EVALUATION OF THE ACCURACY AND REPRODUCIBILITY OF THE PLANNING ISOCENTRE USING AUTOMATIC AND MANUAL COUCH MOVEMENTS

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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.

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DEDICATION

I would like to show my deepest dedication to my cherished parents, who have been the wellspring of my strength, guidance, and motivation throughout this research endeavor. There were moments when I felt like giving up, but their unwavering moral, spiritual, and financial support served as a constant beacon of encouragement, enabling me to complete this research on time.

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ABSTRACT

The present study delves into the subject of analyzing the accuracy and reproducibility of the planned isocenter using automatic and manual couch movements, a pivotal issue within the broader context of radiotherapy. This research was driven by the compelling need to ascertain the deviation from the tumor isocenter during the delivery of radiation to cancerous cells and check whether they are within the acceptable clinical tolerance using the AAPM TG-142 protocol. The methodology adopted for this study was hinged on the analysis of the distances between the treatment isocenter from the planned isocenter. The research process involved a detailed collection of shifts using RANDO phantom from three regions of the body (head and neck, thoracic, and pelvic regions) using both automatic and manual couch movements. Sixty shifts; twenty for each region were recorded from where the distances were calculated. The distances offered a more objective evaluation of the accuracy of both couch movements as opposed to the shifts in coordinates. Moreover, the data was analyzed using MS Excel functions that ensured a comprehensive exploration of the topic and an in-depth understanding of the findings. It was found that automatic couch movements were more accurate in reproducing the planned isocenter as compared to manual couch movement techniques. In addition, the present study records a relatively high shift from the planned isocenter for the thoracic region. Only 20% and 17% of the shifts were within the acceptable limits for automatic and manual couch movement respectively compared to the pelvic, head and neck regions whose shifts tolerance was above 70% for both couch movements These results have far-reaching implications for radiation dose delivery as slight deviations from the planned isocenter could potentially lead to an important under dose to the target, which could lead to tumor recurrence and an excessive dosage to healthy tissue, which could have serious repercussions to normal tissues. In conclusion, the findings from this research not only fill a critical gap in the existing literature but also could potentially influence clinical practices and guidelines in the use of couch movements during treatment planning. Future research endeavors could build upon these findings, thereby paving the way for more comprehensive studies in this field.

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LIST OF ABBREVIATIONS

EPID	Electronic portal imaging device
LINAC	Linear accelerator
AAPM	American Association of Physicists in Medicine
TG	Task Group
CT	Computed Tomography
TPS	Treatment planning system
ASU	Automatic setup unit
DRR	Digital reconstructed radiographs
SBRT	Stereotactic body radiotherapy
EBRT	External beam radiation therapy
SGRT	Surface guided radiation therapy
ESAPI	Eclipse Scripting Application Programming Interface
CCC	Collapsed Cone Convolution

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Following a cancer diagnosis, the medical practitioner, in close collaboration with the patient, carefully selects the most appropriate treatment option based on various factors. These factors encompass the type and stage of cancer, potential side effects, and even the financial implications of the treatment. Cancer treatment methods that are routinely used include surgery, chemotherapy, radiation therapy, and targeted therapy. Each of these modalities serves a unique purpose and is tailored to the specific characteristics of the cancer. Surgery involves the physical removal of the tumor and surrounding tissues to eradicate the cancer cells. It is particularly effective for localized cancers, where the tumor is confined to a specific area. By surgically removing the tumor, the cancer cells are eliminated, offering a curative approach.

Radiation therapy, on the other hand, utilizes high-energy radiation beams to target and destroy cancer cells. It can be employed as a standalone treatment for localized cancers or as a preparatory measure before surgery. In some cases, radiation therapy is used to shrink the tumor, increasing the likelihood of successful surgical removal. Additionally, radiation therapy may be recommended as adjuvant therapy following surgery to eradicate any remaining cancer cells.

On the other hand, chemotherapy entails the delivery of potent medications that identify and arrest cancerous cell’s cycle. It is commonly used for cancers that have spread to distant sites or as a systemic treatment to eradicate cancer cells that may have traveled beyond the initial tumor site. Chemotherapy can be administered through various routes, such as intravenous infusion, oral pills, or injections. Targeted therapy is a newer form of cancer therapy that focuses on specific molecular targets involved in cancer growth and progression. It uses medications to specifically target genes and proteins that aid cancer cell survival and growth. These therapies are designed to interfere with the signaling pathways and mechanisms that drive cancer cell growth, ultimately inhibiting tumor growth or promoting cancer cell death. Because they selectively attack cancer cells while limiting harm to normal cells, targeted therapies provide a more precise approach.

In many cases, a combination of therapies is required, depending on the stage and type of cancer. This is known as multimodal or multidisciplinary treatment. The treatment plan may involve a sequence of radiation therapy, surgery, chemotherapy, or targeted therapy, depending on the specific needs of the patient. The objective is to maximize therapy efficacy while reducing side effects and increasing overall patient outcomes.

Modern radiotherapy treatment necessitates high precision to eradicate cancer cells while minimizing the delivered dose to vicinal normal tissues. According to Li et al. (2009), this can only be achieved by proper treatment planning and precise patient positioning and verification of the same utilizing an electronic portal imaging device (EPID) attached to radiotherapy treatment machines, e.g., Linear Accelerators (LINACS). LINACs are commissioned with an isocenter, a point in space where the couch axis, gantry, and collimator axis meet. It serves as a reference point for the tumor isocenter and is essentially a point in the tumor through which the central beam of the axis passes. The isocenter is usually identified by three translational axes (x, y, z) and is assumed to be inside a spherical volume which must be replicated during patient positioning by ensuring the treatment couch moves in order to achieve the isocenter. As part of quality control, it is recommended that the center of the tumor is positioned at the isocenter accurately, with the central radiation beam directed at the isocenter to minimize isocenter shift.

Many international organizations have developed guidelines to ensure the isocenter shift does not exceed the acceptable clinical tolerance limit. For instance, the AAPM Task Group 142 by Klein et.al (2009), strengthens the < 1mm tolerance limit that is achievable when stereotactic treatments are in use and < 2mm for every other kind of treatment, and if the couch, gantry, and collimator do not coincide with the radiation isocenter, incorrect dose distribution and serious damage to healthy tissues are some of the effects that could be observed. According to Tsai (2020), therapists traditionally rely on triangulation skin tattoos (reference markings) made on a patient during CT simulation and shift instructions from the computerized treatment planning system (TPS) reference point. Room lasers are also positioned to coincide with the radiation isocenter at the CT simulation and the treatment room. Treatment planning begins from the simulation stage, usually based on CT scans where the patient is positioned on the couch with their customized immobilization devices, reference marks made on their bodies for isocenter localization and finally, their scanned images obtained. CT scans are acquired based on the scanning limits identified. The scan images are then transferred to the TPS for beam allocation and dose calculation identification of the tumor isocenter. After treatment planning, the patient is positioned on the patient support table to move in three-dimensional directions, i.e., laterally, vertically, and longitudinally, to achieve the planned tumor isocenter for accurate treatment delivery. Elekta synergy platform version S has a remote automatic set up (ASU) positioning of the table feature in their control system software. Clinically, the ASU is used for positional adjustments, and measurements regarding laser lines, light field cross wires, and treatment room walls are frequently taken (Riis et al., 2009). In addition, the couch can be moved simultaneously in the 3 directions while inside the treatment room. Unlike the table ASU, the couch can be used to manually move the patient to the isocentre by moving the table in the x, y and z directions individually, one at a time. The two ways should move the couch to the exact geometrical position of the tumor isocenter relative to its origin point (0,0,0) isocenter. Portal imaging is the final stage of treatment verification; images are taken first to verify the treatment isocenter or tumor isocenter against the planned isocenter on the DRRs (isocenter shift). Secondly, the images of the subject on the treatment couch are taken to correct any setup errors and ensure accurate beam placement relative to the patient's anatomical structure by matching the images to check for beam coverage. In this study, the EPID (attached to the gantry, see Fig.3.5a) was used to acquire radiographic images of the phantom to determine any isocenter shift due to the manual and ASU couch movements.

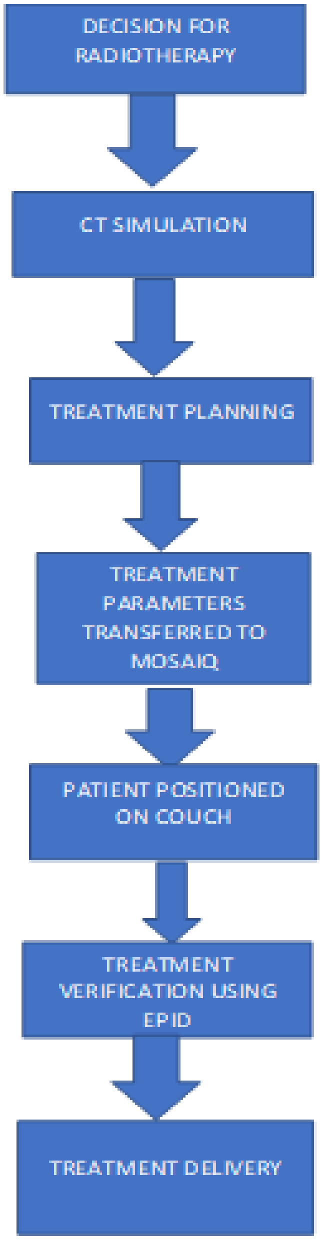

Figure 1. 1. Process of Radiotherapy

Figure.1.1 illustrates the process of radiotherapy starting with making a decision to carry out treatment using radiotherapy up to the final stage when the treatment is delivered. Treatment using radiotherapy can be carried out using photon and electron energies.

