VALIDATION OF MARGINS FROM SETUP ERRORS IN HEAD AND NECK RADIOTHERAPY.

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DECLARATION:

I declare that "Validation of Margins from Setup Errors in Head and Neck Radiotherapy" thesis is my own work and that all sources that I have used or quoted have been indicated and acknowledged by means of complete references. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

Ethics clearance for this study was granted by the University of the Witwatersrand Human Research Ethics Committee (Medical) on 07/10/2015. The clearance certificate number is M150706.

(Signature of candidate)

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ABSTRACT:

Aim:

The aim of this study was to quantify random and systematic setup errors in a population of head and neck cancer patients for the purposes of evaluating departmental positioning and immobilization techniques, verification and treatment protocols, as well as validating the treatment margins used.

Methods and Materials:

All patients had more than one phase of radiation, each consisting of different megavoltage photon field arrangements. Some phases were also treated with electron fields in addition to the photon fields. Random and systematic setup errors in all three principal directions were calculated for two groups of patients, using record and verify system couch position data. For one group (20 patients) the positioning and immobilization device system was mechanically localized to the treatment couch, and for the other group (38 patients), it was visually centered on the treatment couch. Within both groups of patients, the patient position was either verified online with portal imaging or verified offline on a conventional radiotherapy simulator.

Results:

For the patient group treated with the base plate visually centered on the treatment table the population random and systematic setup errors calculated for the photon fields were only indicative of setup uncertainties in the anterior-posterior direction. For the patient group treated with the base plate localized to the treatment couch, the population random and systematic setup errors were found to be within the 5 mm clinical to planning target volume expansion margin used at Livingstone Hospital. Due to treatment couch position differences from fraction to fraction, setup errors made during this study could not reliably be determined for electron field treatments

Conclusions:

Results indicate that the base plate should be localized to the treatment couch when calculating random and systematic setup errors for photon fields using the couch position as a surrogate for patient position. For this method to be used to calculate setup errors for electron fields, shielding should always be fastened to the same position at the endface of the applicator. Offline and online verification did not significantly influence systematic setup errors.

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ABBREVIATIONS

A

AAPM	American Association of Physicists in Medicine
AP	Anterior-Posterior

C

cm	centimeter
CT	Computed Tomography
CTV	Clinical Target Volume

D

DRR	Digitally Reconstructed Radiograph
DVH	Dose Volume Histogram
2D	Two dimensional
3D	Three dimensional

E

EPI	Electronic Portal Images
EPID	Electronic Portal Imaging Device

G

Gy	Gray
GTV	Gross Tumor Volume

I

ICRU	International Commission on Radiation Units and Measurements
IGRT	Image Guided Radiotherapy
IMRT	Intensity Modulated Radiotherapy
ITV	Internal Target Volume

K

kV	Kilovoltage

L

LINAC	Linear accelerator

M

ML	Medio-lateral
MLC	Multi-Leaf Collimator
mm	millimeter
MV	Megavoltage
MVCT	Megavoltage Computed Tomography

O

OARV	Organ at Risk Volume.

P

PRV	Planning Organ at Risk Volume
PTV	Planning Target Volume
PTV_{xx}	Planning Target Volume planned to receive XX Gy
PVC	Poly Vinyl Chloride

Q

QA	Quality Assurance

S

SSD	Source to Surface Distance
SI	Superior-Inferior

T

TCP	Tumor Control Probability

1 INTRODUCTION

1.1 BACKGROUND:

Cancer is the second leading cause of death in low and middle income countries. South Africa has the fourth largest mortality rate due to cancer in the world[1]. Head and neck cancer is an umbrella term for cancer of the paranasal sinuses, nasal cavity, oral cavity, pharynx and larynx. There are an estimated 650 000 new head and neck cancer cases and 300 000 cancer deaths globally each year [2]. Clinical management of patients with cancer of the head and neck can include radiotherapy.

Radiotherapy involves conforming a radiation dose distribution to pre-defined target and avoiding risk volumes. It is important that the daily delivery of dose is accurate and reproducible geometrically so that the target volume is not under dosed or the normal adjacent tissue over irradiated. Different technical approaches are used in radiation oncology departments and therefore determination of the accuracy and reproducibility of radiation treatment in a specific institution is necessary. Any systematic or random displacements from the planned patient position, prior to or during treatment, are often referred to as "setup errors". Setup errors, which are in essence volumetric margins, can be determined in a variety of ways. Once determined, they are not only useful for the technical evaluation of the treatment delivery, but could also be used to validate margins around the target volumes and organ at risk volumes (OARVs).

1.2 HEAD AND NECK TREATMENT PLANNING:

Radiation therapy can be planned using three dimensional (3D) computed tomography (CT) scan data, so that, as with other techniques, a radiation dose distribution encompasses all tissues affected by the malignancy while sparing organs at risk and normal tissue. Some difficulties in delineating the target volume and OARVs may arise, these include:

- Uncertainty in the true extent of the affected area.
- Uncertainties regarding the position and size of normal structures that could influence and be affected by treatment [3].

As such the following volumes, consisting of gross visible disease with margins around the disease as well as OARVs, are defined in the International Commission on Radiation Units and Measurements (ICRU) Report 62 [4].

Treatment is planned according to these volumes:

- The Gross Tumor Volume (GTV) which is the gross determinable volume of the tumor.
- The Clinical Target Volume (CTV) containing the GTV and subclinical disease surrounding the GTV.
- The Internal Target Volume (ITV) containing the CTV and a margin to compensate for changes in size, shape and position of the CTV.
- The Planning Target Volume (PTV) containing all the previously mentioned volumes and also a margin accounting for changes in CTV size and position in the patient anatomy , variations in the patient position relative to the planned treatment fields as well as the machine isocenter position relative to a certain point in the patient .
- The Planning Organ at Risk Volume (PRV) consisting of a proximal organ with a known tolerance for radiation plus a margin to compensate for setup errors, internal organ/ structure movement and patient movement.

The final dose distribution within the PTV should be within -5% and +7% of the prescribed dose [5]. The dose distribution should be such that the radiation dose tolerances of the OARVs are not exceeded. In addition, dose to normal tissues should be minimized.

