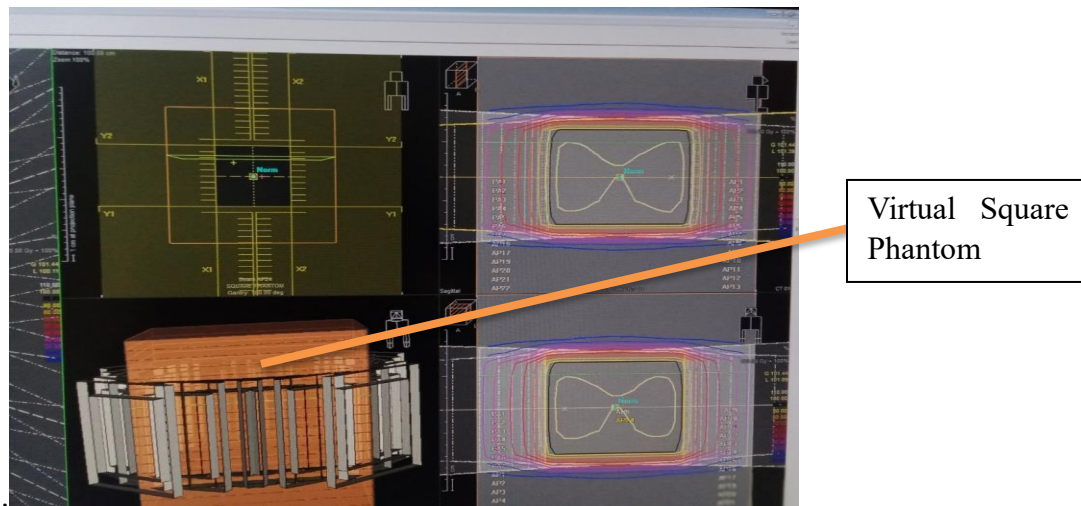


Figure 3.11: Beam placement on the virtual square phantom.

On the planning section, beams were placed on the phantom at different gantry angles ranging from 0° to 348.3° with intervals of 11.25° as in the first phase as shown in Figure 3.12.

3.2.3 Phase 3

Lastly, in this phase radiation dose to the cylindrical ion chamber inside the central groove of CTDI phantom was delivered in order to collect data through an electrometer. This phase was used as a reference phase to determine the actual couch transmission factor of the patient treatment couch (iBEAM evo couch) as shown in Figure 3.14).

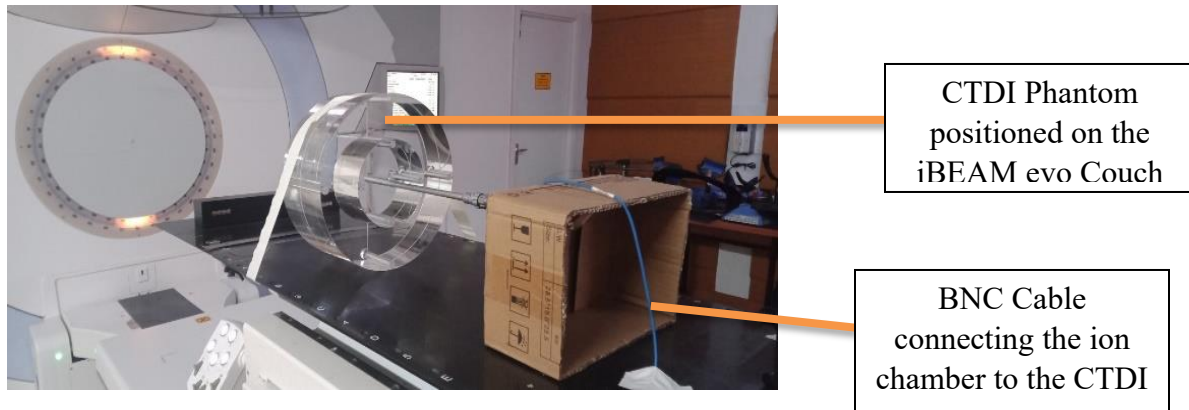


Figure 3.14: CTDI phantom positioning on the Linac treatment couch.

The same gantry angles stated in phase one and two (Chapter 3 Section 3.2.1 and 3.2.2) were used in this phase. This enabled an investigation of the attenuation of each beam due to the presence of the iBEAM evo treatment couch to be carried out. The beam of the most the gantry angles that penetrated through the treatment couch were utilized in the thoracic, abdominal and pelvic region treatments. The treatment couch region that was investigated was the thicker side (See Figure 1.2).

The CTDI phantom was immobilized on the iBEAM evo couch of the Elekta machine using a strapper for stability. The CT scan alignments on the phantom were aligned with the external room lasers. The phantom was then moved under the gantry head so that the field light on the surface of the phantom displayed an SSD of 92cm (See Figure 3.14).

The ion chamber was then placed in the central groove of the CTDI phantom ensuring the crosshair on the machine head cuts the central part of the active volume of the chamber. The ion chamber was connected to the electrometer outside the machine room using BNC cable. On the treatment console an open field size of 10 cm × 10 cm and 100 monitor units was selected. Charges were collected using the PTW Unidos electrometer (See Figure 3.2) at 6MV and 15MV photon energies outside the treatment room. Temperature and pressure corrections were not made because the measurement was relative and not absolute.

CHAPTER FOUR

RESULTS

This Chapter presents the results obtained for each phase as the experiment was conducted as described in Chapter 3 in terms of dose with and without the treatment couch in place. Take note that in each phase, measurements were taken for both 6 MV and 15 MV photon energies and they are recorded below.

4.1 PHASE 1

In order to acquire data the procedure highlighted in Chapter 3 section 3.2.1 was followed and the results presented in Table 4.1 below.

Table 4.1: Data collected from phase 1 for 6 MV.

GAP	GANTRY ANGLES (°)	READING (MU'S)	GANTRY ANGLES (°)	READING (MU'S)	CTF	Dose Attenuated	Dose Attenuated (%)
	WITHOUT COUCH		WITH COUCH				
1	281.3	118.22	101.3	118.63	1.0035	-0.0035	-0.3468
2	292.5	117.26	112.5	118.02	1.0065	-0.0065	-0.6481
3	303.8	117.62	123.8	118.55	1.0079	-0.0079	-0.7907
4	315.0	118.23	135.0	118.12	0.9991	0.0009	0.0930
5	326.3	117.58	146.3	118.31	1.0062	-0.0062	-0.6209
6	337.5	117.39	157.5	118.09	1.0060	-0.0060	-0.5963
7	348.3	117.38	168.8	118.61	1.0105	-0.0105	-1.0479
8	0.0	118.28	180.0	117.64	0.9946	0.0054	0.5411
9	11.3	117.23	191.3	118.41	1.0101	-0.0101	-1.0066
10	22.5	117.76	202.5	117.50	0.9978	0.0022	0.2208
11	33.8	117.73	213.8	118.03	1.0025	-0.0025	-0.2548
12	45.0	118.49	225.0	117.46	0.9913	0.0087	0.8693
13	56.3	117.97	236.3	118.11	1.0012	-0.0012	-0.1187
14	67.5	117.69	247.5	117.44	0.9979	0.0021	0.2124
15	78.8	118.73	258.8	118.35	0.9968	0.0032	0.3201
MEAN		117.84		118.08	1.0021	-0.0021	-0.2116
S.DEV		0.46		0.41	0.0058	0.0058	0.5781

Table 4.1 above shows the findings for phase 1 of the research project for 6MV photon energy beam. The data was collected from the treatment printout preview window of the TPS in monitor units (See Figure 3.13) after planning the scanned CTDI phantom image with a dose of 1 Gray. Beams that penetrated through the couch gave a higher mean dose of 118 monitor units as compared to the ones that penetrated through free air that gave a mean dose of 117.84 monitor units. The standard deviation computed was almost equal for both beams penetrating through free air (without couch) giving a standard deviation of 0.46 and penetrating through the couch having 0.41 (see Table 4.1). The couch transmission factor (CTF) mean computed was 1.0021 with a deviation of 0.0058 as depicted in Table 4.1 for phase 1 with an applied photon energy beam of 6MV. The mean percentage dose attenuation computed using equation 4.2 was 0.21% for phase 1.

Table 4.1 above shows the values of CTF, dose attenuated and percentage dose attenuated. According to Wagner, D., & Vorwerk, H. (2011) the CTF was calculated as follows:

$$CTF = \left(\frac{R_{with}}{R_{without}} \right) \dots\dots\dots (4.1)$$

While according to Smith et al., (2010) the dose attenuated was calculated as follows;

$$Dose\ Attenuated = \left(\frac{R_{without} - R_{with}}{R_{without}} \right) \times 100\% \dots\dots\dots (4.2)$$

Note that the CTF values obtained by equation (4.1) and recorded in Table 4.1 represent the couch transmission factor of the modelled couch in the TPS.

The graph in figure 4.1 of CTF vs gantry angle positions showed an almost constant line curve with a deviation of ±0.0058 in CTF suggesting that the posterior and posterior oblique penetrating beams were not affected by the presence of the couch as they penetrated through the phantom.

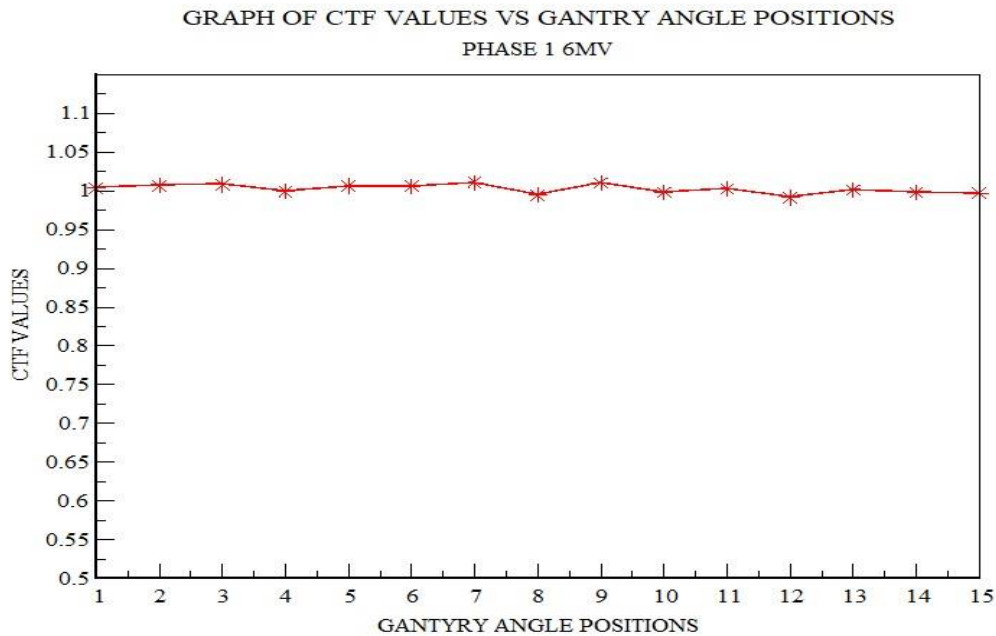


Figure 4.1: The couch transmission factor (CTF) values obtained for 6MV photon energy beam of phase 1.