1.2 STATEMENT OF THE PROBLEM

Accurately localizing the patient to the same position intended for each therapy session is a hurdle during patient setup. It is critical for radiation therapists to accurately orientate a patient on a treatment couch before initiation of therapy (Tsai et al., 2020). Conformal therapies result in spot-on isocenter accuracy, leading to greater tumor control by lowering the toxicity to the normal tissues. The table ASU is the most popular couch movement option because of its automation feature, which supposedly makes treatment smooth, quick, and accurate. However, this system cannot be used if the distance to be moved is greater than 20 cm or a patient is to be treated with multiple isocenters, necessitating manual couch movement. Since the two couch movements are used in locating the patient tumor isocenter, there is a need to examine the accuracy of both table movements. This study aims to examine if the two mechanisms can accurately duplicate the geometric position of the TPS isocenter during patient setup, identify any significant isocenter shifts, and further assess the accuracy and irregularities resulting from the two couch movements.

1.3 OBJECTIVES

1.3.1 Main Objective

The main goal of this study is to analyze the reproducibility of the planning tumor isocentric point utilizing both the automatic and manual couch movements

1.3.2. Specific Objectives

To achieve the main objective, the following specific objectives will be addressed:

i. To determine the discrepancies in isocenter movement as a result of both manual and automatic couch movements.
ii. To determine whether both conform to AAPM TG-142 protocol.

iii. To evaluate the accuracy of both couch movements based on the shifts from the planned isocenter

1.4. HYPOTHESIS/ RESEARCH QUESTIONS

1. During patient positioning, do both automatic and manual couch movements replicate the intended tumor isocenter?
2. Is there any difference in isocenter movement due to the automatic and manual couch movements?
3. What are the error margins if the isocenter movement differs due to both couch movements?
4. Which couch movement method is more accurate, automatic or manual?
5. Is any isocenter displacement caused by both couch movements within clinical tolerance?

1.5. JUSTIFICATION OF THE STUDY

Radiotherapy requires the safe administration of a highly conformal dose distribution to a precisely defined target volume, and geographical errors are a common contributor to significant or serious occurrences of the wrong treatment body site. Yan et al. (2013) established various routes by which wrong-site treatment mistakes can occur, either through incorrect shift instructions or a table shift change during treatment. Additionally, Ezzell et al. (2018), in their study to investigate the typical mistakes that result in mistreatment, discovered that 34 out of 396 cases of errors reported were as a result of wrong shift performed at treatment, and most of those errors resulted in incorrectly delivered treatment. Considering that a patient is first positioned by placing the reference markings in relation to the room lasers before being relocated with the treatment couch following the shift instructions, this study, therefore, is crucial since it aims at verifying the accuracy of the table movements in relocating the patient to the targeted isocenter. This is to prevent any geometric errors due to wrong shift of the isocenter that can induce both an important underdose to the target, which could lead to incomplete regression of the neoplasm, and an excessive dosage to healthy tissue, which could have serious repercussions to normal tissues (Yan et al. 2013). This will, in turn, improve the radiotherapy treatment accuracy. Therefore, this study evaluates the accuracy and reproducibility of the planned isocenter at a large institution in Kenya to ensure patients receive the prescribed dose and thus avoid toxicity to normal tissues.

CHAPTER TWO

LITERATURE REVIEW

The treatment table, although crucial for patient positioning during radiotherapy, is often overlooked in research and clinical practice. This study aims to address this gap by focusing on both remote couches and manual couches separately, comparing their results to identify any differences or similarities. Furthermore, this chapter will critically review the work of other scholars who have previously explored and assessed the precision and repeatability of couch movements in patient positioning. By examining existing literature, the study will identify any gaps or limitations in the current body of research. This review will help to place the study's findings within the broader context of existing knowledge and contribute to advancing the understanding of couch performance in radiotherapy.

In their study to investigate the patient setup error due to couch rotation error using ExacTrac, Schmidhalter, et al. (2014) utilized a patient positioning system comprising of an infrared system, an X-ray system, and a robotic system 6DoF couch. The study identified set-up errors on the linear accelerator from varian medical systems for the Lateral, longitudinal, and vertical axes as 0.11 ± 1.32 mm, 0.21 ± 1.70 mm, and 0.00 ± 1.54 mm, respectively. Another independent study assessed the automatic couch movement by Li et al. (2009). To replicate a patient mass of 90 kg, the team used a humanoid phantom loaded onto the couch with four steel counterweight bricks. Furthermore, the team made use of an optical tracking device with a camera that was adjusted to the linear accelerator's isocenter. The phantom was moved from the isocenter position on the treatment table using remote automatic table movements with repeated motions of +10mm in each translational direction and repeated the cycle seven times in the left-right (L/R) direction (couch lateral), ten to examine each image to eliminate observer mistakes.

The group used the EPID alignment tool to receive images taken in real times in the anterior-posterior (A/P) direction (couch vertical), and twelve times in the superior-inferior (S/I) direction (couch longitudinal). The average error was 0.16 mm, 0.32 mm, and 0.11 mm in the L/R, A/P, and S/I directions, with a standard deviation of 0.48 mm, 0.30 mm, and 0.12 mm, respectively. Also, Brock et al. (2002) adjusted the couch manually 15 times and automatically 13 times on various patients to compare and contrast the two modes of operation's accuracy and speed. Furthermore, two observers were added before and after changes.

Compared to manual correction, computer-controlled setup adjustment was quicker and marginally more accurate (1.8 mm versus 2.5 mm inaccuracy in adjusted setup). Unfortunately, the study only looked at one area, the pelvic region, and did not consider how accurate the two modes were in other areas, including the head and neck or the thoracic region. The only anterior-posterior pictures obtained allowed the team to determine setup faults, which were also limited to 2D and the left-right and inferior-superior directions. Woo et al. (2002) investigated the automatic couch position reproducibility using the Rando phantom in the head and prostrate regions. Five markers were placed on the Rando phantom and then on the couch in five different locations, each with a marker lined up with the right horizontal room laser crosshair. To test the reproducibility of the couch control function, these five couch positions were repeatedly sequenced nine times.

Furthermore, the group used a human volunteer subject to test the couch reproducibility for three couch positions repeated thrice. For both methods, the researchers found that the reproducibility was less than 0.1cm. In their study, Andreozzi et al. (2021) utilized a truncated cone prototype phantom with a c-arm True Beam linac to validate the coincidence of the radiotherapy and imaging isocenter. They used room lasers to ensure the phantom was within acceptable clinical tolerances. Furthermore, the researchers induced misalignments in the beam isocenter by moving the couch in increments (±1mm to ±10mm) in both the z and x-y directions. The mean difference between the known physical diameter and the optically measured horizontal diameter was then calculated. The x-y misalignment was obtained using the star-shot method on the front face of the cone. The radiotherapy and MRI isocenter exhibited detectable isocenter misalignments of approximately 1mm. However, the study did not simulate a real clinical situation of simultaneously moving the couch in both directions to determine the shift.

More recently, the single-isocenter modality of treating cerebral metastases has gained popularity in providing efficient and effective treatment plans. However, concerns over dosimetry and positioning of the target have posed significant challenges due to off-isocenter shifts. Ono et al. (2022) found that beam-positioning errors increased with couch movements and distance from the isocenter. The Winston-Lutz test was performed at the isocenter for four gantry angles (0°, 90°, 180°, and 270°) while the phantom was electronically placed on the treatment table using a portal imaging system. The phantom offsets were situated at 0, 25, 50, 75, and 100 mm from the isocenter in the superior-inferior, anterior-posterior, and left-right directions. At the isocenter and off-axis sites, 17 patterns of 10 mm^2 square fields resembling multileaf collimators were created for each gantry angle. The accuracy of the beam location was evaluated using couch rotation along the yaw axis (0°, 0.5°, and 1.0°). The mean beam-positioning variations at the isocenter and off-isocenter distances for the couch angles of 0°, 0.5°, and 1.0° were 0.46-0.60, 0.44-0.91, and 0.42-1.11 mm, respectively, while the couch was rotated along the yaw-axis. Moreover, the group discovered that automatic couch movements are more accurate in evaluating beam positioning. The findings were in keeping with the recommendations of the AAPM TG 142 by Klein et.al (2009). However, the study does not specify the body region in focus nor explain the importance of manual couch movements for maneuvering distances greater than 20 centimeters and patients with multiple tumor isocenters.

Another related study was conducted by Wang et al. (2021), where couch position is automatically determined to minimize adverse events in radiation treatment. In this experiment, couch tops with marked center lines are detected by an Eclipse Scripting Application Programming Interface (ESAPI), which is incorporated into the treatment planning system (TPS). Afterward, a code script was used to establish the couch position in both Stereotactic Body Radiation Therapy (SBRT) and External Body Radiation Therapy (EBRT). This data was compared to the couch coordinates established during the early treatment arrangement. Here, the couch tops used showed a mean deviation of one and two centimeters for DoseMax and kVue couches, respectively. The Qfix couch-tops (DoseMax and kVue) provide modern patient positioning and immobilization with minimal deviations from the planning isocenter. As such, the automatic couch tops demonstrate patient setup whose variations are in keeping with the recommendations of the AAMP TG-142. However, the experiment fails to incorporate manual couch tops, let alone use different techniques of radiotherapy (SBRT and EBRT) on different automatic couch tops. As such, data from the study is not feasible for comparative studies.