There are many techniques used to plan head and neck radiotherapy, including 2D techniques, virtual simulation or CT-simulation techniques, 3D conformal techniques and forward or inverse planned intensity modulated radiation therapy (IMRT) techniques.

1.3 HEAD AND NECK POSITIONING, IMMOBILIZATION AND SETUP:

Prior to imaging and treatment, patients are positioned in a reproducible way, since it is necessary that the treatment site is kept in the same position relative to the Linear Accelerator (LINAC) coordinate system, throughout treatment. Along with positioning, the patient can also be immobilized so as to limit their ability to move during treatment. These steps are taken so that the patient position for each fraction of treatment is an accurate reproduction of the planned treatment position. Head and neck positioning and immobilization can be challenging due to the following factors:

- The neck is flexible and there is a possibility that the CTV will need to be defined above and below the base of skull. By implication part of the CTV is likely to move if any neck movements occur.
- There are many OARVs in the head and neck region and the probability that the target is close to one or more OARV is significant. [6]

Head and neck positioning and immobilization devices that could be used depend on the treatment technique and include:

- Head and neck support under the patient's head and neck that determines the curvature of the spine. Examples of head and neck positions include being neutral, extended and flexed.
- A customized face mask. Customized masks made of Perspex or Thermoplastic are commonly used [7].
- A base plate to which the head and neck support and customized mask is fixed. Certain base plates can be localized, and some indexed, to the treatment couch.
- Handles or grips, fixed to the base plate or treatment couch, to fixate and pull the patient's shoulders out of the treatment volume.
- A bite block to reproduce the patient's jaw position for each treatment or to deliberately remove the tongue and/or mandible from the treatment volume. [8]
- Stereotactic frames that are fixed to the patient's skull and to the treatment couch, as used in stereotactic radiosurgery or stereotactic radiotherapy.

1.4 HEAD AND NECK TREATMENT VERIFICATION:

Following patient positioning and immobilization, prior to treatment of the first fraction, a setup verification is done to ensure that the planned isocentre position is correct relative to the patient anatomy and the target volumes. The field shape and position is also verified with respect to internal land marks. Offline or online imaging devices can be used. Online (integrated) imaging devices include:

- Film.
- Electronic portal imaging devices (EPIDs).
- kV x-ray units.
- Cone beam CT.

Offline imaging can be performed with a radiotherapy simulator or CT, for instance.

Planar images from portal imagers are compared to digitally reconstructed radiographs (DRRs) of the planned field or isocentre position.

1.5 SETUP ERRORS:

Setup errors occur when the planned radiation dose distribution does not conform to the delineated target volume and normal tissue is irradiated instead.

Setup errors can be classified as:

- Systematic errors that indicate the difference between the planned treatment position and the average position of the patient over the whole course of treatment.
- Random errors that indicate how patient setup differs from fraction to fraction for each patient over the course of treatment.

1.6 VALIDATION OF TREATMENT MARGINS:

The size of the PTV as well as the OARVs is influenced both by organ movements and setup errors. It is justifiable therefore that setup error data be used to evaluate margin size.

1.7 AIM OF THIS STUDY:

The aim of this study was to quantify random and systematic setup errors in a population of head and neck cancer patients for the purpose of evaluating departmental positioning and immobilization techniques, verification and treatment protocols as well as validating the treatment margins used.

1.8 SUMMARY:

Radiation Oncology departments should be aware of how accurate and/or reproducible their treatment techniques are. To this end setup errors can be determined and used.

2 LITERATURE REVIEW:

2.1 POSITIONING AND IMMOBLIZATION IN HEAD AND NECK RADIOTHERAPY:

There are many different ways to ensure radiotherapy is delivered in an accurate and reproducible manner, of which positioning and immobilization of the patient are two. Other methods include:

- Localizing lasers aligned to reference marks on the patient positioning or immobilization device during both imaging and treatment.
- Ensuring the mechanical accuracy of the LINAC by implementing periodic quality control tests.
- The use of offline or online imaging of the patient in the treatment position.
- The use of in-vivo dosimetry to verify dosimetric accuracy of treatment.
- The use of a record and verify system to ensure that the same mechanical machine parameters are downloaded for every treatment and the same amount of monitor units are delivered daily.

Positioning that is accurate and reproducible, combined with immobilization that is rigid, significantly increases the probability of tumor control. This is because under dosing the tumor by only 3%- 5% significantly decreases the tumor control probability (TCP) [6]. Also, unintended morbidity will result from over irradiation.

2.1.1 CUSTOMIZED FACE MASK:

Verhey[6] averaged setup variability using studies from multiple institutions. On average, head and neck treatments where customized face masks were used had an immobilization capability of 2.5 mm – 4 mm from treatment to treatment. Weltens et al[46] found no difference in setup accuracy and reproducibility between plastic and thermoplastic masks. From the study done by Gilbeau et al[13], no significant increase in setup accuracy was achieved with more mask connection points to the base plate.

Tsai et al[44] found that a significant shrinkage of thermoplastic masks occurs over a 24 hour period while the mask dries. Hurkmans et al[24] noted that using newly molded thermoplastic masks could be the cause of setup errors.

2.1.2 HEAD AND NECK SUPPORT:

Commercial head and neck support systems are designed to stabilize the head and neck position throughout treatment. Head and neck supports are typically made of a foam-like material or clear plastic to reduce scatter. Rigid head and neck supports could be subjected to wear and tear slower than non-rigid head and neck supports. Setup errors are affected with the use of different kinds of head and neck supports.

Budrukkar et al[9] compared setup errors for two head and neck support systems, namely a "*neck rest only*" which kept the patient's neck in a neutral position and a "*neck rest with flexion*" system which kept the patient's neck flexed during treatment. The decision to use one or the other head and neck support system depended on the specific site to be treated and different treatment field arrangements were used in each case. It was found that systematic setup errors in both the AP and ML directions were increased when using the "*neck rest with flexion*". [9] Different head and neck supports will result in different field arrangements to ensure isodose coverage of the PTV.