The dose attenuated had a range of - 1 to 0.8% also being on the lower side compared to 2%, 6% and 17% as reported by (Olch et al. 2014). The negative values (depicted in Table 4.1) were an indication that the posterior and posterior oblique beams gave a higher dose than the corresponding opposing beams and vice versa for the positive values.

Similarly the same procedure was followed for Phase 1 as described in Chapter 3 section 3.2.1 to obtain the results presented in Table 4.2 below but a photon energy beam of 15MV was utilized.

Table 4.2: Data collected from phase 1 for a photon energy beam of 15 MV.

GAP	GANTRY ANGLES (°)	READING (MU'S)	GANTRY ANGLES (°)	READING (MU'S)	CTF	Dose Attenuated	Dose Attenuated (%)
	WITHOUT COUCH		WITH COUCH				
1	281.3	106.10	101.3	106.29	1.0018	-0.0018	-0.1791
2	292.5	105.54	112.5	106.03	1.0046	-0.0046	-0.4643
3	303.8	105.63	123.8	106.31	1.0064	-0.0064	-0.6438
4	315.0	105.96	135.0	106.07	1.0010	-0.0010	-0.1038
5	326.3	105.67	146.3	106.21	1.0051	-0.0051	-0.5110
6	337.5	105.36	157.5	105.94	1.0055	-0.0055	-0.5505
7	348.3	105.35	168.8	106.40	1.0100	-0.0100	-0.9967
8	0.0	105.77	180.0	105.67	0.9991	0.0009	0.0945
9	11.3	105.14	191.3	106.11	1.0092	-0.0092	-0.9226
10	22.5	105.59	202.5	105.73	1.0013	-0.0013	-0.1326
11	33.8	105.56	213.8	105.92	1.0034	-0.0034	-0.3410
12	45.0	106.03	225.0	105.56	0.9956	0.0044	0.4433
13	56.3	105.86	236.3	106.06	1.0019	-0.0019	-0.1889
14	67.5	105.56	247.5	105.56	1.0000	0.0000	0.0000
15	78.8	106.36	258.8	106.24	0.9989	0.0011	0.1128
MEAN		105.70		106.01	1.0029	-0.0029	-0.2922
S.DEV		0.32		0.27	0.0040	0.0040	0.3953

Table 4.2 above shows the findings for phase 1 of the research project for 15MV energy beam. The data was collected from the treatment printout preview window of the TPS in monitor units (see Figure 3.13) after placing beams on the scanned CTDI phantom image with a dose of 1 Gray. Beams that penetrated through the couch gave a higher mean dose of 106 monitor units as compared to the ones that penetrated through free air that gave a mean dose of 105.70 monitor units. The standard deviation was almost equal for both beams penetrating through free air (without couch) giving a standard deviation of 0.32 and penetrating through the couch having 0.27 (see Table 4.2). The couch transmission factor (CTF) mean computed was 1.0029 with a deviation of 0.004 as depicted in Table 4.2 above for phase 1 with an applied photon energy

beam of 15MV. The mean percentage dose attenuation computed using equation 4.2 was 0.29 % for phase 1.

Table 4.2 above shows the values of CTF, dose attenuated and percentage dose attenuated calculated using equation 4.1 and 4.2 as depicted in chapter 4 section 4.1. Note that the CTF values obtained by equation (4.1) and recorded in Table 4.2 represent the couch transmission factor of the modelled couch in the Treatment Planning System.

The graph in figure 4.2 of CTF vs. gantry angle positions showed an almost constant line curve with a deviation of ± 0.004 in CTF suggesting that the posterior and posterior oblique penetrating beams were not affected by the presence of the couch as they penetrated through the phantom.

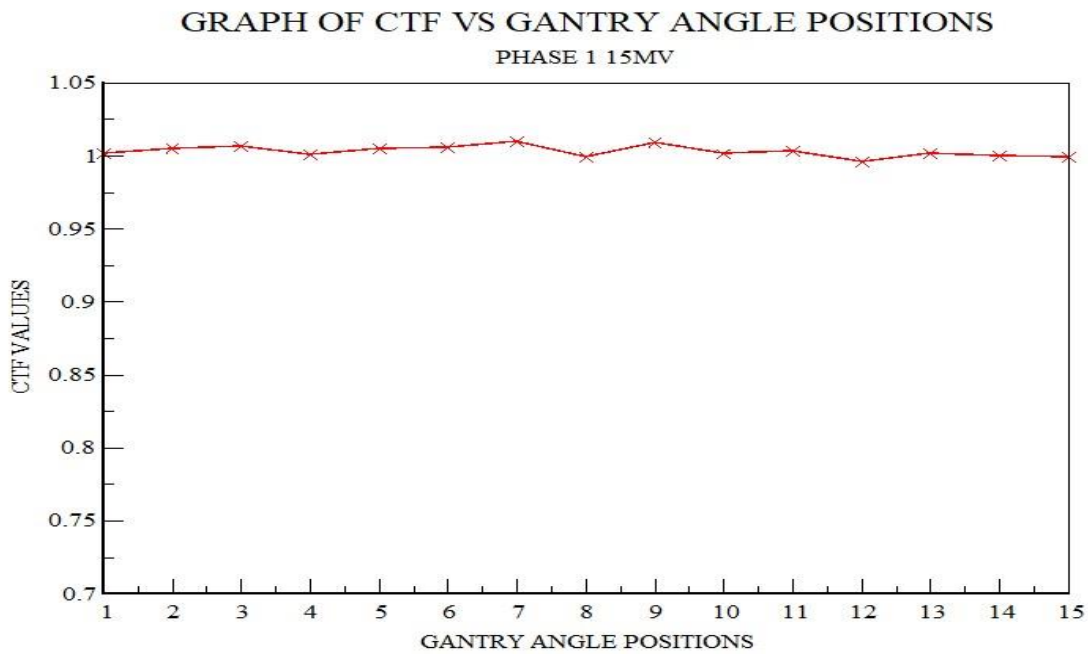


Figure 4.2: The Couch Transmission Factor values obtained for 15MV in phase 1.

The dose attenuated had a range of - 0.9967 to 0.4% also being on the lower side compared to 2%, 6% and 17% as reported by (Olch et al. 2014). The negative values (depicted in Table 4.2) were an indication that the posterior and posterior oblique beams gave a higher dose than the corresponding opposing beams and vice versa for the positive values.

4.2 PHASE 2

As briefly discussed in Chapter 3 Section 3.2.2 the Oncentra treatment planning system was used to investigate the couch transmission factor of the couch model configured in the Treatment Planning System (TPS) with the virtual phantom image created from the TPS itself as opposed to phase 1 highlighted in Chapter 3 Section 3.2.1. The results obtained are recorded and presented in Table 4.3 and 4.4 and Fig 4.3 and 4.4 below.

Table 4.3: Data collected from phase 2 for a photon energy beam of 6MV.

GAP	GANTRY ANGLES (°)	READING (MU'S)	GANTRY ANGLES (°)	READING (MU'S)	CTF	Dose Attenuated	Dose Attenuated (%)
	WITHOUT COUCH		WITH COUCH				
1	281.3	124.09	101.3	124.95	1.0069	-0.0069	-0.6930
2	292.5	127.14	112.5	128.15	1.0079	-0.0079	-0.7944
3	303.8	133.40	123.8	134.41	1.0076	-0.0076	-0.7571
4	315.0	143.01	135.0	144.42	1.0099	-0.0099	-0.9859
5	326.3	133.12	146.3	134.10	1.0074	-0.0074	-0.7362
6	337.5	127.03	157.5	127.86	1.0065	-0.0065	-0.6534
7	348.3	124.18	168.8	124.75	1.0046	-0.0046	-0.4590
8	0.0	123.13	180.0	123.94	1.0066	-0.0066	-0.6578
9	11.3	124.08	191.3	124.96	1.0071	-0.0071	-0.7092
10	22.5	127.19	202.5	128.10	1.0072	-0.0072	-0.7155
11	33.8	133.41	213.8	134.42	1.0076	-0.0076	-0.7571
12	45.0	143.79	225.0	143.76	0.9998	0.0002	0.0209
13	56.3	134.11	236.3	133.08	0.9923	0.0077	0.7680
14	67.5	127.89	247.5	127.00	0.9930	0.0070	0.6959
15	78.8	124.74	258.8	124.04	0.9944	0.0056	0.5612
MEAN		130.02		130.53	1.0039	-0.0039	-0.3915
S.DEV		6.64		6.71	0.0059	0.0059	0.5945

Table 4.3 above shows the findings for phase 2 of the research project for 6MV energy beam. The data was collected from the treatment printout preview window of the TPS in monitor units (see Figure 3.13) after placing beams on the created square virtual phantom image with a dose of 1 Gray. Beams that penetrated through the couch gave a mean dose of 130.53 monitor units as compared to the beams that penetrated through free air (without the couch) that gave a mean dose of 130.02 monitor units. The standard deviation was almost equal for both the beams with beams penetrating through free air giving a standard deviation of 6.64 and beams penetrating through the couch having 6.71 (see Table 4.3). The couch transmission factor (CTF) mean computed was 1.0039 with a deviation 0.0059 as depicted in Table 4.3 above for phase 2 with an applied photon energy beam of 6MV. The mean percentage dose attenuation computed was 0.39 % for phase 2.

Table 4.3 above shows the values of the CTF, dose attenuated and percentage dose attenuated calculated using equation 4.1 and 4.2 in chapter 4 section 4.1. Note that the CTF values obtained by equation (4.1) and recorded in Table 4.2 represent the couch transmission factor of the modelled couch in the TPS.

The graph depicted in figure 4.3 shows an almost constant line curve with a deviation of ± 0.0059 in the CTF suggesting that the posterior and posterior oblique penetrating beams were not affected by the presence of the couch as they penetrated through the created square virtual phantom.

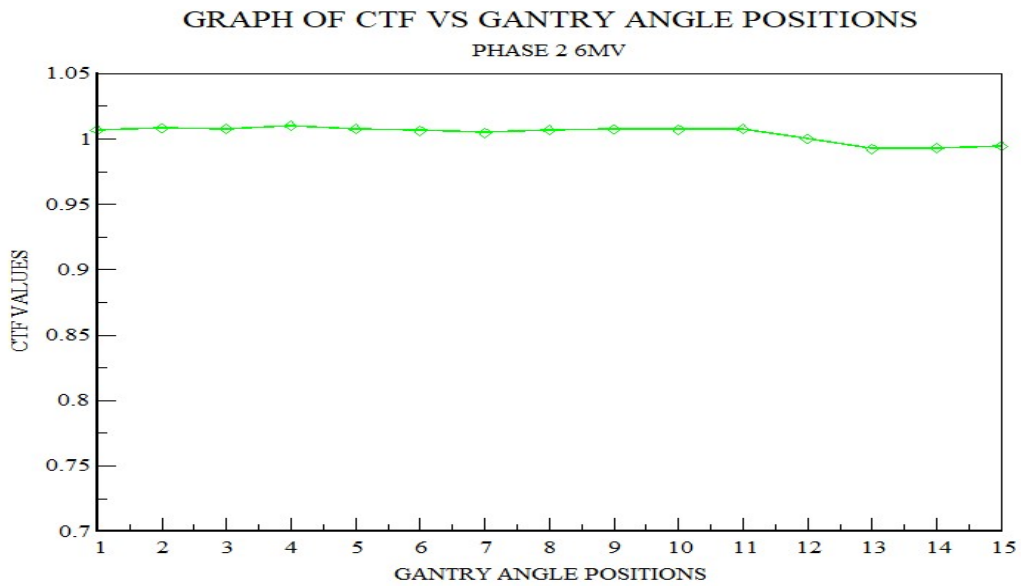


Figure 4.3: The CTF values obtained for 6MV beam photon energy in phase 2.