Similarly, Jursinic et al. (2022) indicate that automatic image analysis is important in yielding precise data for accurate determination of the radiation isocenter and rotation centers of the couch. The study emphasizes the accuracy of automated couch movement due to their adaptability and, consequently, easy reproducibility of the planning isocenter. In addition, the research relies on data from all regions (head, neck, thorax, and pelvic) of the body to increase patient safety by reducing positioning errors. Here, software is used to measure and analyze Winston-Lutz parameters using EPID pictures. The center of a high-density test object is compared to the center of the MLC collimated beam to determine the relative location of the radiation isocenter in space for gantry and couch angulation. In addition, an optical imaging system calculates the target's motion while the couch turns. The findings suggested a tri-axial ellipsoid change in the radiation isocenter due to gantry rotation. As such, the couch's rotational centers and linear accelerator radiation isocenter are precisely determined via image analysis. Therefore, this indicates an agreement in measurement uncertainty in both Winston-Lutz and optical methods. Notably, the study relies significantly on data obtained from methodologies conducted on automatic couches. Although the findings show minor deviations from the AAMP TG-142 recommendations, the lack of manual couch data makes it hard to acknowledge the degree of reproducibility of the planning isocenter using both techniques (manual and automatic setups).

Elsewhere, a study by Kang et al. (2023) sought to establish the efficiency and precision of initial patient arrangement for carcinoma of the breast using the Halcyon system. In this research, Surface-Guided Radiation Therapy (SGRT) was exposed in place of the widely used laser alignment based on topographical markings. An on-site breast phantom was utilized to evaluate the precision of the residual rotational error of the SGRT system after 228 treatment fractions were looked at. The residual translational error was investigated using the couch orientation variation in the vertical, longitudinal, and lateral axes between the reference CT scan and the daily kilo-voltage cone beam computed tomography acquired from the record and verification system. While using an automatically fixed registration between the two pictures based on velocity, the residual rotational error (pitch, yaw, and roll) was also computed. The effectiveness of the routine patient setup for SGRT was assessed using the total setup time, including the initial and imaging times. According to the skin marking method, the average couch position discrepancies for laser alignment were 2.7 ±1.6 mm, 2.0 ±1.2 mm, and 2.1 ±1.0 mm in the vertical, longitudinal, and lateral directions, respectively. The typical variances in the table orientations for SGRT were 1.9±1.2 mm, 2.9±2.1 mm, and 1.9±0.7 mm for the vertical, longitudinal, and lateral directions, respectively. Their research findings stress the importance of automation of couch movements in minimizing rotational errors, therefore increasing the efficiency and precision of the patient arrangement (Baroudi et al., 2023; Kang et al., 2023). Consequently, automatic contouring and effective treatment plans are made possible by incorporating artificial intelligence in couch movements.

Similarly, Knutson et al. (2018) compared datasets obtained from 1D and automated couch movements with 3D water tanks. During radiotherapy, the linear accelerator couch position was moved using an Extensible Markup Language (XML) coded system to establish the phantoms' inline, crossline, and diagonal profiles. Consequently, beam models for commercial treatment planning systems were generated. Compared to the 3DS, 98.7% of the 1DS measured points had a gamma value (2%/2 mm) < 1. The findings suggested that automatic couch motion and 1D scanning tanks produced more accurate beam data than the traditional and manual 3D systems. However, it is crucial to recognize that more cutting-edge, digitized, and integrated applications that link linear accelerators and dosimetry instruments may result in a more repeatable measurement arrangement, potentially reducing the discrepancies currently observed in commissioning due to human error through computerization and improving access for inadequate resource regions to superior commissioning of the sophisticated medical devices used in radiation therapy. Unfortunately, the studies pin pointed above do not provide more data on manual but focus on automatic couch movements, a bias that this research aims to investigate.

CHAPTER THREE

RESEARCH DESIGN

In this chapter, a thorough exploration of the tools, materials, and techniques utilized throughout the study in order to achieve the objectives stated in Chapter 1 section 1.3 is provided. Moreover, a detailed description of the equipment and specialized software utilized is also discussed.

Subsequently, the research site was introduced, providing essential contextual information. This will involve describing the specific location, such as a laboratory, field site, or clinical setting, and elucidating any unique characteristics or considerations associated with the chosen site. By clearly delineating the research site, readers will gain insights into the practical aspects and constraints inherent in the study.

The methodology section is a central component of this chapter, as it elucidated the carefully designed approach implemented to accomplish the research objectives. This included a step-by-step explanation of the experimental design, data collection procedures, and any relevant protocols followed. By presenting a detailed methodology, readers will comprehend the systematic and rigorous process employed to ensure the validity and reliability of the study findings.

3.1. MATERIALS

A variety of materials were used to acquire data. The materials include the Rando phantom, CT scanner, linear accelerator, and the EPID. A brief discussion of the materials is highlighted below.

3.1.1. RANDO phantom

This phantom mimics the human body's anatomical structure, composition, and tissue properties. It is divided into 39 slices and three sections (head and neck, chest and pelvis region). Each slice has holes (see Fig. 3.1) which are plugged with bone-equivalent, soft tissue. The RANDO phantom (see Fig. 3.2) is used as a substitute for a patient.

Figure 3. 1. Assembling of Rando phantom

Figure 3. 2. Rando phantom

3.1.2. Computed Tomography (CT)

The RANDO phantom was imaged using the Siemens Somatom Confidence CT scanner Images from three regions (head and neck, chest, and pelvic region) were scanned and saved to a computer disk (CD) (see Fig.3.3).

Figure 3. 3. Scanned image of RANDO Phantom

3.1.3. Treatment planning software

The software includes features that allow sketching and defining the target volume, as well as calculating the ideal dose distribution while considering the target volume and normal tissue boundaries into account. The program can change parameters including beam angles, beam energy, and beam weights, enabling dosage optimization and visual representations of the dose distribution inside the anatomy of the patient. The target volume of each region was specified in this study using the Oncentra treatment planning program (see Fig. 3.4) which will then assign an isocenter to each tumor. Additionally, a dose calculation algorithm called Collapsed Cone Convolution (CCC) was employed. There are other dose calculation algorithms namely the Pencil Beam algorithm (PB) Monte Carlo algorithm (MC) and Anisotropic

Analytical algorithm (AAA). The PB, MC and AAA dose calculation algorithms were not utilized in this study.

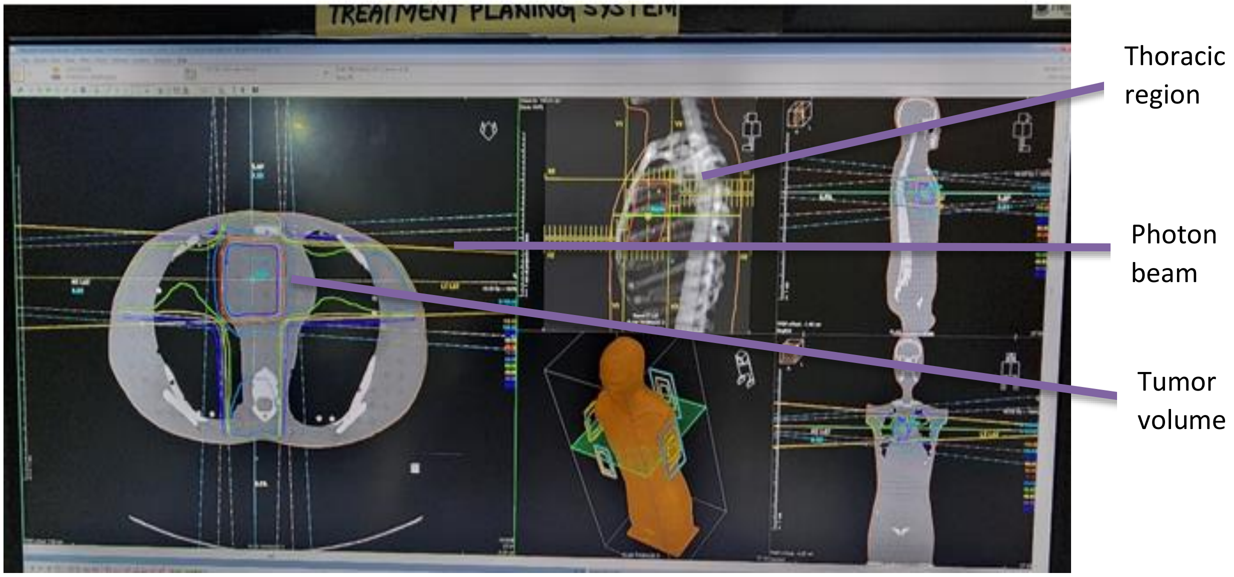

Figure 3. 4. Treatment Planning Software

3.1.4. MOSAIQ

Elekta designed MOSAIQ, a system for managing oncology information. It is utilized to get the treatment plans, dose calculations, and treatment parameters, resulting in accurate and effective treatment delivery.

3.1.5. Treatment machine/linear accelerator

A linear accelerator (see Fig. 3.5) is a medical device used in radiation therapy to deliver high-energy X-rays or electron beams to treat cancerous tumors.

The radiation beams are generated and shaped by a highly developed system that accurately targets and kills cancer cells while causing minimal damage to normal body cells. A linear accelerator Elekta Version S was utilized for this study. This linear accelerator can be configured to a range of photon and electron energies for instance 6MV and 15MV photon energies and 6MeV, 9MeV, 12MeV, and 15MeV electron energies. For this study, 6MV and 15MV photon energies were utilized.

Figure 3. 5. Linear Accelerator

3.1.6. Treatment Table

A specialized table or couch (see Fig 3.6) is designed to assist the patient during radiation therapy treatment. It is also referred to as a treatment table. It enables accurate patient placement, supports immobilization devices, allows radiation beam access, and helps the stability and reproducibility of therapy delivery. The iBEAM evo couch (see Fig 3.7) that can be adjusted manually or with the help of the Table ASU in three different dimensions (vertically, horizontally, and longitudinally) was used. The iBEAM evo couch top that consists two thin carbon fiber plates, 2 mm thick, sandwiching 46 mm of foam. The thicker part of the couch measures 200× 53 ×5cm^3 while the thinner part measures 41.5 × 53 × 2cm$^{3.}$ It ensures that the patient is positioned in the same way as during the simulation to treat the appropriate volume.