Clinical examples of using different head and neck supports include [3]:

- Using a head and neck support to extend a patient's neck during treatment of the maxillary antrum so that the superior apex of the antrum is included in the treatment fields while ensuring that the eye on the affected side is not over irradiated.
- Using a head and neck support to flex a patient's neck during treatment of the pituitary gland to avoid the eye, including the optic chiasm and retina.

2.1.3 BASE PLATE:

Both the customized mask and head and neck support are usually fixed to a base plate. Bentel et al [10] found a significant negative impact on setup reproducibility when the base plate was not localized to the treatment couch. Many institutions use base plates that localize to the treatment couch for the treatment of head and neck cancer patients [10–12]. Patton et al[13] states that treatment devices that are not fixed to the treatment couch contribute to setup errors and recommends that fixed treatment devices are used to improve reproducibility. However, as couch designs are not universal, base plate fixation is not always possible without modification of the base plate or couch. Not all institutions have the ability to locally modify devices.

2.2 TREATMENT VERIFICATION:

Online treatment verification can be done in-beam with megavoltage (MV) photons using film or an EPID or using a Megavoltage CT (MVCT). Kilovoltage (kV) x-rays can also be used for online imaging using a flat panel detector compatible with kV x-ray or using kV cone beam CT imaging. Better visualization of the bony landmarks and tissue are achieved when using kV x-rays as compared to images obtained with MV photons. Using MV photons for verification also increases dose to the patient compared to kV imaging [3].

When verifying the patient position offline the patient treatment position is duplicated and verified at a station different from the treatment unit, e.g. the radiotherapy simulator or CT. The patient is then moved to the treatment unit for their first fraction of treatment. Offline verification using a radiotherapy simulator, can also be performed with fluoroscopy.

Hess et al [14] measured differences in patient position for head and neck cancer patients between simulation and the first online check film and found 50% of the absolute deviations were within 3mm, 95% were within 9mm and 20% exceeded 5mm. They also suggested that setup errors are much bigger between simulation and the first online verification than between the first online verification and the rest of treatment. Mitine et al[15] used an offline simulation film as the image of the intended treatment position which was then compared to a DRR. However, online MV port films were also taken and used to calculate setup errors. Each individual online port film's displacement in every direction was compared to the mean displacement of all the online port films. When offline port film displacements were compared to online port film displacements, it was found that large systematic errors were found when using the offline port film for verification and that the online port films resulted in better reproducibility of the setup. The results found in this study however, contradict the findings of Mitine et al. [15]

2.3 SETUP ERRORS IN HEAD AND NECK RADIOTHERAPY:

2.3.1 CAUSE OF SETUP ERRORS:

Setup errors could be caused by mechanical misalignment of the light and radiation field or the lasers, incorrect or insufficient immobilization, incorrect or unclear referencing, mistakes made by the radiotherapists treating the patient or by an uncooperative patient who finds it difficult to keep still [16].

2.3.2 METHODS OF QUANTIFYING PHOTON FIELD SETUP ERRORS:

Techniques that could be used to gather information for the determination of photon field setup errors include:

- Comparing portal images from online or offline imaging devices to digitally reconstructed radiographs (DRRs). This technique has been used in literature to assess and review three dimensional (3D) setup errors in head and neck patient setups [16,17]. With this technique inter-observer variability could occur if manual measurement of the setup error is done. Manual measurement of setup errors is also a time consuming process. Setup errors determined in this way will be influenced by the finite sampling resolution of the DRRs and electronic portal images (EPIs) and this will affect both automated and manual setup error measurements[18]. EPIDs do however have image quality enhancing tools to avoid repeated exposures from poor image quality. Furthermore EPI's are not necessarily taken daily.
- Computer tracked fiducial markers could be used to evaluate setup errors. Hong et al[19] used an optical position sensor system that captured the positions of passive markers, having known locations on a custom bite plate used for positioning and immobilization, to determine setup errors in head and neck cancer patients treated with IMRT. This approach takes up session time. Depending on the quality of the optical position sensor system and its software, some patient movements might not be detected. Furthermore this approach of determining setup errors is time-consuming and resource intensive.
- Setup errors can also be assessed using record and verify system data and using the absolute position of the treatment couch relative to the isocentre as a surrogate for patient position [7,20]. Many authors have noted that record and verify system data could be useful as a tool for clinical studies and research [21–23]. Computerized record and verify systems entered the field of Radiation Oncology in the 1970's [13]. They were introduced to assist in more complex treatments and to facilitate increased accuracy and reproducibility of radiation delivery [20]. Record and verify systems ensure that certain parameters used to treat patients during every fraction of treatment exactly match the treatment prescription and treatment plan, and that certain parameters used during treatment, such as collimator angle, gantry angle and all couch parameters, are within the local tolerance of planned values to avoid verification failures.

Record and verify systems also keep a record of every treatment, including dose delivered, treatment field parameters, therapist identity, etc. Podmaniczky et al[22] specifically noted that record and verify system data may be useful when comparing it to prescribed parameters to evaluate setup standards.

2.3.3 METHODS OF QUANTIFYING ELECTRON FIELD SETUP ERRORS:

Imaging electron treatments is not viable because of the inadequate penetration of low energy electron beams and the fact that when an electron beam strikes tissue, the electrons will undergo coulomb interactions with the electrons and the nuclei of atoms within the tissue and will be scattered in directions transverse to their incoming directions as a result [24]. Portal images are thus generally unavailable for comparison with DRRs for fields treated with electron beams. It is possible to use record and verify system data to assess electron field setup accuracy and reproducibility as mentioned previously. The treatment couch position could be used as a surrogate for patient position. Reproducibility in setup when treating electron fields could theoretically be defined as consistent translation from the isocenter of other treatment fields. Since the center of the electron field may vary daily depending on manual field shaping, it may be more difficult to quantify setup error for these ports. In literature, planned isodose distributions and dose volume histograms (DVH) of electron treatment fields have been evaluated prior to treatment in an attempt to predict the accuracy of the treatment [25,26]. Treatment errors were also studied retrospectively to determine their origin. For electron beams it was found that geometric misses due to setup errors constituted the largest source of error [27]. Because of a general lack of portal image availability, very few studies have measured setup errors in electron beam therapy.