The dose attenuated had a range of - 0.99 to 0.77 % also being on the lower side compared to 2%, 6% and 17% as reported by (Olch et al. 2014). The negative values (depicted in Table 4.3) were an indication that the posterior and posterior oblique beams gave a higher dose than the corresponding opposing beams and vice versa for the positive values.

Similarly the same procedure was followed for Phase 2 as described in Chapter 3 section 3.2.2 to obtain the results presented in Table 4.4 below for an energy beam of 15MV which was utilized.

Table 4.4: Data collected for phase 2 for a photon energy beam of 15MV.

GAP	GANTRY ANGLES (°)	READING (MU'S)	GANTRY ANGLES (°)	READING (MU'S)	CTF	Dose Attenuated	Dose Attenuated (%)
	WITHOUT COUCH		WITH COUCH				
1	281.3	110.48	101.3	111.02	1.0049	-0.0049	-0.4888
2	292.5	112.37	112.5	113.03	1.0059	-0.0059	-0.5873
3	303.8	116.33	123.8	116.94	1.0052	-0.0052	-0.5244
4	315.0	122.26	135.0	123.16	1.0074	-0.0074	-0.7361
5	326.3	116.15	146.3	116.72	1.0049	-0.0049	-0.4907
6	337.5	112.35	157.5	112.89	1.0048	-0.0048	-0.4806
7	348.3	110.56	168.8	110.87	1.0028	-0.0028	-0.2804
8	0.0	109.87	180.0	110.37	1.0046	-0.0046	-0.4551
9	11.3	110.47	191.3	111.03	1.0051	-0.0051	-0.5069
10	22.5	112.41	202.5	113.00	1.0052	-0.0052	-0.5249
11	33.8	116.33	213.8	116.96	1.0054	-0.0054	-0.5416
12	45.0	122.80	225.0	122.78	0.9998	0.0002	0.0163
13	56.3	116.73	236.3	116.12	0.9948	0.0052	0.5226
14	67.5	112.91	247.5	112.33	0.9949	0.0051	0.5137
15	78.8	110.86	258.8	110.44	0.9962	0.0038	0.3789
MEAN		114.19		114.51	1.0028	-0.0028	-0.2790
S.DEV		4.15		4.19	0.0042	0.0042	0.4223

Table 4.4 above shows the findings for phase 2 of the research project for 15MV beam photon energy. The data was collected from the treatment printout preview window of the TPS in monitor units (see Figure 3.13) after placing beams on the created square virtual phantom image in the TPS with a dose of 1 Gray. Beams that penetrated through the couch gave a higher mean dose of 114.51 monitor units as compared to the ones that penetrated through free air (without the couch) that gave a mean dose of 114.19 monitor units. The standard deviation was almost equal for beams penetrating through free air giving a standard deviation of 4.15 and beams penetrating through the couch having 4.19 (see Table 4.4). The couch transmission factor (CTF) mean computed was 1.0028 with a deviation of 0.0042 as depicted in Table 4.4 above for phase 2

with an applied photon energy beam of 15MV. The mean percentage dose attenuation computed was 0.279 % for phase 2.

Table 4.4 above shows the values of the CTF, dose attenuated and percentage dose attenuated calculated using equation 4.1 and 4.2 in chapter 4 section 4.1. Note that the CTF values obtained by equation (4.1) and recorded in Table 4.4 represent the couch transmission factor of the modelled couch in the TPS.

The graph depicted in figure 4.4 of CTF vs. gantry angle positions shows an almost constant line curve with a deviation of ± 0.0042 in CTF suggesting that the posterior and posterior oblique penetrating beams were not affected by the presence of the couch as they penetrated through the phantom.

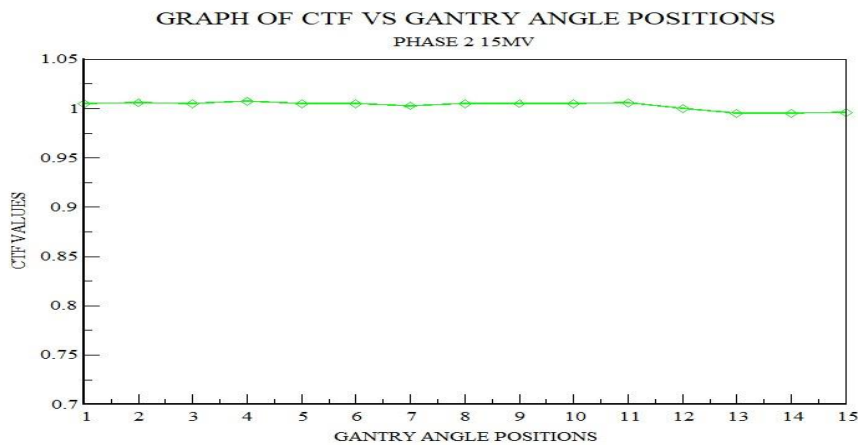


Figure 4.4: The CTF values obtained for a photon beam of energy 15MV in phase 2.

The dose attenuated had a range of - 0.74 to 0.52 % also being on the lower side compared to 2%, 6% and 17% as reported by (Olch et al. 2014). The negative values (depicted in Table 4.4) were an indication that the posterior and posterior oblique beams gave a higher dose than the corresponding opposing beams and vice versa for the positive values.

4.3 PHASE 3

As briefly discussed in Chapter 3 Section 3.2.3 the physical CTDI phantom was used to investigate the couch transmission factor of the iBEAM evo couch (see Figure 1.2) used with the Elekta Synergy Version S LINAC. Phase 3 was used as a reference phase to determine the actual couch transmission factor. The results obtained were recorded and presented in Table 4.5 and 4.6 and Fig 4.5 and 4.6 below.

Table 4.5: Data collected from phase 3 for 6MV photon energy beam.

GAP	GANTRY ANGLES (°)	READING (nC'S)	GANTRY ANGLES (°)	READING (nC'S)	CTF	Dose Attenuated	Dose Attenuated (%)
	WITHOUT COUCH		WITH COUCH				
1	281.3	17.10	101.3	17.00	0.9942	0.0058	0.5848
2	292.5	17.10	112.5	17.10	1.0000	0.0000	0.0000
3	303.8	17.10	123.8	16.30	0.9532	0.0468	4.6784
4	315.0	17.10	135.0	15.90	0.9298	0.0702	7.0175
5	326.3	17.00	146.3	16.50	0.9706	0.0294	2.9412
6	337.5	17.00	157.5	16.60	0.9765	0.0235	2.3529
7	348.3	17.07	168.8	16.67	0.9766	0.0234	2.3437
8	0.0	17.10	180.0	16.70	0.9766	0.0234	2.3392
9	11.3	17.07	191.3	16.60	0.9727	0.0273	2.7344
10	22.5	17.10	202.5	16.50	0.9649	0.0351	3.5088
11	33.8	17.10	213.8	15.60	0.9123	0.0877	8.7719
12	45.0	17.10	225.0	16.30	0.9532	0.0468	4.6784
13	56.3	17.10	236.3	17.10	1.0000	0.0000	0.0000
14	67.5	17.10	247.5	17.10	1.0000	0.0000	0.0000
15	78.8	17.10	258.8	17.10	1.0000	0.0000	0.0000
MEAN		17.08		16.60	0.9720	0.0280	2.7967
S.DEV		0.04		0.45	0.0264	0.0264	2.6447

Table 4.5 above shows the findings for phase 3 of the research project for 6MV photon energy beam. The data was collected from the PTW Unidos electrometer (see Figure 3.2) after irradiating the ion chamber inside the physical CTDI phantom groove with a dose of 1 Gray. Beams that penetrated through the couch gave a lower mean dose of 16.6 nano coulombs (nC) as

compared to the beams that penetrated through free air (without the couch) that gave a mean dose of 17.08 nano coulombs (nC). The standard deviation for beams penetrating through free air was calculated to be 0.04 and 0.45 for beams penetrating through the couch (see Table 4.5). The mean computed of the couch transmission factor (CTF) was 0.9720 with a deviation 0.0264 as depicted in Table 4.5 above for phase 3 with an applied photon energy beam of 6MV. The mean percentage dose attenuation computed was 2.7967 % for phase 3.

Table 4.5 above shows the values of the CTF, dose attenuated and percentage dose attenuated calculated using equation 4.1 and 4.2 in chapter 4 section 4.1. Note that the CTF values obtained by equation (4.1) and recorded in Table 4.5 represent the couch transmission factor of the actual iBEAM evo couch (see figure 1.2) used for treatment.

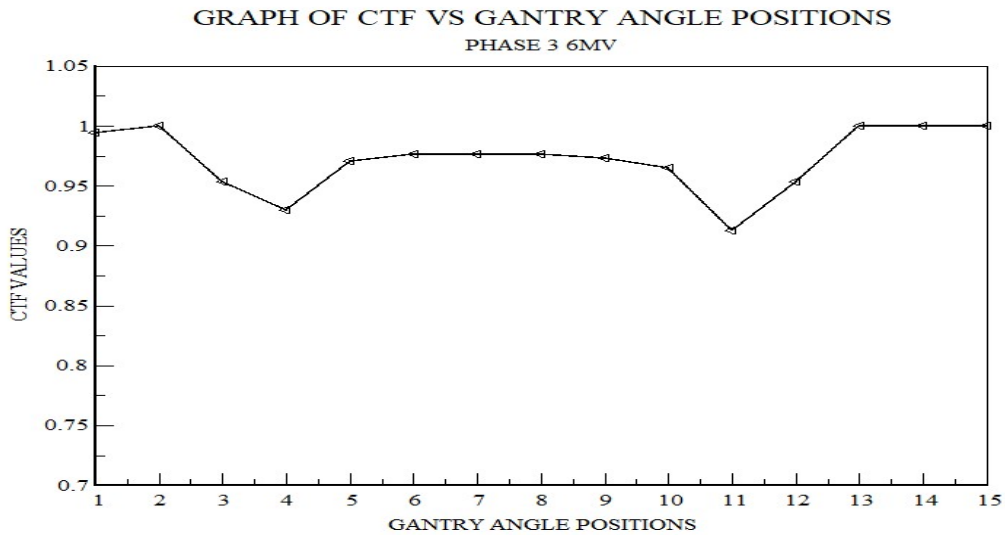


Figure 4.5: The CTF values obtained for a 6MV photon energy beam in phase 3.