Figure 3. 6. Treatment couch

Figure 3. 7. A closer view of the iBEAM evo Couch

3.1.7. Electronic portal imaging device (EPID)

To verify radiation therapy treatment, the EPID offers high-quality imaging capabilities. In order for clinicians to compare the actual treatment position with the intended position, they record X-ray images of the patient either before or during treatment. This permits changes to ensure accurate radiation delivery and aids in identifying any differences or shifts. Amorphous silicon electronic portal imaging device (a-Si EPID) Elekta iViewGT (see Fig. 3.8 and Fig. 3.9) was used for this study.

Figure 3. 8. Closer view of the EPID

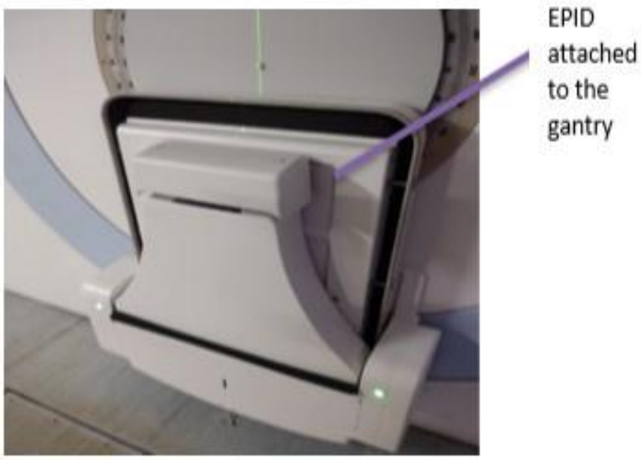

Figure 3. 9. Electronic portal imaging device

3.2 SITE OF THE STUDY

To ensure the study's findings reflect real-world scenarios, the research was conducted within a clinical setting, specifically a hospital. This allowed for a comprehensive understanding of the practical challenges and circumstances that may arise during the treatment process. By conducting the study in a hospital environment, the results obtained will apply to the experiences faced by healthcare practitioners and patients in their day-to-day interactions.

3.3. METHODOLOGY

The discussion that follows highlights the steps that were followed to obtain the results. The steps for obtaining results using the automatic couch movement are outlined first and thereafter the manual couch movement will be discussed. The RANDO phantom, which combines the slices from the head and shoulder, chest, and pelvis phantoms was assembled as shown in (see Fig 3.1). for scanning purposes, the slices are connected by pins through holes. On the CT simulation table, the phantom was placed, and the reference points together with the external lasers (see Fig 3.10) were used to help precisely position and localize the treatment area.

In each region (head and neck, thorax and pelvic) reference marks using radio-opaque markers were made. These markers usually aid in accurately and consistently positioning the phantom throughout each treatment session. The imaging technique for each treatment site (region of interest) was followed to capture images of each region. The obtained scans were then exported through the DICOM system and imported into the treatment planning.

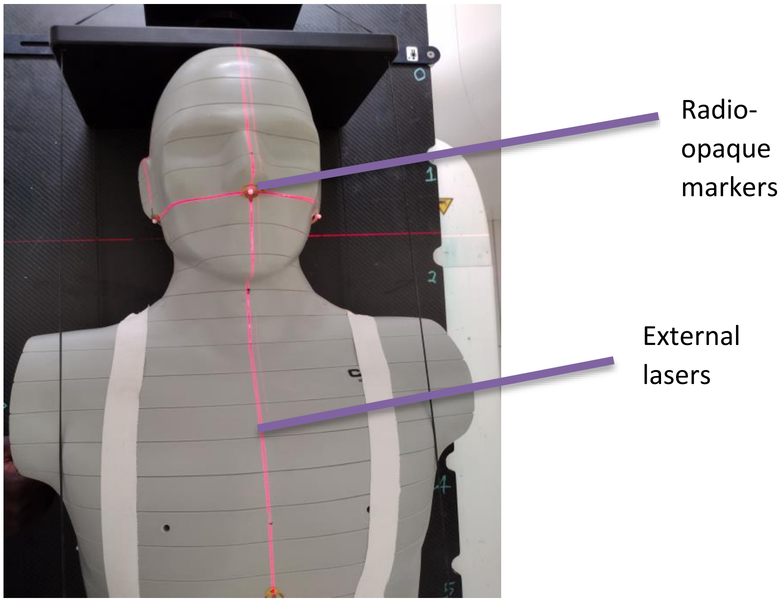

Figure 3. 10. RANDO phantom on CT table

Using the Oncentra Treatment Planning System (TPS) program, a target volume was identified and indicated in red during the second step of treatment planning. Each case was thereafter prescribed a total radiation dosage of 50 Grays throughout 25 fractions, with the dose normalized to the center of the tumor. Radiotherapy doses typically ranges from 45 Grays up to 70 Grays or slightly higher depending on the modality. Four photon energy beams (see Fig.3.11) that is anterior, posterior and two opposing with equal beam weighting were assigned for the thoracic region, while three beams that is two lateral and an anterior beam were assigned for the head and neck regions.

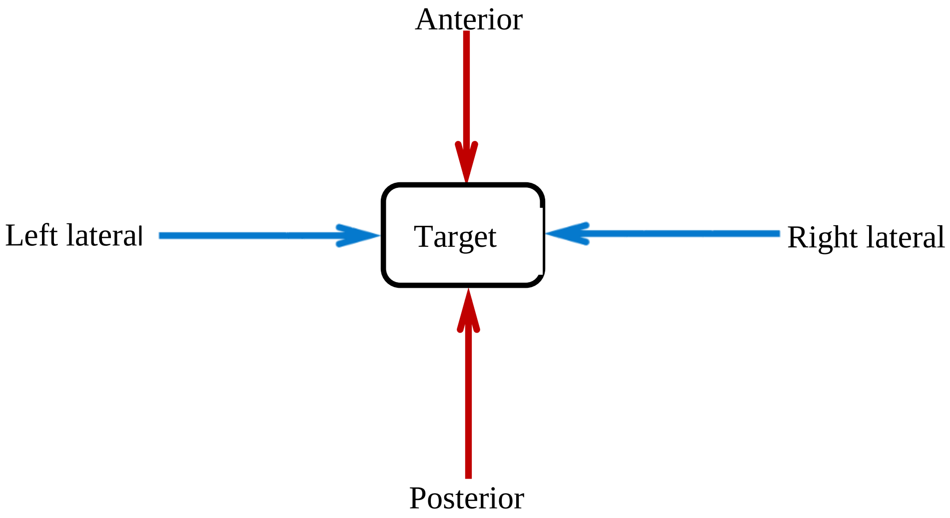

Figure 3. 11. Radiation beams

In addition, the pelvic region utilized a four-box technique. An isocenter was set for each case in relation to the position of the radio-opaque markers and a calculation was done using the Collapsed Cone Convolution algorithm. For portal imaging, setup beams were assigned, one for the anterior and the other for the lateral positions.

After that, MOSAIQ, which helps with therapy delivery, receives the parameters of the treatment plan. MOSAIQ records information such as the phantom radiotherapy number, the diagnosis, the total dosage and fractions, the gantry angle, energy, and monitor units. Once the therapy delivery process is complete the phantom is placed on the treatment couch. The phantom was positioned one region at a time and aligned using the lasers and the markers placed during the simulation process. The table was then moved to the tumor isocentre using a command employing Table ASU (which simultaneously moves the couch in three directions), and the EPID is utilized to picture the precise position of the phantom as shown in Fig 3.12. The open field option in the EPID was used to calculate the degree of misalignment (offsets) from the planned isocentre and the results obtained were used to check the accuracy of the isocentre coordinates.

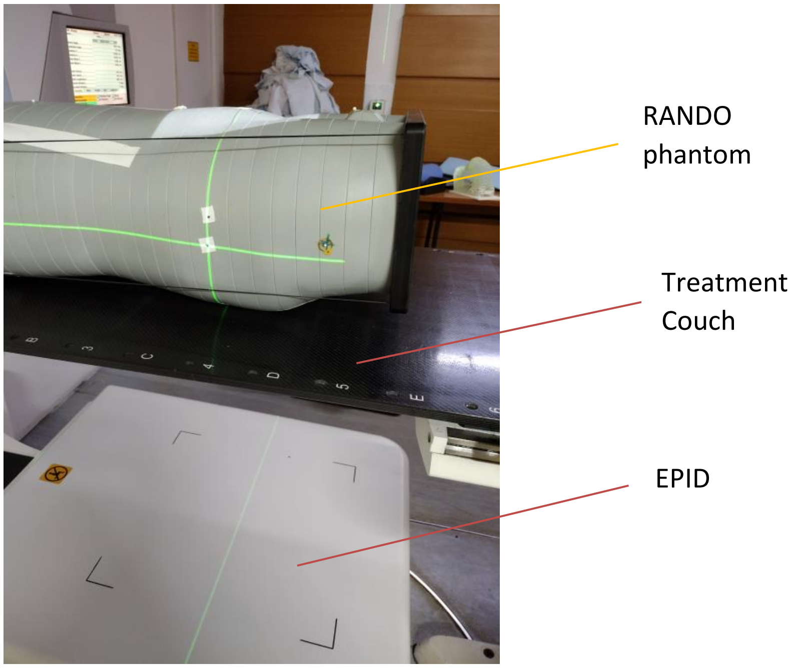

Figure 3. 12. The EPID Set up

The final mechanism involved moving the couch manually. In this procedure, the same steps discussed above were repeated to acquire the results for each region of interest, but this time the table was manually moved by using the table control to move it to the same isocenter. The current phantom position imaging is carried out in each of the three locations, and 10 sets s of data were gathered for each couch movement in each region, yielding a total of 60 readings. Finally, the results obtained for both couch movement were compared for the isocentre's accuracy and reproducibility in each region.