2.3.4 RANDOM AND SYSTEMATIC ERRORS:

The effect of random setup errors can be represented by blurring of the dose distribution. Random errors happen from day to day during treatment.

Systematic errors shift the entire dose distribution away from the planned dose distribution and usually originate in the process leading up to treatment [28].

Individual systematic and random setup errors can be calculated per patient [29,30]. A group of patients have a distribution of systematic errors which is stochastic [31] and a patient population distribution of random setup errors. An individual systematic setup error is the mean displacement from the planned patient position for all fractions treated. An individual random error is the standard deviation of the difference in daily treatment positions for all fractions treated. [30]

If the data has a normal distribution, the population systematic and random error distributions can be specified respectively by their mean and standard deviation [29]. The population systematic error is the standard deviation of the distribution of individual patient setup errors. The population random error is the mean of the individual random errors [28,30].

Table 2.1 provides examples of systematic and random setup errors in the anterior-posterior (AP), medio-lateral (ML) and superior-inferior (SI) directions found in several different studies. The number of patients and the number of images used in the respective studies are also given.

Number of patients:	25	30	31	110	27	22
Number of images:	186	915	Not given.	330	234	138
Direction:	AP: ML: SI:	AP: ML: SI:	AP: ML: SI:	AP: ML: SI:	AP: ML: SI:	AP: ML: SI:
Systematic error (mm):	0.96 0.98 1.2	Head: 1.2 2.2 1.6 Neck: 2.1 1.5 1.5 Shoulder: N/A 2.8 2.8	2 1.8 1.7	2.1 7.2 5.3	4.6 4.3	2.1 1.8 2.1
Random error (mm):	1.94 1.97 2.48		1.6 1.5 1.1	7.7 5.8 7.4	2 2.5	2.1 1.5 2.1
Reference:	15	13	3	47	35	21
Number of patients:	12	43				
Number of images:	43	515				
Direction:	AP: ML: SI:	AP: ML: SI:				
Systematic error (mm):	1.7 1.8 2.2	Orfit: 3.4 3.4 PVC: 3.6 3.6				
Random error (mm):	1.4 1.4 1.4	Orfit: 2.1 2.1 PVC: 2.1 2.1				
Reference:	14	46				

Table 2.1: Random and systematic setup errors in the anterior-posterior (AP), medio-lateral (ML) and superior-inferior (SI) directions found in literature with the number of patients used in the study and number of verification films taken specified.

2.4 TREATMENT MARGINS IN HEAD AND NECK RADIOTHERAPY:

Image guided adaptive radiotherapy (IGART) techniques, where the patient is imaged frequently and their position adjusted during the course of the treatment, is thought to greatly assist in improving accuracy and reproducibility of radiotherapy. However, there are still certain positioning accuracy issues that cannot be completely addressed by techniques such as IGRT, including:

- Making sure the GTV is accurately defined.
- Certain patient movements are not detected by imaging devices or are extremely complex to correct.
- Significant organ movement resulting in large ITVs.
- Changes in CTV that are not visible on imaging.

It is thus still necessary to define treatment margins [32].

Random and systematic error data contribute to PTV and PRV definition. Van Herk noted that margins used to define the PTV and PRV are defined because of positioning uncertainty and organ motion, and that these can be linearly separated [28]. Many margin recipes have been developed [28,31,33–35]. Van Herk et al[31] analyzed how random and systematic errors influenced the prescribed dose and used the analysis to derive the dimensions of the margin used to define the PTV. Stroom et al[33] generated a "*matrix of coverage probabilities*" by convolving a matrix of values indicating where the CTV is with the correct probability distribution matrix. The "*matrix of coverage probabilities*" was then used to define the PTV so that it corresponds to a certain "*iso-probability level*". McKenzie et al[34] looked at margins around organs at risk to define the PRV so that all of the organ at risk was covered in 90% of cases. In some cases (parallel or large serial organs) only systematic errors were used to define the margin and in other cases both the random and systematic setup error data was used [34]. McKenzie et al [34] also suggested that a margin to account for systematic errors be drawn around the CTV so that the mean CTV position was covered in 90% of cases. The margin was then extended to include the effects of random errors [36]. Van Herk et al [37] calculated tumor control probabilities (TCP) for different margin sizes in prostate patients. Parker et al [38]derived a CTV-PTV margin using a Monte Carlo algorithm by using measured random and systematic setup errors. Margin criteria was such that the minimum CTV dose would be 95% of the PTV dose and that 90% of the CTV received the entire PTV dose. Table 2.3 contains some of the margin recipes that were suggested in the literature:

Margin recipe:	Reference:	Year of publication:
CTV-PTV margin: $2.5\ \sigma_{systematic}+1.64(\sigma_{random}-\sigma_p)$ Simplified as: $2.5\sigma_{systematic}+0.9\sigma_{random}$	31	2000
CTV-PTV margin: $2.5\ \sigma_{systematic}+\beta(\sigma_{random}-\sigma_p)$	36	2000
CTV-PTV margin: $\sigma_{systematic}+\sqrt{(\sigma_{random}{}^2+\sigma_{systematic}{}^2)}$	38	2002
CTV-PTV margin: $\sqrt{(1.6^2\sigma_{random}{}^2+2.7^2\sigma_{systematic}{}^2)}$ -2.8mm Simplified as: $2.5\sigma_{systematic}+0.7\sigma_{random}$-3mm	39	2002
CTV-PTV margin: $2\sigma_{systematic}+0.7\sigma_{random}$	33	1999
OAR –PRV margin: $1.3\sigma_{systematic}$+/- $0.5\sigma_{random}$	34	2002

Table 2.2: Margin recipes from literature with published date noted. With $\sigma_{systematic}$: the population systematic setup error σ_{random}: the population random setup error, $\sigma_p$the width of beam penumbra fitted to a Gauss function, and β a constant.

Margin recipes could also be expanded further to include corrections for movement due to respiration and non-uniform cell density[28].

2.5 SUMMARY:

The accuracy and reproducibility of treatment in head and neck radiotherapy can be influenced by many factors including:

- Positioning and immobilization, the material that the customized face mask is made of, the optimal use of a head and neck support and the localizing and/or indexing of the base plate to the treatment couch.
- Treatment verification techniques including offline versus online verification.