The depicted graph above in figure 4.5 shows a deviation of ± 0.0264 in the CTF suggesting that the posterior and posterior oblique penetrating beams were affected by the presence of the couch as they penetrated through the phantom. The dose attenuated had a range of 0.6 to 8.8 %

compared to 2.4% as reported by ([https://ecatalog.elekta.com/oncology/ibeam\(r\)-evo-couchtop/products/0/20368/22373/20231/ibeam\(R\)-evo-couchtop.aspx](https://ecatalog.elekta.com/oncology/ibeam(r)-evo-couchtop/products/0/20368/22373/20231/ibeam(R)-evo-couchtop.aspx)) for the iBEAM evo treatment couch. Similarly, the same procedure was followed for Phase 3 as described in Chapter 3 section 3.2.3 to obtain the results presented in Table 4.6 below for a photon energy beam of 15MV which was utilized.

Table 4.6: Data collected from phase 3 for 15MV photon energy beam.

GAP	GANTRY ANGLES (°)	READING (nC'S)	GANTRY ANGLES (°)	READING (nC'S)	CTF	Dose Attenuated	Dose Attenuated (%)
	WITHOUT COUCH		WITH COUCH				
1	281.3	20.60	101.3	20.60	1.0000	0.0000	0.0000
2	292.5	20.60	112.5	20.63	1.0016	-0.0016	-0.1618
3	303.8	20.60	123.8	20.00	0.9709	0.0291	2.9126
4	315.0	20.60	135.0	19.60	0.9515	0.0485	4.8544
5	326.3	20.60	146.3	20.20	0.9806	0.0194	1.9417
6	337.5	20.60	157.5	20.20	0.9806	0.0194	1.9417
7	348.3	20.60	168.8	20.30	0.9854	0.0146	1.4563
8	0.0	20.60	180.0	20.30	0.9854	0.0146	1.4563
9	11.3	20.50	191.3	20.20	0.9854	0.0146	1.4634
10	22.5	20.60	202.5	20.10	0.9757	0.0243	2.4272
11	33.8	20.60	213.8	19.30	0.9369	0.0631	6.3107
12	45.0	20.60	225.0	19.90	0.9660	0.0340	3.3981
13	56.3	20.60	236.3	20.60	1.0000	0.0000	0.0000
14	67.5	20.60	247.5	20.60	1.0000	0.0000	0.0000
15	78.8	20.60	258.8	20.60	1.0000	0.0000	0.0000
MEAN		20.59		20.21	0.9813	0.0187	1.8667
S.DEV		0.03		0.39	0.0191	0.0191	1.9085

Table 4.6 above shows the findings for phase 3 of the research project for a 15MV photon energy beam. The data was collected from the PTW Unidos electrometer (see Figure 3.2) after irradiating the ion chamber inside the physical CTDI phantom groove with a dose of 1 Gray. Beams that penetrated through the couch gave a lower mean dose of 20.21 nano coulombs (nC) as compared to

the beams that penetrated through free air (without the couch) that gave a mean dose of 20.59 nano coulombs (nC).

The standard deviation for beams penetrating through free air was 0.03 and penetrating through the couch having 0.39 (see Table 4.6). The couch transmission factor (CTF) mean computed was 0.9813 with a deviation 0.0191 as depicted in Table 4.6 above for phase 3 with an applied photon energy beam of 15MV. The mean percentage dose attenuation computed was 1.8667% for phase 3.

Table 4.6 above shows the values of CTF, dose attenuated and percentage dose attenuated calculated using equation 4.1 and 4.2 in chapter 4 section 4.1. Note that the CTF values obtained by equation (4.1) and recorded in Table 4.6 represent the couch transmission factor of the actual iBEAM evo couch (see Figure 1.2) used for treatment.

The graph depicted in figure 4.6 below of CTF values shows a standard deviation of ± 0.0191 in CTF suggesting that the posterior and posterior oblique penetrating beams were affected by the presence of a couch as they penetrated through the phantom. The dose attenuated had a range of - 0.2 to 6% compared to 1.9% as reported by ([https://ecatalog.elekta.com/oncology/ibeam\(r\)-evocouchtop/products/0/20368/22373/20231/ibeam\(R\)-evo-couchtop.aspx](https://ecatalog.elekta.com/oncology/ibeam(r)-evocouchtop/products/0/20368/22373/20231/ibeam(R)-evo-couchtop.aspx)) for the iBEAM evo couch.

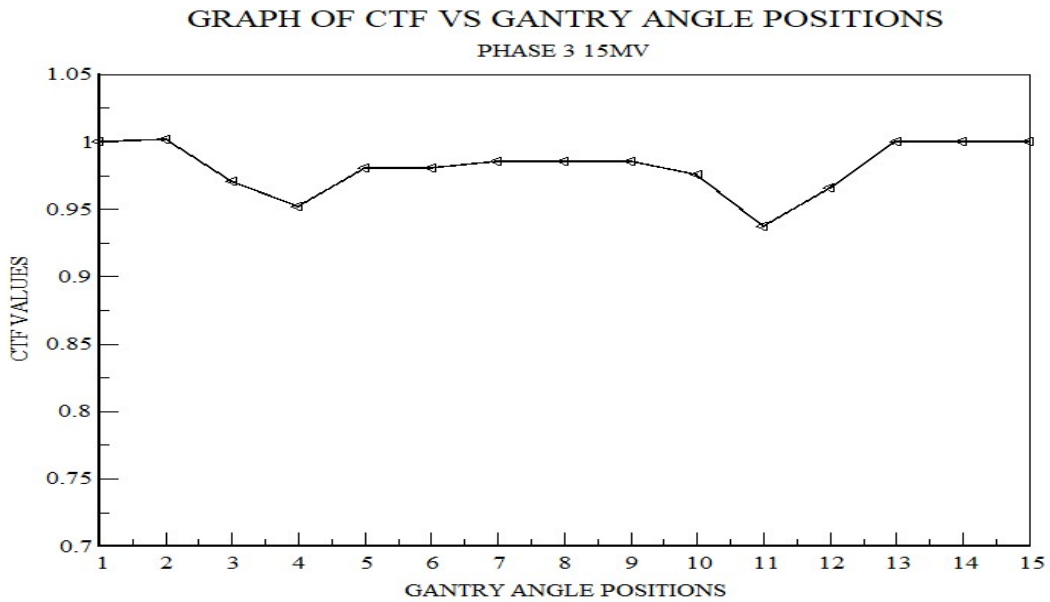


Figure 4.6: The CTF values obtained for a photon beam of energy 15MV in phase 3.

Table 4.7: Deviations of the CTF values for phases 1 and 2 from 3 for 6MV.

GAP	PHASE 1	PHASE 2	PHASE 3	DEV PHASE 1	PERCENT DEV	DEV PHASE 2	PERCENT DEV
1	1.00	1.01	0.99	-0.01	-0.93	-0.01	-1.28
2	1.01	1.01	1.00	-0.01	-0.65	-0.01	-0.79
3	1.01	1.01	0.95	-0.05	-5.47	-0.05	-5.44
4	1.00	1.01	0.93	-0.07	-6.92	-0.08	-8.00
5	1.01	1.01	0.97	-0.04	-3.56	-0.04	-3.68
6	1.01	1.01	0.98	-0.03	-2.95	-0.03	-3.01
7	1.01	1.00	0.98	-0.03	-3.39	-0.03	-2.80
8	0.99	1.01	0.98	-0.02	-1.80	-0.03	-3.00
9	1.01	1.01	0.97	-0.04	-3.74	-0.03	-3.44
10	1.00	1.01	0.96	-0.03	-3.29	-0.04	-4.22
11	1.00	1.01	0.91	-0.09	-9.03	-0.10	-9.53
12	0.99	1.00	0.95	-0.04	-3.81	-0.05	-4.66
13	1.00	0.99	1.00	0.00	-0.12	0.01	0.77
14	1.00	0.99	1.00	0.00	0.21	0.01	0.70
15	1.00	0.99	1.00	0.00	0.32	0.01	0.56
MEAN	1.00	1.00	0.97	-0.03	-3.01	-0.03	-3.19
S.DEV	0.01	0.01	0.03	0.03	2.68	0.03	3.00

From table 4.7 above CTF values for Phases 1 and 2 had a mean of 1 while the mean for phase 3 was 0.97. The standard deviation obtained for phases 1 and 2 was 0.01 while that in phase 3 was 0.03. The percentage deviation was computed and found to be 3.01 % between phases 1 and 3, and 3.19% between phases 2 and 3 as shown in table 4.7 above.

From figure 4.7 below, the CTF values for phases 1 and 2 were almost constant as compared to phase 3 which was characterized by troughs and peaks at some points due to attenuation by the couch material.

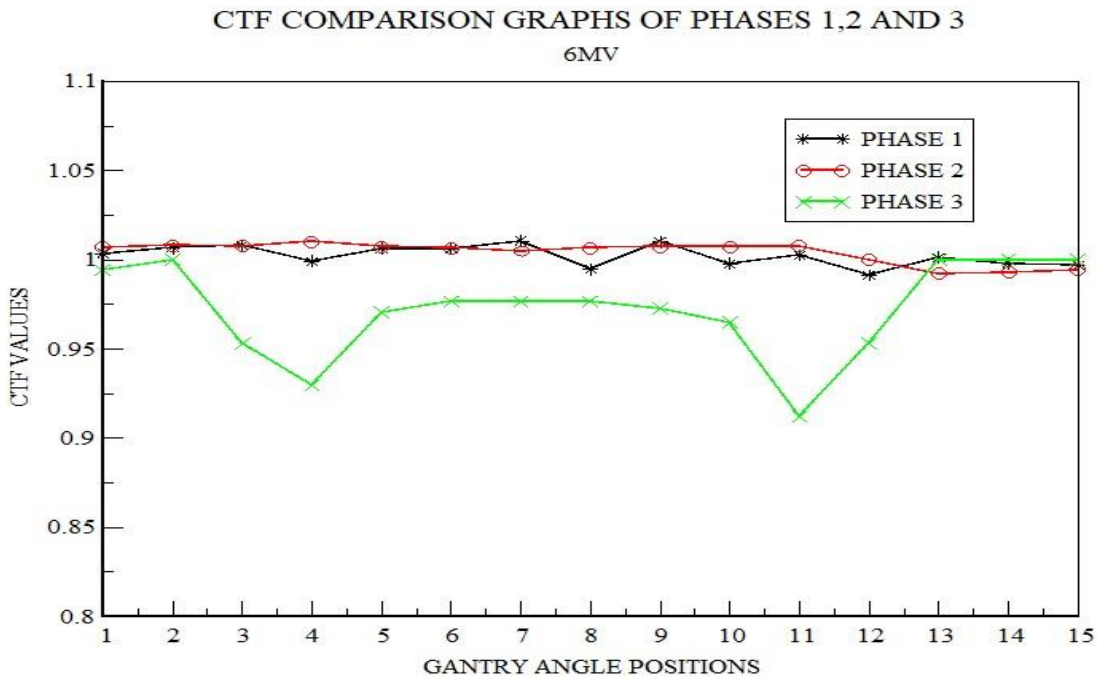


Figure 4.7: The CTF values obtained for phases 1, 2 and 3 combined for photon energy of 6MV.