3.4. STATISTICAL ANALYSIS OF DATA

A total of sixty readings for the three specific regions were acquired. For each region, ten readings were obtained for every movement of the treatment couch. These readings provided valuable data to evaluate the precision and consistency of the couch motions in reproducing the intended isocentre accurately. To analyze the data collected and determine the accuracy of the treatment planning isocentre, Microsoft Excel was employed as a valuable tool. By using Excel any inconsistencies between the intended isocentre and the treatment isocentre were identified which enabled a comprehensive evaluation of the two couch movement mechanisms. This analysis helped to determine whether the observed inconsistencies fall within permissible limits or if they exceed the expected tolerances. Furthermore, the most precise couch movement within each of the three regions was identified during treatment delivery since it provided valuable guidance for optimizing patient setup procedures.

CHAPTER FOUR

RESULTS AND DATA ANALYSIS

This Chapter presents data obtained after following the steps highlighted in Chapter 3 Section 3.3 and Section 3.4 for both couch movements. The discrepancies in isocenter movement as a result of both couch movements were recorded for the three regions (head and neck, thoracic, and Pelvic). Furthermore, the offsets were analyzed to check whether they conformed to the AAPM TG-142 protocol by Klein et.al (2009). Lastly, the accuracy of both couch movements (automatic and manual) was evaluated based on the shifts from the isocenter.

4.1. SHIFTS

In order to establish the shifts for every patient that have occurred the coordinates for the three regions (head and neck, thoracic, and pelvic) were set some distance away from the origin (0, 0,0) as presented in Table 4.1 below in order to target the tumor isocenter as established by the treatment planning system.

Table 4.1. Coordinates set for the planned isocenter.

Isocenter coordinates	Head and neck region	Thoracic region	Pelvic region
X(cm)	-0.02	1.46	-0.2
Y(cm)	-7.2	-7.67	-13.28
Z(cm)	0.18	-4.85	-1.7

For the head and neck region, an anterior beam and two laterals i.e., right lateral and left lateral beams (see Fig 3.11) were used and the results obtained are shown in (Table 4.2 below)

Table 4.2. Head and Neck region shifts recorded.

Planned isocenter (TPS) coordinates			**Automatic couch movement(shifts)**			**Manual couch movement(shifts)**		
X (table lateral)	Y (table longitudinal)	Z (table vertical)	X(cm)	Y(cm)	Z(cm)	X(cm)	Y(cm)	Z(cm)
0.02	7.2	-0.18	0.1	0	0.2	0.1	0.1	0.3
0.02	7.2	-0.18	0.1	0	0.1	0.1	0	0.2
0.02	7.2	-0.18	0.2	0	0.2	0.2	0.1	0.2
0.02	7.2	-0.18	0.3	0.1	0.2	0.1	0	0.3
0.02	7.2	-0.18	0.1	0	0.3	0.2	0	0.2
0.02	7.2	-0.18	0.2	0	0.3	0.1	0	0.2
0.02	7.2	-0.18	0.1	0	0.3	0.1	0.1	0.3
0.02	7.2	-0.18	0.2	0.1	0.3	0.2	0.1	0.3
0.02	7.2	-0.18	0.4	0.1	0.2	0.2	0	0.1
0.02	7.2	-0.18	0.2	0.1	0.3	0.2	0.1	0.2

A four –field beam (box) technique (see Fig.3.11) was utilized for the thoracic region. The shifts recorded are presented in Table 4.3.

Table 4.3. Thoracic region shifts recorded.

Planned isocenter (TPS) coordinates			**Automatic couch movement(shifts)**			**Manual couch movement(shifts)**		
X (table lateral)	Y (table longitudinal	Z (table vertical)	X(cm)	Y(cm)	Z(cm)	X(cm)	Y(cm)	Z(cm)
-1.46	7.67	4.85	0.1	0.2	2.6	0.3	2.9	2.1
-1.46	7.67	4.85	0.1	3	2.2	0.2	2.3	0.3
-1.46	7.67	4.85	0.3	4.2	4.1	0.2	2.9	2.1
-1.46	7.67	4.85	0.7	4.5	3.6	0.6	4.6	3.5
-1.46	7.67	4.85	0.3	2.9	2.1	0.3	2.8	1.6
-1.46	7.67	4.85	0.9	3.8	0.2	0.1	3	1.7
-1.46	7.67	4.85	0.2	2.8	1.6	0.1	2.3	0.3
-1.46	7.67	4.85	0.3	2.9	1.9	0.2	5	4.6
-1.46	7.67	4.85	0.3	3	1.4	0.3	2.1	1.5
-1.46	7.67	4.85	0.2	2.9	1.4	0.4	4.2	3.5

A four-field beam (box) technique was employed for the pelvic region and the outcomes are displayed in Table 4.4 below.

Table 4.4. Pelvic region shifts recorded.

Planned isocenter (TPS) coordinates			**Automatic couch movement(shifts)**			**Manual couch movement(shifts)**		
X (table lateral)	Y (table longitudinal)	Z (table vertical)	X(cm)	Y(cm)	Z(cm)	X(cm)	Y(cm)	Z(cm)
-0.2	13.28	1.7	0.1	0	0.9	0	0	0.6
-0.2	13.28	1.7	0.2	0	0.2	0	0	0.6
-0.2	13.28	1.7	0.2	0	0.4	0.4	0.1	0.4
-0.2	13.28	1.7	0.1	0	0.5	0.2	0.2	0.4
-0.2	13.28	1.7	0.1	0.1	0.4	0.1	0.1	0.7
-0.2	13.28	1.7	0.1	0	0.7	0.1	0	0.7
-0.2	13.28	1.7	0	0	0.4	0	0	0.6
-0.2	13.28	1.7	0	0.1	0.5	0	0.1	0.5
-0.2	13.28	1.7	0	0	0.5	0	0.1	0.6
-0.2	13.28	1.7	0.1	0	0.5	0	0.1	0.5

4.2. DISCREPANCIES IN ISOCENTER MOVEMENTS

The distance between the planned isocentre, P, and the treatment isocentres of the three body regions using both automatic and manual methods were calculated and recorded in Table 4.5. First, to analyze the discrepancies in the isocenter shifts as a result of automatic and manual couch movements, the distance between the planned isocenter and the new isocenter as a result of couch motion was determined. Note that the planned isocenter was used as the point of reference from where all deviations were calculated. The automatic and manual systems determined the new treatment isocenter and the data was used to calculate the individual shifts in all three planes.

However, the shifts provided by the system could not be used to evaluate the reproducibility of the planned isocenter which is a point in a three-dimensional space as opposed to the provided individual shifts in the X, Y, and Z axes. Therefore, to get the distance between any two points in space, equation (4.1) was applied using MS Excel.

$$D= \sqrt{x^2 + y^2 + z^2} \quad \ldots\ldots\ldots\ldots \quad (4.1)$$

For instance, given two points that is the planned isocenter, P(x,y,z) and automatic isocenter, A(x,y,z), the distance between the two would be

$$D= \sqrt{(x_A - x_P)^2 + (y_A - y_P)^2 + (z_A - z_P)^2} \ldots\ldots\ldots\ldots \quad (4.2)$$

where subscript A and P indicate coordinates of Automatic couch movements and planned isocenter respectively. However, since the planned isocenter is the point of reference from where all the shifts in the X, Y, and Z planes were calculated, it is considered as point P (0, 0, 0). It is worth noting that if the shifts in the three planes were calculated from point zero of the Cartesian plane, then the planned isocenter would have not been the point reference and consequently not point P (0, 0, 0). Since the point of reference in this study is considered P (0, 0, 0), then all the coordinates with the subscript P will equal zero simplifying equation (4.2) into equation (4.1), where all the coordinates refer to the individual shifts automatic couch movements. Therefore, the same equation (4.1) was applied to determine the distance between the planned isocenter and the new treatment isocenter as a result of manual couch movements. Finally, the data are presented as shown in Table 4.5. as well as cluster column charts (see Fig 4.1,4.2 and 4.3) to provide a side-by-side comparison of the two movement techniques for the head and neck, thoracic, and Pelvic regions.