Treatment accuracy and reproducibility can be quantified by systematic and random setup errors, which can be determined using computerized record and verify system treatment couch position data as a surrogate for patient position.

Despite techniques such as IGRT, which have greatly improved the accuracy and reproducibility of treatment, it is still necessary to define margins around the CTV and OARVs to account for setup errors and organ motion. Setup errors could be used to calculate the margins used to define the PTV and PRV. Many such margin recipes can be found in literature.

3 MATERIALS AND METHODOLOGY:

58 head and neck cancer patients were irradiated using a standardized 3D conformal technique at Livingstone Hospital between 08/10/2015 and 01/11/2016. The total dose delivered was 70 Gray (Gy) when the primary tumor and involved nodes were irradiated, 66 Gy when positive resection margins or nodal spread were present or 60 Gy when adjuvant treatment was given. A dose of 50 Gy was delivered to the anterior neck region to treat the uninvolved nodes prophylactically [40].

3.1 MATERIALS:

3.1.1 COMPUTERISED TOMOGRAPHY SCANNER (CT):

The CT scanner used for patient data acquisition was a Philips Brilliance® Big Bore CT scanner with a minimum slice width of 2 mm. A 3 mm slice width is used in Livingstone Oncology to scan head and neck patients.

3.1.2 RADIOTHERAPY TREATMENT PLANNING SYSTEM:

The treatment planning system used to plan the treatment was an ELEKTA™ XiO- Release V5.00.01.1. (LINUX). The planning system generated digitally reconstructed radiographs for comparison with verification images.

An example of a treatment plan screenshot on XiO can be seen in figure 3.1.

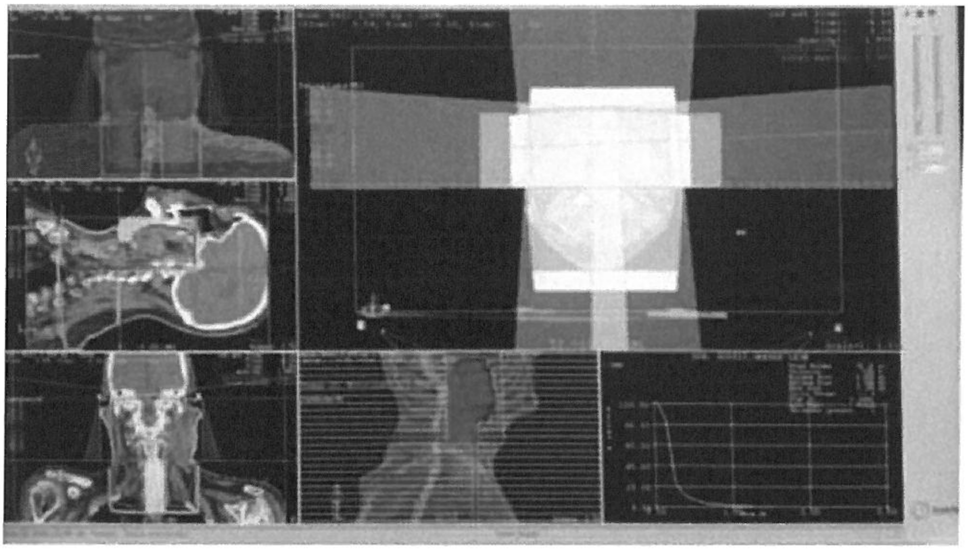

Figure 3.1: An example of a field arrangement visualization screenshot from the XiO treatment planning system.

3.1.3 <u>RADIOTHEAPY SIMULATOR:</u>

The simulator used for offline verification of the patient position was the Nucletron™ Simulux HQ simulator. The simulator has fluoroscopic capabilities that were used to localize the treatment area.

3.1.4 <u>ELECTRONIC PORTAL IMAGING DEVICE:</u>

EPIs were obtained using the ELEKTA™iViewGT- Release 3.4b102-SP2. EPIs are not as clear as DRRs (which can be modified to enhance contrast) due to the fact that 4 MV photons are used to generate EPIs.

An example of a DRR alongside an EPID image is shown in Figure 3.2.

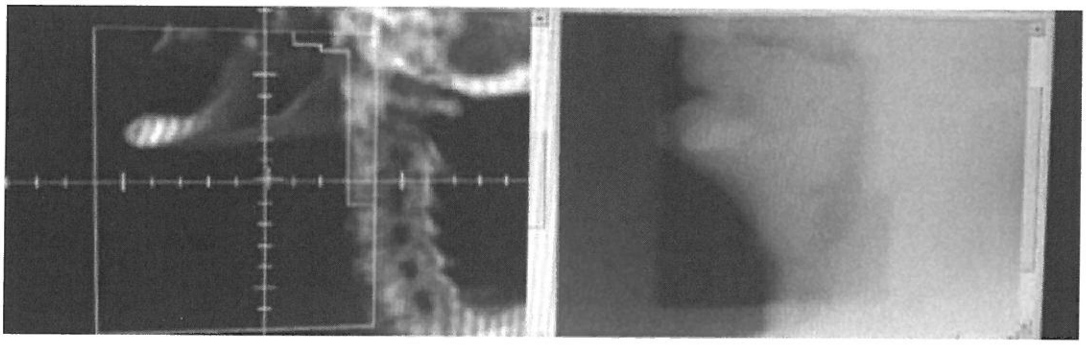

Figure 3.2: The DRR (left) generated by the treatment planning system of a small lateral field compared to an EPI (right) of the same field when the patient is set up on the LINAC.

3.1.5 LINAC AND TREATMENT COUCH:

Patients whose data were used for this study were treated with an ELEKTA™ Synergy Platform LINAC, as shown in figure 3.3.

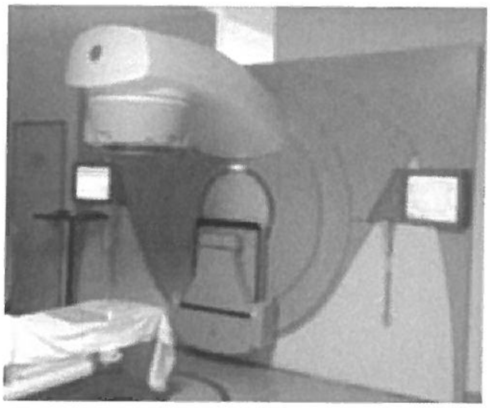

Figure 3.3. The treatment couch that was used has an isocentric base, column rotation capability and vertical, lateral and longitudinal movements, which are all graduated.