Table 4.8: Deviations of the CTF values for phases 1 and 2 from 3 for photon energy of beam 15MV.

GAP	PHASE 1	PHASE 2	PHASE 3	DEV PHASE 1	PERCENT DEV	DEV PHASE 2	PERCENT DEV
1	1.00	1.00	1.00	0.00	-0.18	0.00	-0.49
2	1.00	1.01	1.00	0.00	-0.30	0.00	-0.43
3	1.01	1.01	0.97	-0.04	-3.56	-0.03	-3.44
4	1.00	1.01	0.95	-0.05	-4.96	-0.06	-5.59
5	1.01	1.00	0.98	-0.02	-2.45	-0.02	-2.43
6	1.01	1.00	0.98	-0.02	-2.49	-0.02	-2.42
7	1.01	1.00	0.99	-0.02	-2.45	-0.02	-1.74
8	1.00	1.00	0.99	-0.01	-1.36	-0.02	-1.91
9	1.01	1.01	0.99	-0.02	-2.39	-0.02	-1.97
10	1.00	1.01	0.98	-0.03	-2.56	-0.03	-2.95
11	1.00	1.01	0.94	-0.07	-6.65	-0.07	-6.85
12	1.00	1.00	0.97	-0.03	-2.95	-0.03	-3.38
13	1.00	0.99	1.00	0.00	-0.19	0.01	0.52
14	1.00	0.99	1.00	0.00	0.00	0.01	0.51
15	1.00	1.00	1.00	0.00	0.11	0.00	0.38
MEAN	1.00	1.00	0.98	-0.02	-2.16	-0.02	-2.15
S.DEV	0.0004	0.0004	0.02	0.02	1.94	0.02	2.15

From table 4.8 above CTF values for Phases 1 and 2 had a mean of 1 while the mean for phase 3 was 0.98. The standard deviation obtained for phases 1 and 2 was 0.0004 while that in phase 3 was 0.02. The percentage deviation was computed and found to be 2.16 % between phases 1 and 3, and 2.15% between phases 2 and 3 as shown in table 4.8 above.

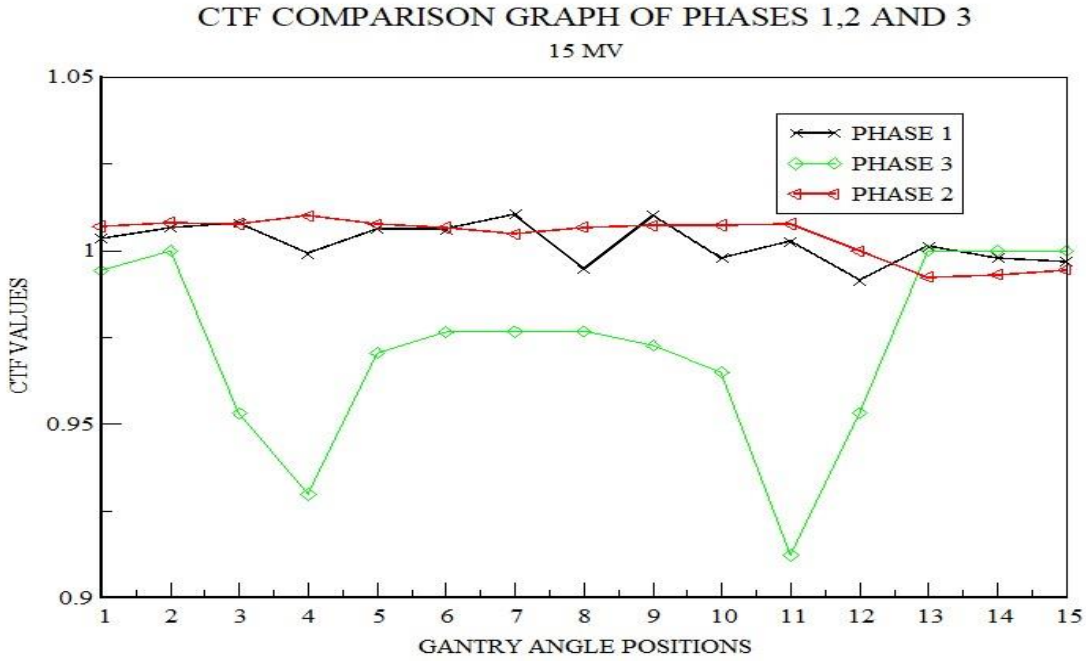


Figure 4.8: The CTF values for phases 1, 2 and 3 combined for photon energy beam of 15MV.

From figure 4.8 above, the CTF values for phases 1 and 2 were almost constant as compared to phase 3 which was characterized by troughs and peaks at some points due to the attenuation by the couch material.

Table 4.9 below shows the calculated values using equation 4.3 and 4.4 of Actual reading with the couch in place and the deviations obtained for phase 1 for a photon energy beam of 6MV.

The Actual Reading with Couch from

$$\text{Calculations} = \text{Actual CTF in Phase 3} \times \text{Phase 1 Reading without Couch} \dots\dots\dots 4.3$$

While
$$\text{Deviations} = \text{Phase 1 (reading with couch)} - \text{Actual Reading (with Couch From Calculation)} \dots\dots\dots 4.4$$

Table 4.9: Calculated treatment couch readings of dose received by phantom and deviations

from the TPS couch reading for phase 1 for a photon energy beam of 6MV.

GAP	PHASE 3 CTF	PHASE 1 READING (MU'S)	ACTUAL READING (MU'S)	PHASE 1 READING (MU'S)	DEVIATIONS
		WITHOUT COUCH	WITH COUCH FROM CALCULATION	WITH COUCH	(MU'S)
1	0.9942	118.22	117.5287	118.6300	1.1013
2	1.0000	117.26	117.2600	118.0200	0.7600
3	0.9532	117.62	112.1173	118.5500	6.4327
4	0.9298	118.23	109.9332	118.1200	8.1868
5	0.9706	117.58	114.1218	118.3100	4.1882
6	0.9765	117.39	114.6279	118.0900	3.4621
7	0.9766	117.38	114.6289	118.6100	3.9811
8	0.9766	118.28	115.5132	117.6400	2.1268
9	0.9727	117.23	114.0245	118.4100	4.3855
10	0.9649	117.76	113.6281	117.5000	3.8719
11	0.9123	117.73	107.4028	118.0300	10.6272
12	0.9532	118.49	112.9466	117.4600	4.5134
13	1.0000	117.97	117.9700	118.1100	0.1400
14	1.0000	117.69	117.6900	117.4400	-0.2500
15	1.0000	118.73	118.7300	118.3500	-0.3800
MEAN	0.9720	117.84	114.5415	118.0847	3.5431
S.DEV	0.0264	0.46	3.1439	0.4116	3.1571

The Actual CTF in phase 3 was taken as the reference CTF since it was manually calculated from directly measured values. The actual calculation readings show the amount of dose that the area of interest will receive when the CTF is incorporated in the TPS while the phase 1 reading displays the actual dose from the TPS window. From table 4.9, the mean of the actual dose the phantom will receive if the dose calculation does not include the CTF is 114.5415 MU's which is lower compared to the mean dose of 118.0847 MU's displayed by the TPS. From figure 4.9 below the highest dose recorded was 10.63 monitor units for GAP 11 (213.8 °).

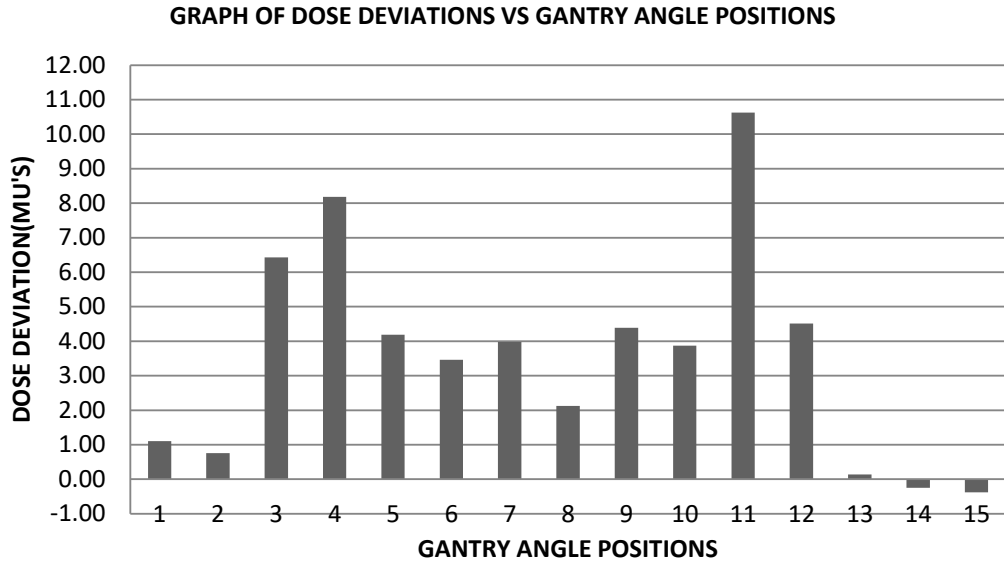


Figure 4.9: Histogram of dose deviations (MUS') at various gantry angle positions.

Table 4.10: Calculated treatment couch readings of dose received by phantom and deviations from the TPS couch reading for phase 1 for a photon energy beam of 15MV.

GAP	PHASE 3 CTF	PHASE 1 READING (MU'S)	ACTUAL READING(MU'S)	PHASE 1 READING (MU'S)	DEVIATION
		WITHOUT COUCH	WITH COUCH FROM CALCULATION	WITH COUCH	(MU'S)
1	1.0000	106.10	106.1000	106.2900	0.1900
2	1.0016	105.54	105.7108	106.0300	0.3192
3	0.9709	105.63	102.5534	106.3100	3.7566
4	0.9515	105.96	100.8163	106.0700	5.2537
5	0.9806	105.67	103.6182	106.2100	2.5918
6	0.9806	105.36	103.3142	105.9400	2.6258
7	0.9854	105.35	103.8158	106.4000	2.5842
8	0.9854	105.77	104.2297	105.6700	1.4403
9	0.9854	105.14	103.6014	106.1100	2.5086
10	0.9757	105.59	103.0271	105.7300	2.7029
11	0.9369	105.56	98.8984	105.9200	7.0216
12	0.9660	106.03	102.4270	105.5600	3.1330
13	1.0000	105.86	105.8600	106.0600	0.2000
14	1.0000	105.56	105.5600	105.5600	0.0000
15	1.0000	106.36	106.3600	106.2400	-0.1200
MEAN	0.9813	105.70	103.7261	106.0067	2.2805
S.DEV	0.0191	0.32	2.0738	0.2728	2.0525

Table 4.10 shows calculated values of Actual reading with the couch in place and the deviations obtained for phase 1 for a photon energy beam of 15MV. The Actual CTF in phase 3 was taken as the reference CTF since it was manually calculated from directly measured values. The actual calculation readings show the amount of dose that the area of interest will receive when the CTF is incorporated in the TPS while the phase 1 reading displays the actual dose from the TPS window.