Table 4.5. The distance between planned isocenter and the treatment isocenter

Distance: Head and Neck region	
Automatic (cm)	Manual (cm)
0.22	0.33
0.14	0.22
0.28	0.30
0.37	0.32
0.32	0.28
0.36	0.22
0.32	0.33
0.37	0.37
0.46	0.22
0.37	0.30

Distance: Thoracic region	
Automatic (cm)	Manual (cm)
2.61	3.59
3.72	2.33
5.88	3.59
5.81	5.81
3.59	3.24
3.91	3.45
3.23	2.32
3.48	6.80
3.32	2.60
3.23	5.48

Distance: Pelvic region	
Automatic (cm)	Manual (cm)
0.91	0.60
0.28	0.60
0.45	0.57
0.51	0.49
0.42	0.71
0.71	0.71
0.40	0.60
0.51	0.51
0.50	0.61
0.51	0.51

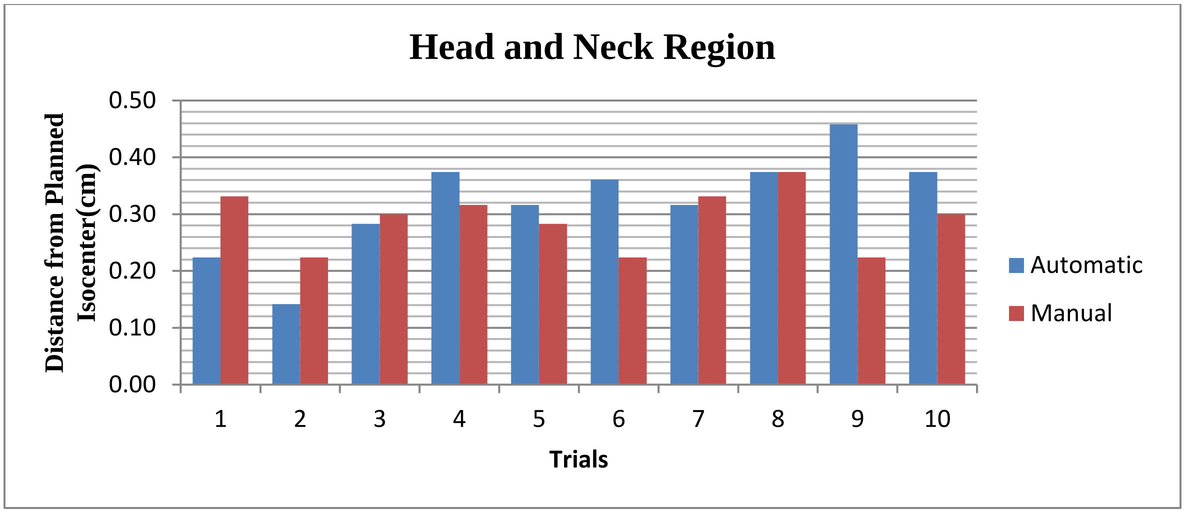

Figure 4. 1. Comparison of the distance from planned isocenter of the Head and Neck region using the two couch movements

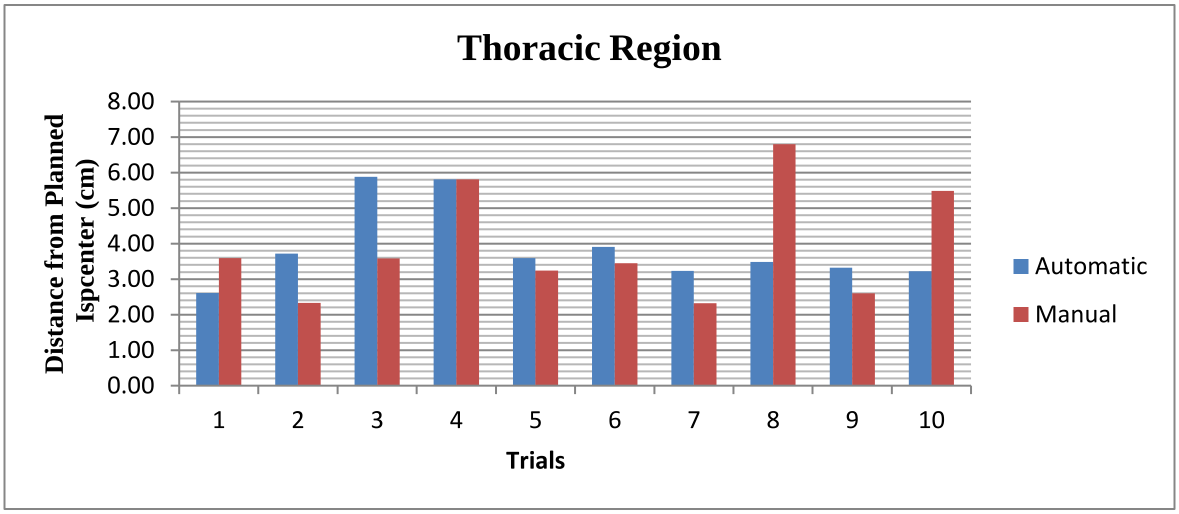

Figure 4. 2. Comparison of the distance from planned isocenter of the Thoracic region using the two couch movements

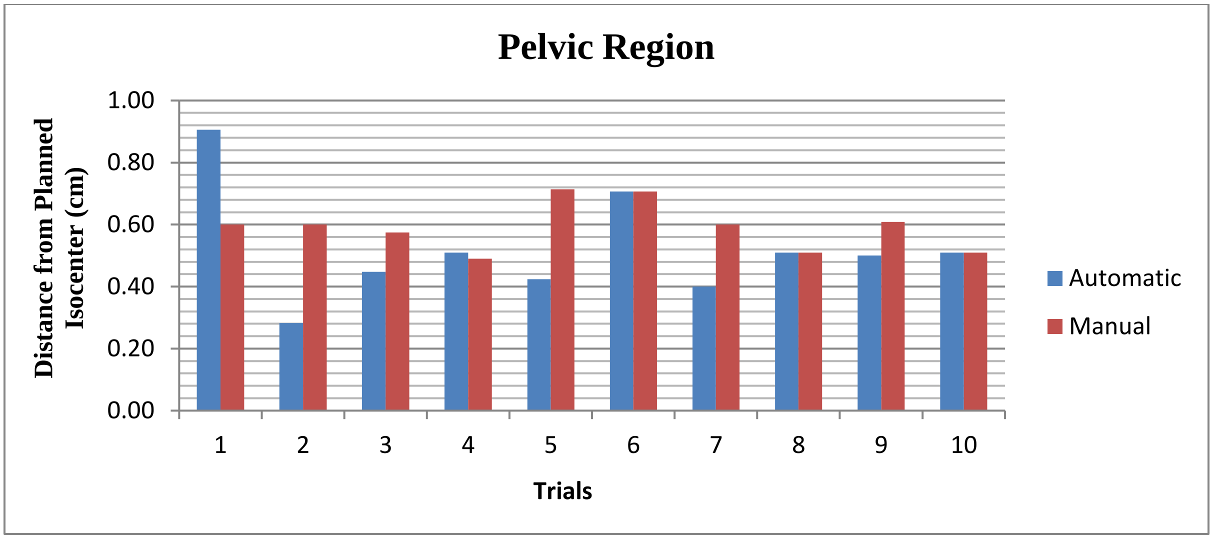

Figure 4. 3. Comparison of the distance from the planned isocenter of the pelvic region using the two couch movements

4.3. CONFORMITY OF THE MANUAL AND AUTOMATIC COUCH MOVEMENTS TO AAPM TG-142 PROTOCOL

According to the AAPM TG-42 by Klein et.al (2009), protocol a tolerance ± 0.2cm is acceptable from the planned isocenter in order to optimize treatment outcomes while minimizing cytotoxicity to normal body tissue.

To check whether the shifts determined are in agreement with the AAPM TG-142 by Klein et.al (2009) protocol, a percentage was computed using the Microsoft Excel function defined by equation (4.3)

= (COUNTIF(Range,"≤0.2")/COUNT(Range)) *100………………………………. (4.3)

Where Range refers to the cells containing the shifts in the X, Y, and Y axes for both automatic and manual couch movements. This function was utilized in calculating the percentages for the head and neck, thoracic, and Pelvic regions. The less than or equal to criteria for the COUNTIF function was represented as "≤0.2", where 0.2 refers to the tolerance limit in centimeters. The COUNTIF function gives the number of cells that have met the criteria and the COUNT function returns the total number of cells within the specified range. Therefore, multiplying the quotient of COUNTIF and COUNT functions with hundred will give the percentage of cells that have met the tolerance limit of ± 0.2 cm; the percentage of the shifts that are within the acceptable limit of ±0.2 cm.

In addition, a conditional formatting function was used to visualize and highlight data that was inconsistent with the 0.2 cm tolerance limit. The conditional formatting style with cell rule, greater than 0.2 was applied to all regions for both automatic and manual couch movements. The formatting technique highlighted cells that contained values greater than 0.2 in red, as shown in Appendices I, II, and III.

The percentages obtained are recorded in Table 4.6 below. It was noted that more than half of shifts were within the tolerance limit in all three regions of the body.

Table 4.6. Shift Tolerances percentages for the regions

Region	**Automatic**	**Manual**
Head and Neck	77%	87%
Thoracic	20%	17%
Pelvic	70%	63%
Average	**56%**	**56%**

4.4. THE ACCURACY OF BOTH SYSTEMS BASED ON SHIFTS FROM THE PLANNED ISOCENTER

Using the mean shifts, the accuracy of both the automatic and manual couch movements was evaluated and recorded. The average distances in the three regions are shown in Table 4.7.

Table 4.7. Average distances for the three regions using both couch movement mechanisms.

Regions	**Automatic(cm)**	**Manual(cm)**
Head and Neck Region	0.32	0.29
Thoracic Region	3.88	3.92
Pelvic Region	0.52	0.59
Average distances of the regions	**1.57**	**1.60**

The mean distances were plotted on a column chart and the following were the results for both the regional and mean deviations.