In the treatment room there is a display of the couch position, which includes:

- Isocentric couch rotation values and column rotation values relative to the isocenter.
- The vertical couch movement.
- The central lateral position relative to the isocenter
- The longitudinal couch movement relative to the zero position set on installation of the treatment couch.

3.1.6 POSITIONING AND IMMOBILIZATION DEVICES:

The head and neck immobilization system used included a 2.4 mm thick customized thermoplastic face mask, a Silverman head and neck support system that positioned the patient's neck in one of three positions namely neutral, extended or flexed, and a base plate to which the mask and head and neck support were fixed. All devices were supplied by Klarity®. An example of the head and neck positioning and immobilization system at Livingstone Hospital can be seen in figure 3.4.

Figure 3.4: The positioning and immobilization system used at Livingstone Hospital consisting of a customized face mask, head and neck support and base plate.

3.1.7 RECORD AND VERIFY SYSTEM:

The record and verify system that was used is the Mosaiq™ (version: 2.50.05D7) system from Elekta. An example of a screenshot of a treatment history is shown in figure 3.5.

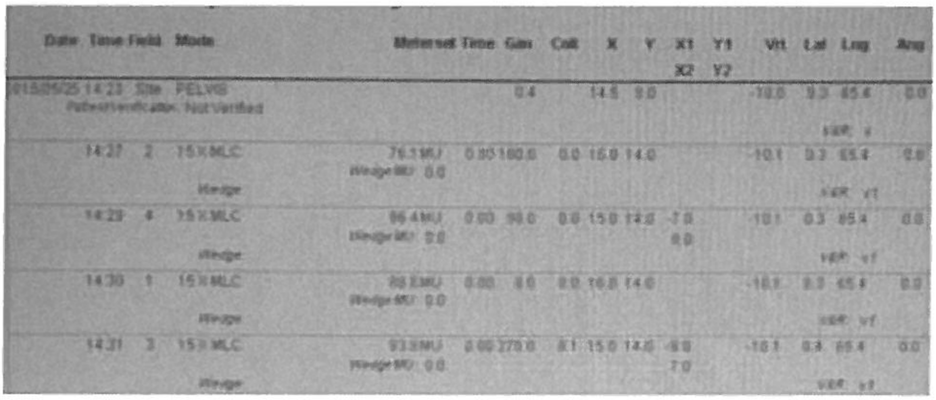

Figure 3.5: Example of record and verify system data that was used in this study. The example indicates the lateral (Lat), longitudinal (Lng) and vertical (Vrt) treatment couch positions.

3.2 METHODOLOGY:

3.2.1 TREAMENT PLANNING, POSITIONING AND VERIFICATION PROCESS:

Prior to treatment, CT scan data of the patients were acquired. Radio opaque markers to indicate the position of the planning reference position were placed on the customized mask. The location of the planning reference position was standardized to the internal intersection of the axial slice passing through the tip of the tragus on each side of the patient's head, and the central cranio-caudal axis of the patient's body passing through the nasium, suprasternal notch and xiphisternum. All patients were positioned and immobilized using:

- A customized thermoplastic face mask.
- A rigid, hollow Perspex head and neck support that positioned the patient's neck in one of three positions namely neutral, extended or flexed.
- A base plate to which the face mask and head and neck support were fixed.

Livingstone Hospital used two standardized 3D conformal techniques to treat patients in three phases. A description of the technique used with the base plate not localized to the treatment couch follows. Firstly PTV_{50} was treated, where the subscript refers to the radiation dose in Gy. PTV_{50} was prescribed to treat the involved areas as well as the uninvolved nodes prophylactically. The following fields were used to treat PTV_{50}: Two parallel opposed lateral photon fields for the primary tumour, a photon field to irradiate the neck nodes and the anterior neck and lastly electron fields to irradiate the tumor and/or affected nodes posteriorly. The anterior neck field was matched superiorly to the lateral photon fields. The electron fields were matched anteriorly to the posterior border of the parallel opposed lateral fields and the inferior border of the electron fields depended on the extent of the tumor, but did not overlap into the anterior neck field. The electron field sizes and positions were clinically marked on the mask and the LINAC field light was aligned with this outline from fraction to fraction. Secondly PTV_{60} or PTV_{66} was irradiated to treat the primary tumor as well as positive resection margins and nodal spread. 60 Gy was prescribed instead of 66 Gy when adjuvant treatment was given. The following fields were used to treat PTV_{60} or PTV_{66}: parallel opposed lateral photon fields, plus an anterior field to irradiate the neck nodes. Thirdly PTV_{70} consisting of the primary tumor and involved nodes was treated. The field configuration used to treat PTV_{70} was individualized. An example of field configurations for PTV_{50}, $PTV_{60/66}$ and PTV_{70} is shown in figures 3.6 to 3.8.

The following field distribution was used to treat patients with the base plate not localized to the treatment couch. To treat PTV_{50} right and left anterior oblique fields, right and left posterior oblique fields, right and left lateral fields and an anterior neck field were used. The fields used to treat $PTV_{60,\ 66\ or 70}$ depended on the tumour size and location in the patient and was individualized. An example of field configurations for PTV_{50}, $PTV_{60/66}$ and PTV_{70} is shown in figures 3.9 to 3.11. No electron fields were used for this treatment technique.

All photon fields were treated isocentrically and all electron fields were treated using a constant source to surface distance technique. Not all patients at Livingstone Hospital were treated with all of the above mentioned fields and field combinations. The treatment fields used depended on the extent and staging of the disease.