From table 4.10, the mean of the actual dose the phantom will receive if the dose calculation does not include the CTF is 103.7261 which is lower as compared to the mean dose of 106.0067 displayed by the TPS. From figure 4.10 below the highest dose recorded was 7 monitor units for GAP 11 (213.8 °).

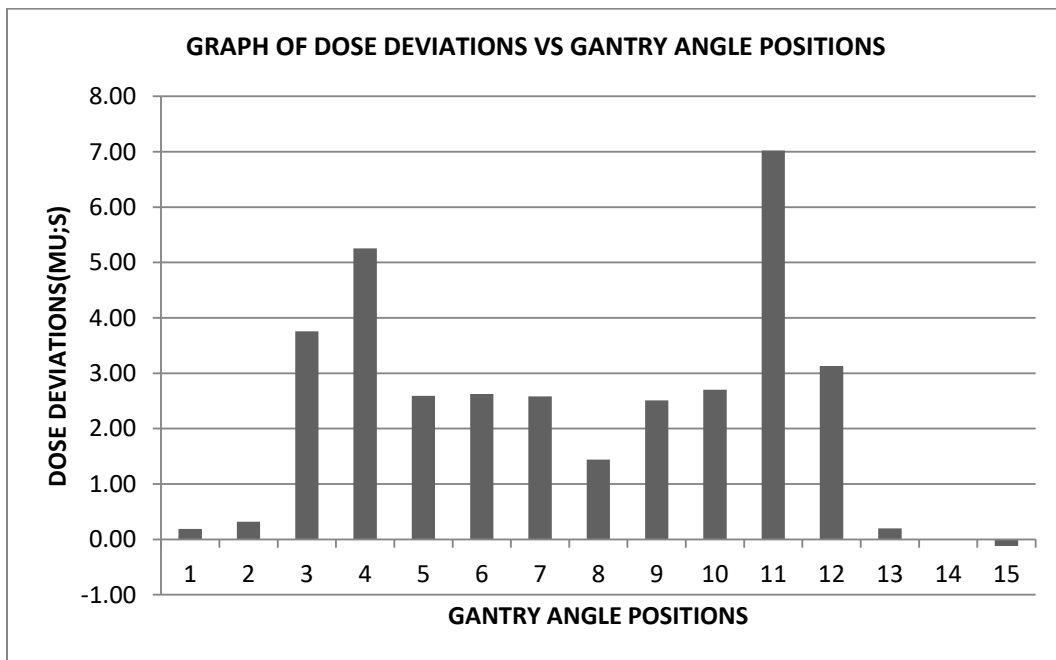


Figure 4.10: Histogram of dose deviations (MUS') at gantry angle positions.

Table 4.11: Calculated treatment couch readings of dose received by phantom and the deviations from the TPS couch readings for phase 2 for photon energy beam of 6MV.

GAP	PHASE 3 CTF	PHASE 2 READING (MU'S)	ACTUAL READING (MU'S)	PHASE 2 READING (MU'S)	DEVIATION
		WITHOUT COUCH	WITH COUCH FROM CALCULATION	WITH COUCH	(MU'S)
1	0.9942	124.09	123.36	124.95	1.5857
2	1.0000	127.14	127.14	128.15	1.0100
3	0.9532	133.40	127.16	134.41	7.2509
4	0.9298	143.01	132.97	144.42	11.4458
5	0.9706	133.12	129.20	134.10	4.8953
6	0.9765	127.03	124.04	127.86	3.8189
7	0.9766	124.18	121.27	124.75	3.4805
8	0.9766	123.13	120.25	123.94	3.6902
9	0.9727	124.08	120.69	124.96	4.2728
10	0.9649	127.19	122.73	128.10	5.3728
11	0.9123	133.41	121.71	134.42	12.7126
12	0.9532	143.79	137.06	143.76	6.6970
13	1.0000	134.11	134.11	133.08	-1.0300
14	1.0000	127.89	127.89	127.00	-0.8900
15	1.0000	124.74	124.74	124.04	-0.7000
MEAN	0.9720	130.02	126.29	130.53	4.2408
S.DEV	0.0264	6.64	5.19	6.71	4.1192

Table 4.11 shows calculated values of Actual reading with the couch in place and deviations obtained for phase 2 for a beam of photon energy of 6MV. The Actual CTF in phase 3 was taken as the reference CTF since it was manually calculated from directly measured values. The actual calculation readings show the amount of dose that the area of interest will receive when the CTF is incorporated in the TPS while the phase 1 reading displays the actual dose from the TPS window. From table 4.11, the mean of the actual dose the phantom will receive if the dose calculation does not include the CTF is 126.29 which is lower compared to the mean dose of 130.53 displayed by the TPS. From figure 4.11 below the highest dose recorded was 12.7126 monitor units for GAP 11(213.8 °).

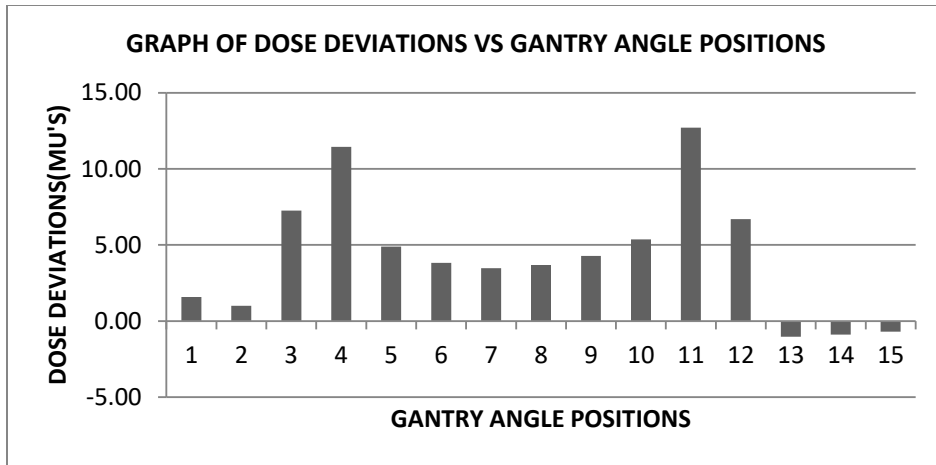


Figure 4.11: Histogram of dose deviations (MUS') at various gantry angle positions.

Table 4.12: Table showing calculated treatment couch reading received by phantom and deviations from the TPS couch reading in phase 2 15MV.

		PHASE 2 READING (MU'S)	ACTUAL READING (MU'S)	PHASE 2 READING (MU'S)	DEVIATION (MU'S)
GAP	PHASE 3 CTF	WITHOUT COUCH	WITH COUCH FROM CALCULATION	WITH COUCH	
1	1.0000	110.48	110.48	111.02	0.5400
2	1.0016	112.37	112.55	113.03	0.4782
3	0.9709	116.33	112.94	116.94	3.9983
4	0.9515	122.26	116.33	123.16	6.8350
5	0.9806	116.15	113.89	116.72	2.8253
6	0.9806	112.35	110.17	112.89	2.7216
7	0.9854	110.56	108.95	110.87	1.9201
8	0.9854	109.87	108.27	110.37	2.1000
9	0.9854	110.47	108.85	111.03	2.1766
10	0.9757	112.41	109.68	113.00	3.3184
11	0.9369	116.33	108.99	116.96	7.9712
12	0.9660	122.80	118.63	122.78	4.1528
13	1.0000	116.73	116.73	116.12	-0.6100
14	1.0000	112.91	112.91	112.33	-0.5800
15	1.0000	110.86	110.86	110.44	-0.4200
MEAN	0.9813	114.19	112.02	114.51	2.4952
S.DEV	0.0191	4.15	3.22	4.19	2.5459

Table 4.12 shows calculated values of Actual reading with the couch in place and the deviations obtained in phase 2 for a beam of photon energy 15MV. The Actual CTF in phase 3 was taken as the reference CTF since it was manually calculated from directly measured values. The actual calculation readings show the amount of dose that the area of interest will receive when the CTF is incorporated in the TPS while the phase 1 reading displays the actual dose from the TPS window. From table 4.12, the mean of the actual dose the phantom will receive if the dose calculation algorithm does not include the CTF is 112.02, which is lower compared to the mean dose of 114.51 displayed by the TPS. From figure 4.12 below the highest dose recorded was 7.9712 monitor units for GAP 11 (213.8 °).

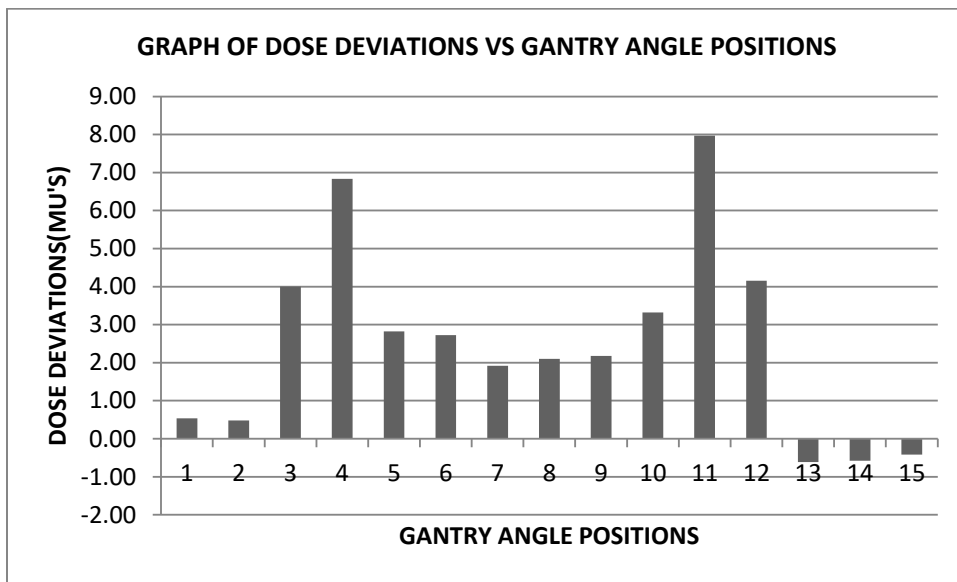


Figure 4.12: Histogram of dose deviations (MU's) at various gantry angle positions.