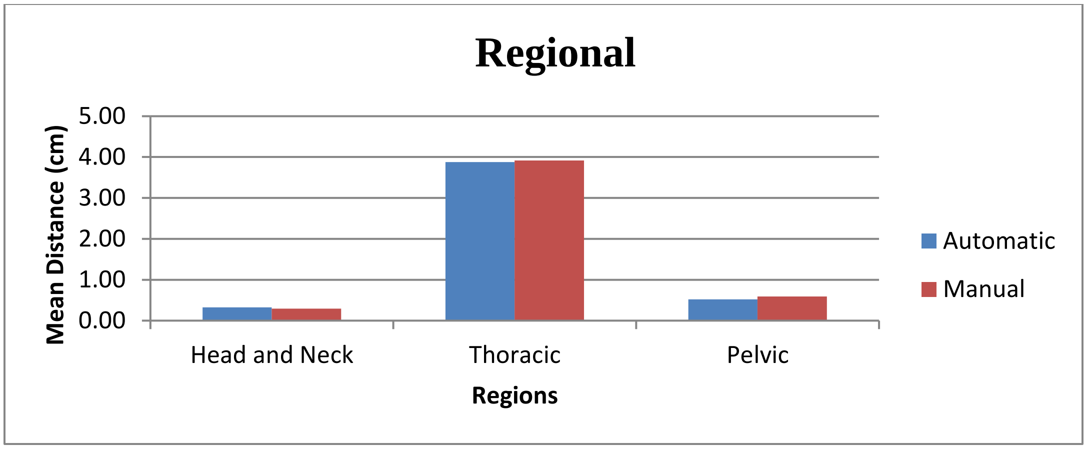

Figure 4. 4. Mean distances for all regions

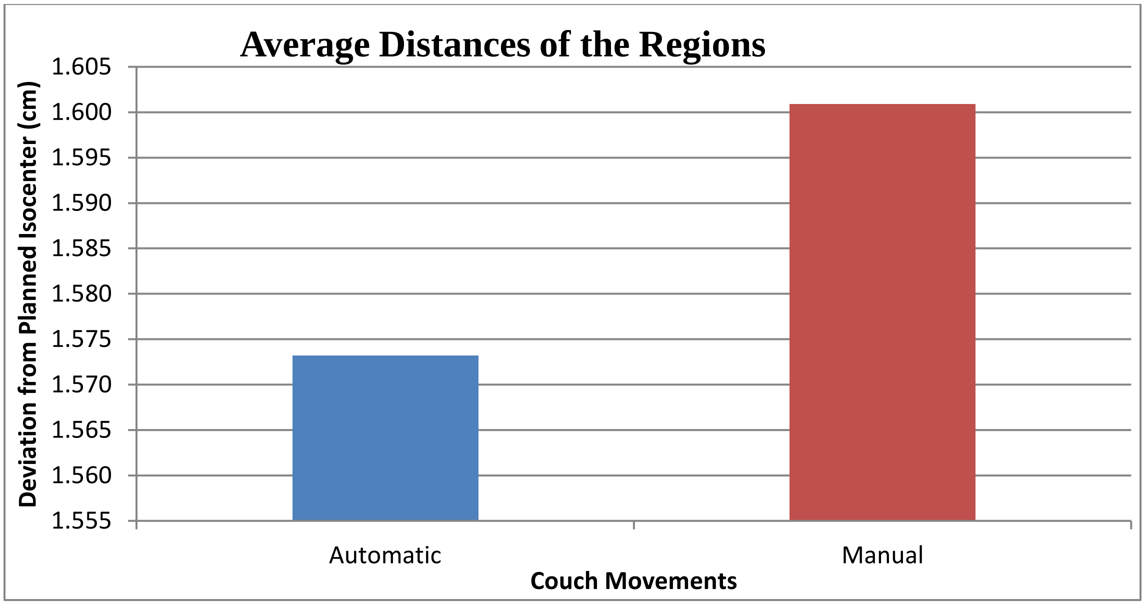

Figure 4. 5. Mean deviations for both couch movements

CHAPTER FIVE

DISCUSSION

5.1. DISCREPANCIES

To determine if there were any discrepancies in reproducing the planned isocenter, distances between the treatment and the planned isocenters were calculated as described in Chapter 4, section 4.1. The distances give a more reliable and three-dimensional evaluation of the accuracy of the two couch movement systems as opposed to the shifts in coordinates recorded in tables 4.2, 4, 3, and 4.4. Therefore, when the treatment isocenters are displaced by a small distance, they are considered more accurate as opposed to isocenters that are displaced by relatively large distances. Here, the study utilized the shifts in coordinates to determine the displacement using equation (4.1) highlighted in Chapter 4, section 4.1.

For the head and neck regions, the discrepancies show variability in different patients/subjects in one and between both couch movements. As such, this indicates that other than the couch movement mechanism employed, other factors such as accurate patient positioning play a critical role in the accurate reproducibility of the planned isocenter. The same pattern of variability is reflected across all regions and between the two couch movement mechanisms. From Table 4.5, the patient pair number two results under the head and neck indicate the least discrepancies for both automatic and manual couch movements. Conversely, the thoracic region of the third patient indicates the highest discrepancy in automatic couch movements. Similarly, the sixth patient’s thoracic region displays the greatest isocenter shift for manual couch movements. Generally, the thoracic region showed the greatest shift from the tumor isocenter. As a result, the thoracic region is more likely to experience normal cell cytotoxicity as compared to the other two regions.

These study findings are in agreement with the findings of Ono et al. (2022) and Kang et al. (2023) that correlate the accuracy of the mode of couch movements with the accuracy of reproducibility of the planning isocenter. As a result of this study findings, it implies that a precise positioning system leads to less shift of the treatment from the planned isocenter.

5.2. TOLERANCES

According to the AAPM TG-142 by Klein et.al (2009), protocol, the recommended tolerance limits for the shifts in coordinates ought to be within ± 0.2 cm since the group established that deviations of more than 0.2 cm can cause errors of up to 2% at clinically significant depths. It is therefore vital to ensure optimum outcomes while minimizing normal tissue damage as such, the various shifts can be used to determine which mechanism of couch movements has less adverse effects on normal cells. However, these shifts can only be used to infer but not definitively ascertain the least cytotoxic modality. This is because the coordinates cannot pinpoint the tumor isocenter when applied in isolation from the other two planes. To illustrate this, an X-axis value cannot be plotted alone to realize a point in the three-dimensional space but needs both Y and Z axes values to establish that. Furthermore, a small and large X-axis shift does not necessarily indicate accuracy to the smallest shift. This is because, despite small shifts in the X-axis, the Y and Z-axis shifts are required to establish a point in the three-dimensional space. In a case where the shifts in the Y and Z axes are relatively bigger, the small shift in the X axis will not translate to a small shift from the planned isocenter.

Using the AAPM TG-142 by Klein et.al (2009), recommendation, the results obtained (see Table 4.4.) indicate varying tolerances in all regions when both manual and automatic couch movements are utilized. Here, the shifts were inspected if they were within the tolerance limits and the percentage of those that were within the tolerance limit was calculated and recorded (See

Table 4.6.) The manual couch movements for the head and neck region indicated the highest tolerance while the thoracic region indicated the least tolerance at seventeen percent (see Table 4.6.) Generally, the thoracic region returned the least mean percentage of tolerance of about 18 % for both movement mechanisms whereas the head and neck region had the highest percentage of about 80% as displayed in Table 4.6. Even though the tolerances vary across all the regions and between the two couch movement mechanisms~~,~~ the average tolerance for both manual and automatic couch movements was found to be about fifty-six percent as shown in Table 4.6. Therefore, from these findings it can be implied that no particular method of couch movement is superior to the other in reproducing shifts within the tolerance limit suggested by the AAMP TG-142. In general, the z- coordinates recorded the highest shift, with nearly all of the shifts outside of tolerance in all three regions, perhaps due to geometric faults in the equipment or the calculation in that direction, however this is an issue that cannot be proven.

The findings of this study are congruent with the findings of Li et al. (2009) which also indicate variability in tolerance during radiotherapy. Moreover, the pelvic region findings agree with Brock et al. (2002) who specify a higher tolerance for automatic than manual couch movements. However, this research findings show significant divergence from the findings of Schmidhalter et al. (2014), Andreozzi et al. (2021), and Wang et al. (2021), which indicate an almost one hundred percent tolerance when using the automatic couch movements. On the other hand, this study reveals a fifty-six percent tolerance for automatic couch movements. Given that both automatic and manual methods have the same percentage tolerance (see table 4.6.) this probably suggests that both couch movement mechanisms have significant discrepancies regarding the planned isocenter, therefore, it is necessary to find ways of minimizing such discrepancies to avoid undesirable cytotoxic effects of radiotherapy.

5.3. ACCURACY AND REPRODUCIBILITY

In order to compute the mean distances or deviations equation 4.1 was used and the results obtained are displayed by Table 4.5 and summarized in Table 4.7. In addition, charts showing the mean distances or deviations are depicted as shown by Fig4.5. Note that the deviations were calculated from the planned isocenter so that the accuracy and reproducibility of both couch movement mechanisms are evaluated.

The results indicated the lowest deviation in manual couch movements for the head and neck region. Conversely, the highest deviation was recorded at the thoracic region during manual couch movements. This could be that the thoracic region is susceptible to causing normal tissue injury for both automatic and manual couch movements.

The mean deviations (see table 4.7.) indicated that the automatic couch movements were slightly more accurate than manual couch movements. From the results obtained it implies that the automatic couch movements are less likely to cause undesirable tissue radiation cytotoxicity. Notably, the difference in mean deviations between the automatic and manual techniques might be small (<0.1 cm) but the impact on the outcome might not necessarily be commensurate. Most likely, the impact might be significant since a small deviation from the tumor isocenter can lead to normal tissue destruction.