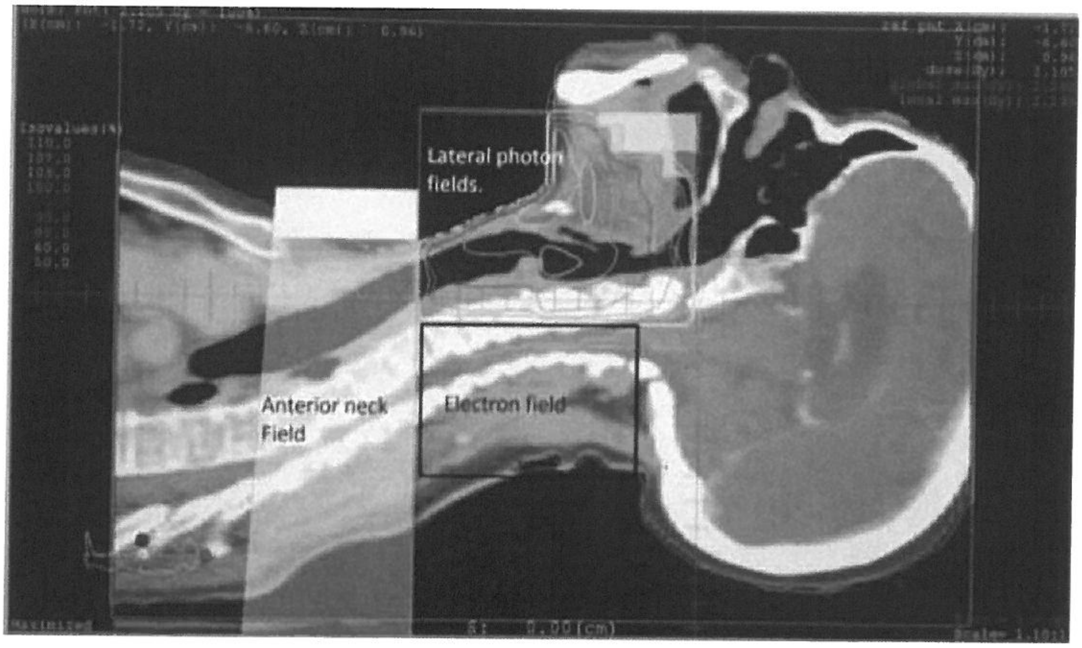

Figure 3.6: An example of the field configuration used to treat PTV_{50} at Livingstone Hospital with the base plate not localized to the treatment couch.

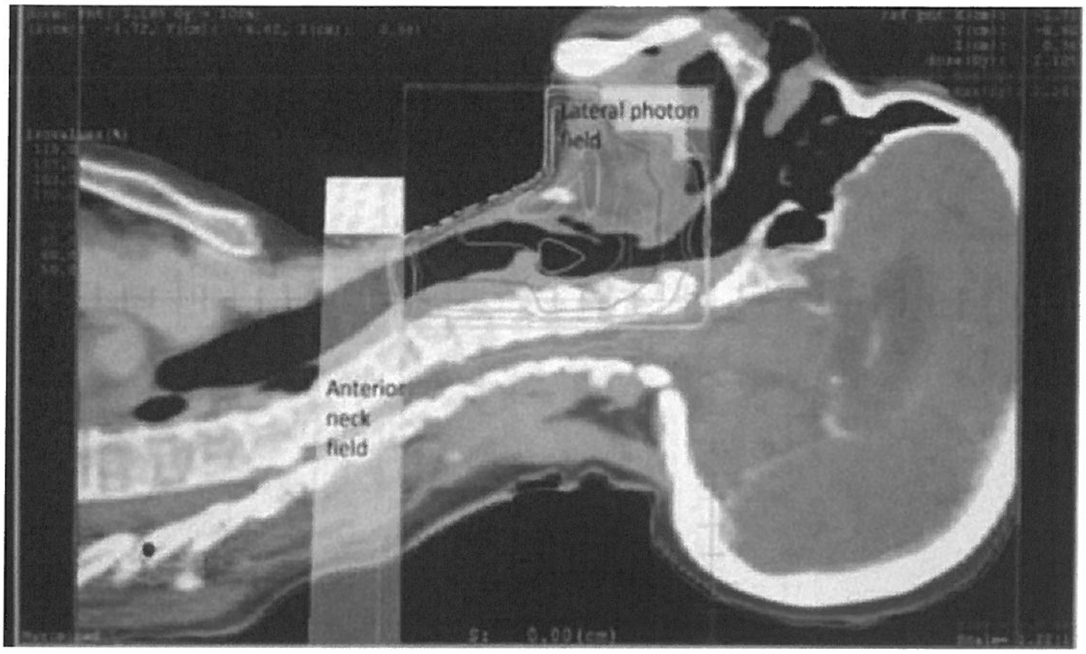

Figure 3.7: An example of the field configuration used to treat $PTV_{60/66}$ at Livingstone Hospital with the base plate not localized to the treatment couch.

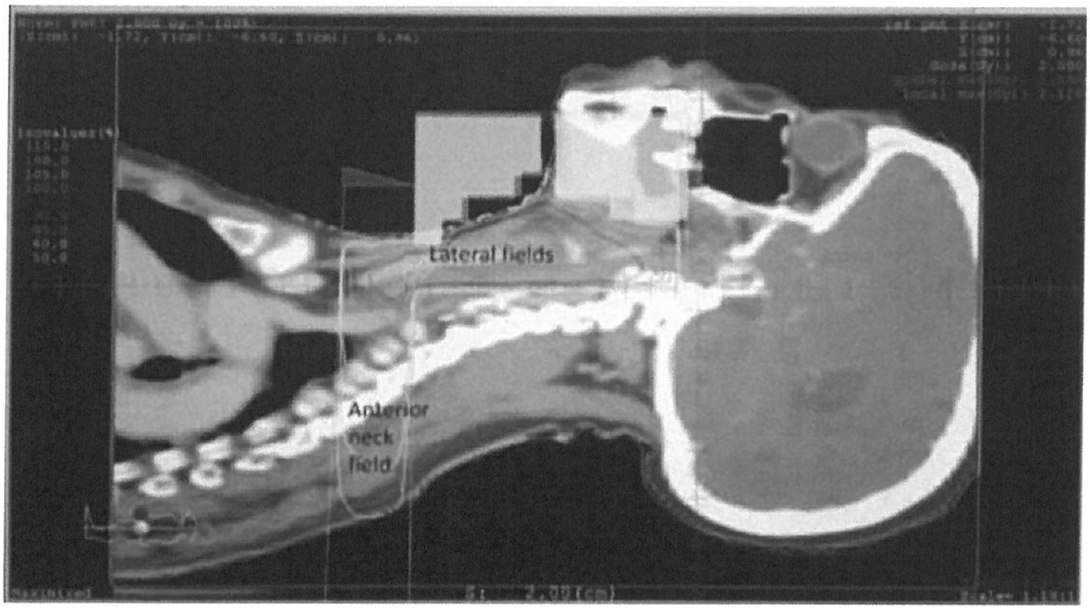

Figure 3.8: An example of the field configuration used to treat PTV_{70} at Livingstone Hospital with the base plate not localized to the treatment couch.