CHAPTER FIVE

DISCUSSION

The measurements were done in phases as described in chapter 3 sections 3.2 in order to determine the couch transmission factor of the physical iBEAM evo treatment couch and the Treatment Planning System couch model. From the results in chapter 4 section 4.3, the treatment couch has an effect on the delivered dose; therefore, its presence in the treatment planning system would reduce the dose attenuated by the couch. This will in turn improve the effectiveness of patient treatment by achieving a higher dose sufficient to eradicate all cancerous cells. According to the TG 176 report, by Olch et al. (2014), most researchers have been performing experiments based on the dose attenuated by the couch, but this research focused much at comparing the couch transmission factors and assessing their effect in the treatment of patients. In the TG 176 report, Olch et al. (2014) reported a dose attenuation of 2-5% from the research done on modern couches, which are in close agreement with results obtained and recorded in chapter 4, section 4.3 of 1.45% to 6% for 15MV and 2.34% to 8% for 6MV photon beam energies on the iBEAM evo treatment couch.

Kong et al. (2022) used a QUASAR cylindrical phantom to perform dose attenuation measurements on a Monaco treatment planning system. Kong et al. (2022) reported a dose attenuation of 6.74% and 4.05% at higher oblique gantry angles and a sharp increase at 110° and 250° angles. From this research, in phase 3, there was a steady increase in dose attenuation from a 180° gantry angle moving outward at oblique angles. From the results obtained and recorded in chapter 4, section 4.3, table 4.5 and 4.6, the highest dose attenuation was 8.8% and 6.3% at GAP 11 (213.8°) for 6MV and 15MV photon energies, respectively. The lowest attenuation was 2.34% and 1.46% at GAP 8 (180°) for 6MV and 15MV photon energies, respectively. In phase

1, the lowest dose attenuation was -1.05% at GAP 7 (168.8°) and the highest was 0.87% at GAP 12 (225°) for 6MV (See Chapter 4, section 4.1, table 4.1). In phase 2, the lowest dose attenuation was -0.99% at GAP 4 (135°) and the highest was 0.77% at GAP 13 (236.3°) for 6MV photon energies (See Chapter 4, section 4.2, table 4.3). These values were lower than those recorded by previous researchers in TG 176 by Olch et al. (2014). This gave an indication of dose calculation algorithms in the Oncentra treatment planning system not incorporating the CTF in dose calculations.

5.1 COUCH TRANSMISSION FACTOR

As previously stated, couch transmission factor is required for dose calculations to compensate for the dose attenuated by the treatment couch. In this research, the CTF for each phase was calculated using equation 4.1 in chapter 4 section 4.1. From the results obtained and recorded in chapter 4, all CTF values that had a factor of 1.0 represented no attenuation at those gantry angle positions, giving an indication of equal doses between the posterior beam passing through the couch and the opposing anterior beam passing in air before reaching the phantoms' isocentre.

In phase 1, the collapsed convolution cone dose calculation algorithm gave a mean CTF of 1.00 ± 0.0029 for 6MV photon energy and 1.00 ± 0.002 for 15MV. It was noted that all the CTF values were almost constant, with a standard deviation of 0.00578, the highest being 1.010478 for gantry angle positions (GAP) 7 at 348.3° and 168.8°, and the lowest CTF value was 0.99131 for GAP 12 at 45° and 225° (See table 4.1). The CTF values in phase 1 had almost constant values for both energies, hence no significant difference from their mean values. From this research, findings from this phase indicated the absence of the CTF values in the dose calculation done by the Oncentra TPS (see chapter 4, section 4.1, and table 4.1 and 4.2).

In phase 2, the collapsed convolution cone dose algorithm in the TPS gave a mean CTF of 1 ± 0.0030 for 6MV photon energy and 1 ± 0.0021 for 15MV. Just like in phase 1, the CTF values were almost constant, with a standard deviation of ± 0.00422 , the highest being 1.00794 for gantry angle position (GAP) 2 at 112.5° and 292.5° and the lowest being 0.99232 for GAP 13 at 56.3° and 236.3° of gantry angle (See table 4.3). In phase 2, based on the CTF values calculated, the dose calculation algorithm did not include the CTF values in the calculations, giving an indication of the absence of the couch in the TPS (see chapter 4, section 4.2 and table 4.3 and 4.4).

In phase 3, from the measured data, a mean CTF of 0.97 ± 0.0134 was calculated for 6MV photon energies and 0.98 ± 0.0097 for 15MV. For 6MV photon energies, the highest CTF calculated was 0.97661 at GAP 8 for 0° and 180° gantry angles, and the lowest was calculated at GAP 11 for 33.8° and 213.8° gantry angles as 0.91228. For 15MV photon energies, the highest calculated CTF was 0.985436 at GAP 8 for 0° and 180° gantry angles, and the lowest was 0.93689 at GAP 11 for 33.8° and 213.8° gantry angles.

The above CTF were from the attenuating gantry angle positions only (See table 4.5 and 4.6). From the 15 gantry angle positions measured, only 4 positions had a CTF value of 1 ± 0.03 for 6MV photon energy and 1 ± 0.02 for 15MV photon energy, indicating no attenuation. Eleven (73%) of the gantry angle positions had a CTF of less than 0.99, indicating attenuation properties as reported by Olch et al. (2014) in TG 176 report. Data collected from phase 3 and the calculated CTF indicated the radiotranslucence nature of the iBEAM evo treatment couch attenuating dose (see chapter 4, section 4.3 and table 4.5 and 4.6).

According to TG 53 report by Fraass et al., (2014), the dose calculation error in the TPS exceeding 3% is significant (Kong et al. 2022). From the CTF calculated from the summarized

data in table 5.1 below shows the percentage deviations of the CTF in phases 1 and 2 in the TPS from the actual CTF in phase 3 at different gantry angle positions (GAP)

Table 5.1: Percentage deviations of the Calculated CTF from the Actual CTF.

	PHASE 1	PHASE 2		PHASE 1	PHASE 2
GAP	6MV	6MV		15MV	15MV
3	5.47%	5.44%			
4	6.92%	8.00%		4.96%	5.59%
11	9.03%	9.53%		6.65%	6.85%
12		4.66%			

From table 5.1 above, it was noted that the percentage deviations were higher than 3%, hence significant. From these findings, it is clear that the CTF values are not included in the TPS; hence there is a possibility of under dosing. Figure 5.1 below displays histograms showing a comparison of the CTF of the three phases. Series 1 in all the histograms represents the CTF for phases 1 and 2, while series 2 represents phase 3 CTF. In the CTF, values of 1 or 0.99 represent gantry angle positions with no attenuation. This is mostly observed in phases 1 (see chapter 4, section 4.1, table 4.1 and 4.2) and phases 2 (see chapter 4, section 4.2, table 4.3 and 4.4) indicating the absence of the couch in the dose calculation as compared to the calculations that were done in phase 3, which included the couch.

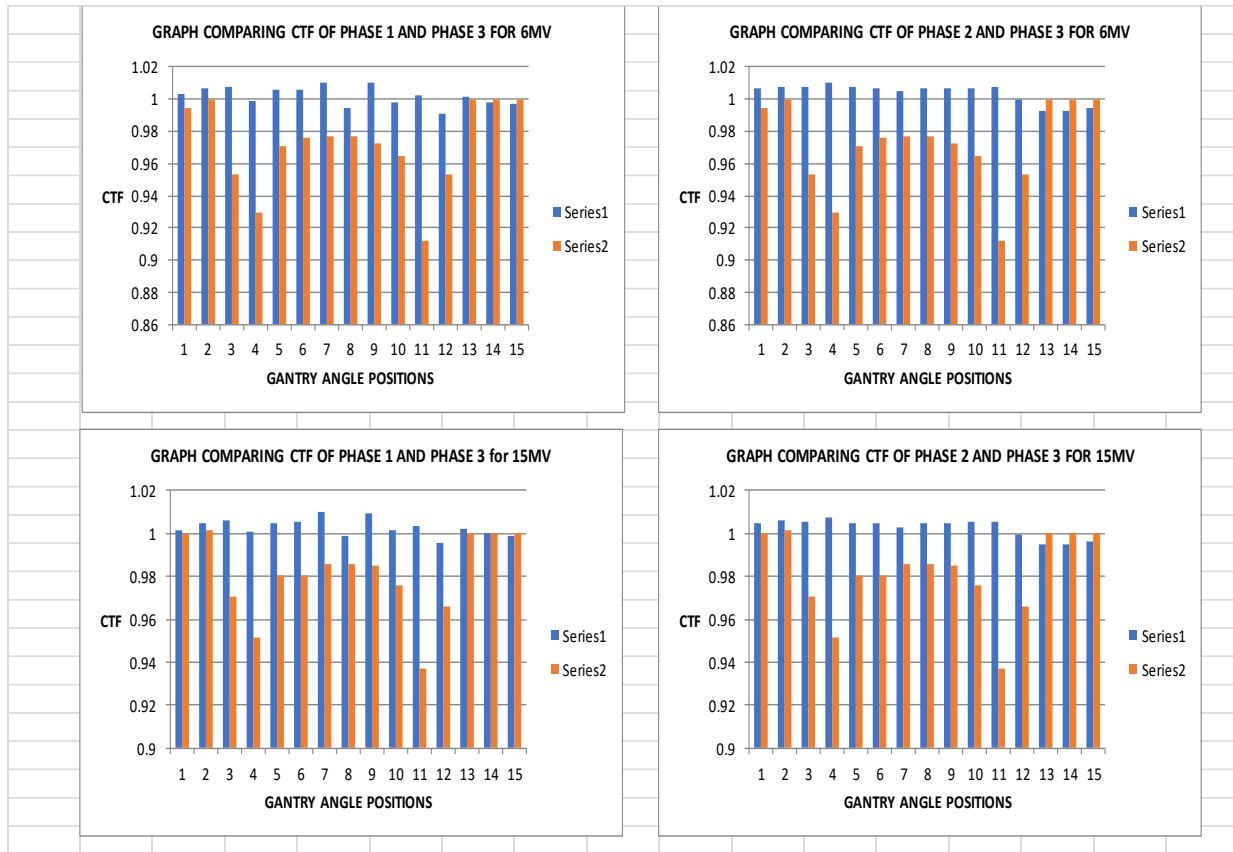


Figure 5.1: Histograms showing comparison of the CTF values for all the phases for 6MV and 15MV photon beam energies.

The relationship between gantry angle position and the CTF values was best defined using scatter plot curves. From the R^2 values in table 5.2 extracted from figure 5.2 of the correlational curves, the R^2 value for phases 1 and 2 was about 0.2776 and 0.6045, respectively, for 6MV photon beam energies and 0.1873 and 0.5985, respectively, from 15 MV photon beam energies. In phase 3 the R^2 values were 0.0101 and 0.002 for 6MV and 15MV photon beam energies respectively. The R^2 values were low in phase 3 as compared to phases 1 and 2, indicating no relationship.

Table 5.2: Correlational coefficients from figure 5.2.

	R²	R²
	6MV	15MV
PHASE 1	0.2776	0.1873
PHASE 2	0.6045	0.5985
PHASE 3	0.0101	0.002

However, in phase 3, the CTF values that were close to the 180° gantry angle decreased as the gantry angle increased from 180° to 213.8° and from 180° to 135°. This indicated that the iBEAM evo couch attenuated more doses at posterior oblique angles. Angles close to 90° gantry angle (112.5°, 101.3°) and 270° gantry angle (236.3°, 247.5°, and 258.8°) had no attenuation (see chapter 4, section 4.3, table 4.5 and 4.6).