The findings are in agreement with Ono et al. (2022) and Jursinic *et al*. (2022), with regard to automatic couch movement's superiority. Consequently, such accuracy in positioning resulted in fewer deviations of planned isocenter during the treatment period. The lesser the deviation from the planned isocenter, the more the tumor is irradiated with the optimum dose and the lesser the cytotoxic effects. Likewise, the former authors suggested that automated couch movements are accurate and adaptable in reproducing the planned isocenter.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The present study has evaluated the accuracy of the reproducibility of the planned isocenter using automatic and manual couch movements. In addition, the study recorded differences in planned isocenter when using both couch movements. The mean differences in isocenters for the head and neck region were; 0.19 cm, 0.04 cm and 0.24 cm in x, y z directions respectively for automatic couch movement and 0.15 cm, 0.05 cm and 0.2 cm for manual couch movements. For the thoracic region, the differences were; 0.34 cm, 3.02 cm and 2.11 cm in the x, y and z directions respectively in the automatic couch movement while 0.27 cm, 3.21 cm and 2.12 cm in the x, y and z directions respectively for the manual couch movement. On the other hand, the discrepancies in the pelvic region were 0.09 cm, 0.02 cm and 0.5 cm in the x, y and z directions respectively for the automatic couch and 0.08 cm, 0.07 cm and 0.56 cm in the x, y and z directions for the manual couch movement.

According to the AAPM TG-142 by Klein et.al (2009), protocol which states that the shifts tolerance should be within ± 0.2 cm to ensure optimum outcomes while minimizing normal tissue damage, the present study determined the tolerance for the head and neck, pelvic and thoracic regions. Only 77%, 20% and 70% of the shifts were within the acceptable limits for automatic couch movement and 87%, 17% and 63 % for manual couch movement respectively (see table 4.6.)

The present research has compared the accuracy of both manual and automatic couch movements (see table 4.7. and fig. 4.5.) by incorporating three regions of the body namely the head and neck, pelvic and thoracic regions as opposed to most studies found in the literature that focus on one region of the body. The average distance from the planned isocenter was 1.57 cm for the automatic couch while that of the manual couch was 1.60 cm. From the findings positioning, using the automatic couch movements mechanism is more accurate compared to the manual couch movements mechanism in reproducing the planned isocenter. The results obtained from the present study could potentially influence clinical practices and guidelines in the use of couch movements during treatment planning.

The present study has provided valuable insights into the use of automatic and manual couch movements in treatment planning, paving the way for more efficient and accurate practices in the field across different settings and populations.

6.2 RECOMMENDATIONS

From the present study a few challenges were experienced which will need future attention. The present study records a relatively high shift from the planned isocenter for the thoracic region, it will be vital to conduct further research to investigate and understand the cause of the high shift.

Note that understanding why the thoracic regions returned such results would play a critical role in optimizing care for patients since the radiotherapists would strive to adopt techniques that reduce the offsets. Since current radiotherapy techniques require minimal patient movements while delivering the dosage, it is critical to find a solution to the thoracic region that is in constant respiratory movements during radiotherapy.

Last but not least an investigation of the effect of changes in deviation and cellular cytotoxicity should be carried out. This would help predict the severity of the toxic effects of radiotherapy, thus helping to minimize them. Furthermore, this will help radiotherapists in making critical decisions when deciding on which mode of couch movements to use to optimize the outcomes.

Future studies could also explore other factors that may influence the accuracy of couch movements.

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APPENDICES

Appendix I. Tolerances for the head and neck region

Automatic couch movement(shifts)			**Manual couch movement(shifts)**		
X(cm)	Y(cm)	Z(cm)	X(cm)	Y(cm)	Z(cm)
0.1	0	0.2	0.1	0.1	**0.3**
0.1	0	0.1	0.1	0	0.2
0.2	0	0.2	0.2	0.1	0.2
0.3	0.1	0.2	0.1	0	**0.3**
0.1	0	**0.3**	0.2	0	0.2
0.2	0	**0.3**	0.1	0	0.2
0.1	0	**0.3**	0.1	0.1	**0.3**
0.2	0.1	**0.3**	0.2	0.1	**0.3**
0.4	0.1	0.2	0.2	0	0.1
0.2	0.1	**0.3**	0.2	0.1	0.2
0.19	0.04	**0.24**	0.15	0.05	0.23

Appendix II. Tolerances for the thoracic region

Automatic couch movement(shifts)			Manual couch movement(shifts)		
X(cm)	Y(cm)	Z(cm)	X(cm)	Y(cm)	Z(cm)
0.1	0.2	2.6	0.3	2.9	2.1
0.1	3	2.2	0.2	2.3	0.3
0.3	4.2	4.1	0.2	2.9	2.1
0.7	4.5	3.6	0.6	4.6	3.5
0.3	2.9	2.1	0.3	2.8	1.6
0.9	3.8	0.2	0.1	3	1.7
0.2	2.8	1.6	0.1	2.3	0.3
0.3	2.9	1.9	0.2	5	4.6
0.3	3	1.4	0.3	2.1	1.5
0.2	2.9	1.4	0.4	4.2	3.5
0.34	3.02	2.11	0.27	3.21	2.12

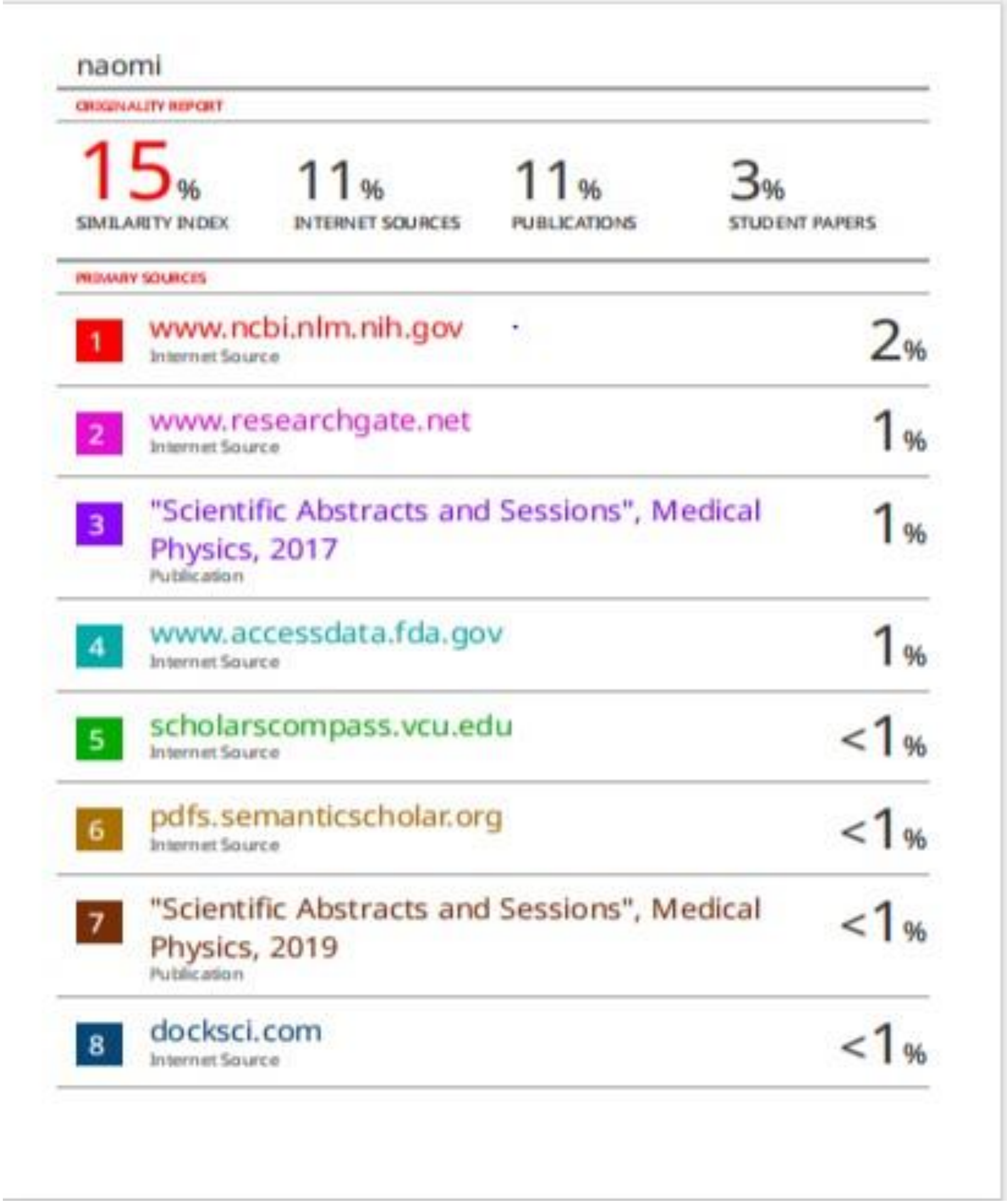
Appendix III. Tolerances for the pelvic region

Automatic couch movement(shifts)			**Manual couch movement(shifts)**		
X(cm)	Y(cm)	Z(cm)	X(cm)	Y(cm)	Z(cm)
0.1	0	**0.9**	0	0	**0.6**
0.2	0	0.2	0	0	**0.6**
0.2	0	**0.4**	**0.4**	0.1	**0.4**
0.1	0	**0.5**	0.2	0.2	**0.4**
0.1	0.1	**0.4**	0.1	0.1	**0.7**
0.1	0	**0.7**	0.1	0	**0.7**
0	0	**0.4**	0	0	**0.6**
0	0.1	**0.5**	0	0.1	**0.5**
0	0	**0.5**	0	0.1	**0.6**
0.1	0	**0.5**	0	0.1	**0.5**
0.09	0.02	**0.5**	0.08	0.07	**0.56**

Appendix IV. MOSAIQ

MOSAIQ is a multifaceted, integrated software suite that serves as a comprehensive electronic oncology management system for medical and radiation oncology facilities. MOSAIQ offers image-enabled electronic patient charting and record management, as well as medical transcribing and billing capability, to both medical and radiation oncology customers. It also offers the ability to import and export radiation treatment plan information, plan multileaf collimator (MLC) forms, and check and record treatment setup and delivery for radiation oncology users.

Appendix V. Plagiarism report



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