The CTF in phase 3 was taken as the actual CTF and used to compute the actual dose the CTDI phantom would receive if it were to be treated using a plan from the TPS (See chapter 4, tables 4.9, 4.10, 4.11 and 4.12). Through manual calculations, the dose was calculated, and deviations were found between the dose displayed in the treatment printout preview window in the TPS and the actual dose calculated through the CTF values in phase three using equations 4.3 and 4.4.

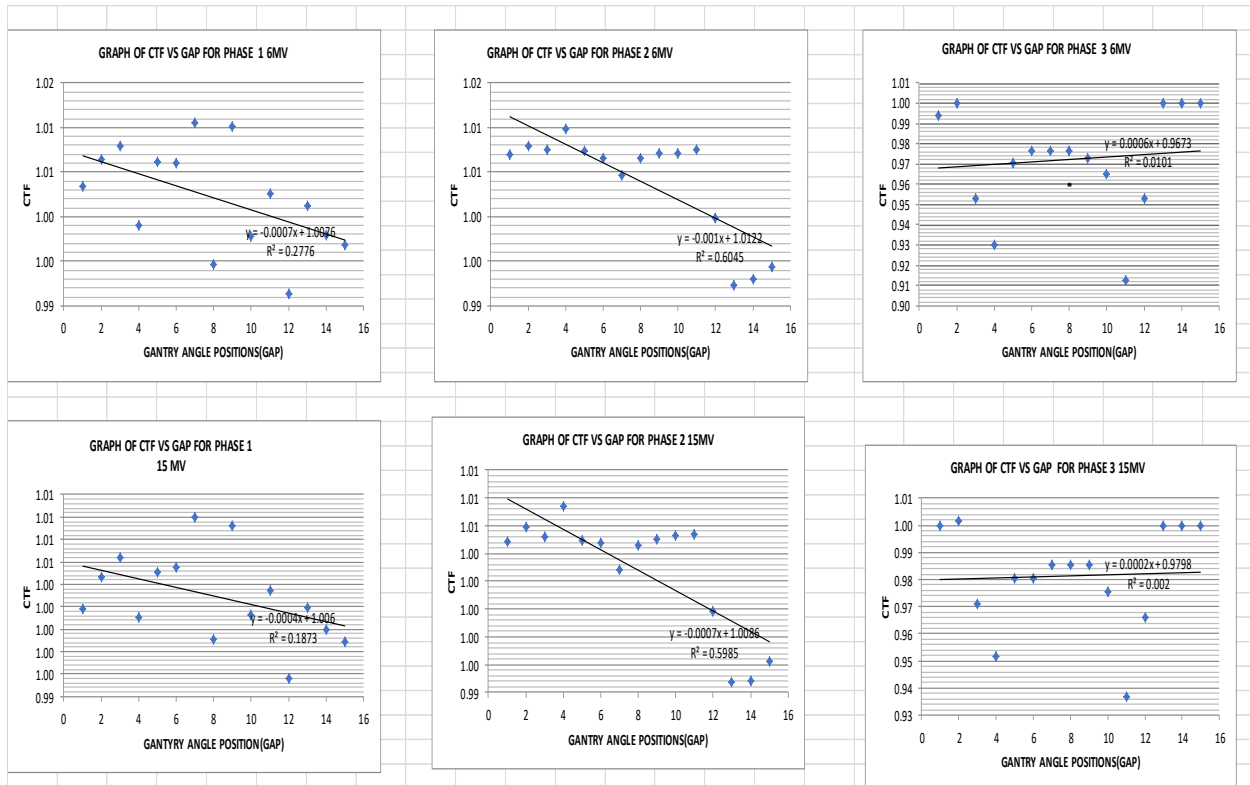


Figure 5.2: Correlation curves of the CTF values at various Gantry Angle positions.

The following tables (5.3, 5.4, 5.5 and 5.6) display a summary of the dose deviations in monitor units for phases 1 and 2 for different gantry angle positions (GAP) from phase 3 as the reference CTF for 6MV and 15MV photon energy beams. All of the above deviations were above the 3% allowed tolerance in TG 53 report by Fraass et al., (2014).

Table 5.3: Dose deviations for phase 1 (6MV) from phase 3 as the reference CTF.

	PHASE 1 6 MV			
GAP(degrees)	Dose From TPS(MU'S)	Actual Dose Received(MU'S)	Deviations	% DEV
3	118.55	112.12	6.43	5.73
4	118.12	109.93	8.19	7.45
5	118.31	114.12	4.19	3.67
9	118.41	114.02	4.39	3.85
11	118.03	107.40	10.63	9.90
12	117.46	112.95	4.51	3.99
MEAN	118.15	111.76	6.39	5.77

Table 5.4: Dose deviations for phase 1(15MV) from phase 3 as the reference CTF.

		PHASE 1 15MV		
GAP	Dose From TPS (mu's)	Actual Dose Received(mu's)	Deviations	%DEV
3	106.31	102.55	3.76	3.67
4	106.07	100.82	5.25	5.21
11	105.92	98.90	7.02	7.10
MEAN	106.10	100.76	5.34	5.32

Table 5.5: Dose deviations for phase 2 (6MV) from phase 3 as the reference CTF.

		PHASE 2 6MV		
GAP	Dose From TPS(mu's)	Actual Dose Received(mu's)	Deviations	%DEV
3	134.41	127.16	7.26	5.71
4	144.42	132.97	11.45	8.61
5	134.10	129.20	4.90	3.79
9	124.96	120.69	4.27	3.54
10	128.10	122.73	5.37	4.38
11	134.42	121.71	12.71	10.44
12	143.76	137.06	6.70	4.89
MEAN	134.88	127.36	7.52	5.91

Table 5.6: Dose deviations in phase 2 (15MV) from phase 3 as the reference CTF.

		PHASE 2 15MV		
GAP	Dose From TPS(mu's)	Actual Dose Received(mu's)	Deviations	%DEV
4	123.16	116.33	6.83	5.87
11	110.87	108.99	7.97	7.31
12	122.78	118.63	4.15	3.50
MEAN	118.94	114.65	6.32	5.56

From tables (5.3, 5.4, 5.5 and 5.6) above, there could be an underdose at posterior and posterior oblique gantry angles where the CTF from phase 3 was less than 1, if the plans from phases 1 and 2 could be delivered to the CTDI phantom. In phase 1, the highest percentage deviation was

9.89% at GAP 11 (213.8° and 33.8°), and in phase 2, the highest was 10.44% at GAP 11. For 15 MV photon energies, in phase 2, the highest percentage deviation was 7.31%, and in phase 1, it was 7.1%. Generally phase 2 recorded the highest percentage deviation in dose, with a mean of 5.91% for 6MV and 5.56% for 15MV photon energies. This is contrary to Kong et al., (2022) reports from Fraass et al. (2014) TG 53 report of the dose calculation error in the TPS not exceeding $\pm 3\%$. This is a clear indication that the CTF was not incorporated into the TPS dose calculations.

CHAPTER SIX

CONCLUSION

Measurements were done in three phases. Phases 1 and 2 investigated the Couch Transmission Factor (CTF) of the virtual couch model in the Treatment Planning System (TPS), while phase 3 investigated the CTF of the physical iBEAM evo treatment couch. Using equation 4.1, phases 1 and 2 gave an equal mean CTF of 1.00 for 6MV and 15MV photon energy, while phase 3 gave a mean CTF of 0.97 for 6MV and 0.98 for 15MV photon energy (see Chapter 4, sections 4.1, 4.2 and 4.3 respectively).

The CTF values in all the phases were supposed to be the same or with slight deviations of less than $\pm 3\%$ as reported by Fraass et al. (2014), which could have indicated the inclusion of the couch transmission factor (CTF) in dose calculations. This was contrary to this research, as it gave equal CTF values in phases 1 and 2 (mean of 1.0 for all energies) and different CTF values in phase 3 (mean of 0.97 and 0.98) for 6MV and 15MV photon energy, respectively. The deviations in CTF in some gantry angle positions (GAP) of the three phases exceeded $\pm 3\%$. The highest deviations recorded between CTF values in phase 1 and phase 3 (actual CTF) were at GAP 3 (-5.47%), GAP 4 (-6.92%) and GAP 11 (-9.03%) for 6MV photon energy and GAP 4 (-4.96%) and GAP 11 (-6.65%) for 15MV photon energy. The highest deviations recorded between CTF values in phase 2 and phase 3 (actual CTF) were at GAP 3 (-5.44%), 4 (-8%), 5 (-3.68%), 10 (-4.22%), 11 (-9.53%) and 12 (-4.66%) for 6MV photon energies and GAP 3 (-3.44%), 4 (-5.59%), 11 (-6.85%) and 12 (-3.38%) for 15MV photon energy were more than $\pm 3\%$ (See Chapter 4, Tables 4.7 and 4.8, Figures 4.7 and 4.8). Radiation beams in Phases 1 and 2 were not affected by the presence of the couch in the TPS, while in Phase 3, the radiation beams,

especially those that penetrated the CTDI phantom posteriorly, were affected by the presence of the couch.

According to the TG 176 report by Olch et al. (2014), to maximize the goal of radiotherapy, the dose accuracy should be within 3% to 5%. A manual dosimetric calculation was done using equation 4.3, equation 4.4 and Couch Transmission Factor (CTF) in phase 3 to get the dose received by the CTDI phantom if the plans in phases 1 and 2 were delivered. From the calculations, in phases 1 and 2, there was an under dose in all the posterior Gantry Angle Positions (GAP). From phase 1, the highest recorded underdose was at GAP 3 (5.73%), 4 (7.45%), 5 (3.67%), 9 (3.85%), 11 (9.9%) and 12 (3.99%) for 6MV photon energy and GAP 3 (3.67%), 4 (5.21%) and 11 (7.1%) for 15MV photon energy. From phase 2, the highest recorded under dose was at GAP 3 (5.71%), 4 (8.61%), 5 (3.79%), 9 (3.54%), 10 (4.38%), 11 (10.44%) and 12 (4.89%) for 6MV photon energy and GAP 4 (5.87%), 11 (7.31%) and 12 (3.5%) for 15MV photon energy (See chapter 5, Tables 5.3, 5.4, 5.5, and 5.6).

RECOMMENDATION

From the results obtained as discussed in chapter 5, the couch transmission factor (CTF) of the iBEAM evo treatment couch was not incorporated in the Oncentra Treatment Planning System. This resulted in an underdose from calculations in posterior gantry angle positions.

I would recommend the institution to find a suitable way to model the couch in the TPS to avoid underdose. From the two methods described in the TG 176 report by Olch et al. (2014) of couch inclusion in the TPS, phases 1 and 2 measurements can be repeated while including the CT image couch attached to the imported image in the TPS in the body or external contour, then visualize if the CTF results tally with the CTF in phase 3 of the iBEAM evo treatment couch.

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