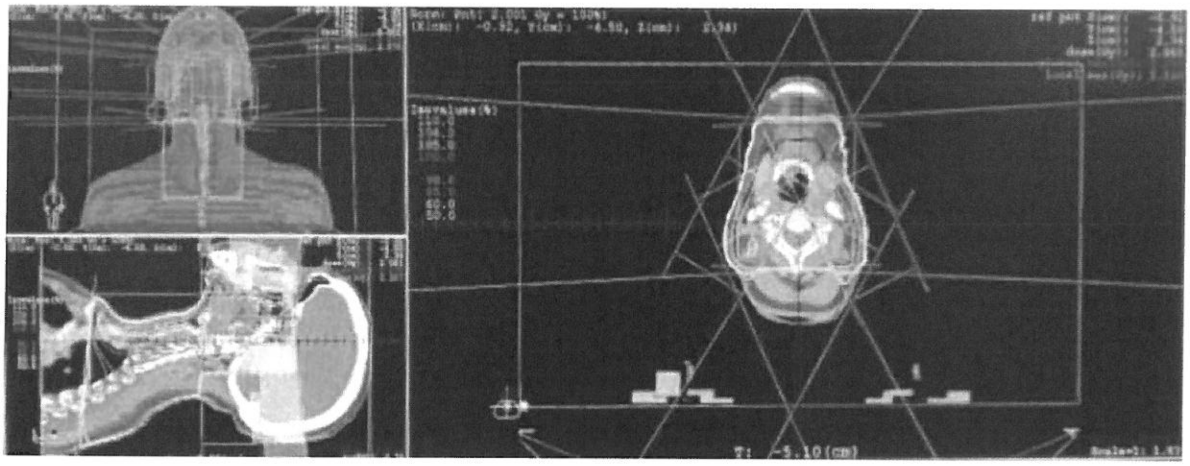

Figure 3.9: An example of the field configuration used to treat PTV_{50} at Livingstone Hospital with the base plate localized to the treatment couch.

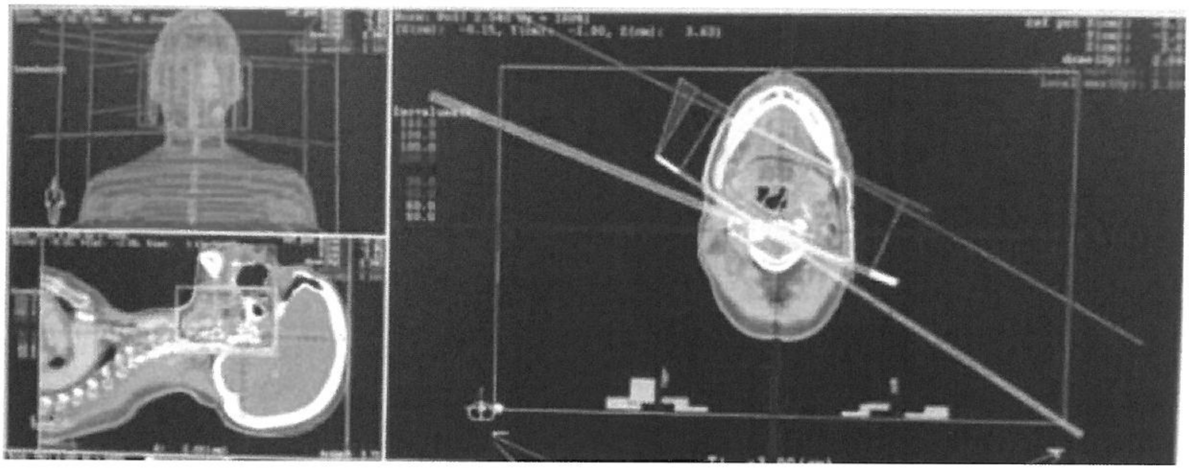

Figure 3.10: An example of the field configuration used to treat $PTV_{60/66}$ at Livingstone Hospital with the base plate localized to the treatment couch.

Figure 3.11: An example of the field configuration used to treat PTV_{70} at Livingstone Hospital with the base plate localized to the treatment couch.

The ICRU reference point is unique for each phase of treatment and the following defines it:

- *"The dose at that point should be clinically relevant.*
- *The point should be easy to define in a clear and unambiguous way.*
- *The point should be selected so that the dose can be accurately determined.*
- *The point should be in a region where there is no steep dose gradient"* [4].

Thus the point is:

- *"At the center (or in a central part) of the PTV, and*
- *When possible, at the intersection of the beam axes"* [4].

At Livingstone Hospital the ICRU reference point is defined as close as possible to the center of the target volume but not in an air cavity (such as in the sinuses) or bone. The ICRU reference point was defined for each PTV.

Prior to treatment, the patient treatment position was verified. During the verification process, patients were moved from the planning reference position to the position of the ICRU reference point (defined in the planning process), which coincided with the LINAC isocenter[5]. The patients were moved according to a set of couch translations derived from the treatment plan.

All head and neck treatments examined in this study were fractionated. Just before the first fraction of treatment, portal imaging of the planned photon fields was done to confirm the planned patient position and the position of the isocenter in relation to patient anatomy. This was done using planar imaging either offline on the radiotherapy simulator or online at the treatment machine on the first visit.

The planar images were compared to DRRs of the planned patient position for each phase of treatment, i.e. PTV_{50}, PTV_{60} and PTV_{70}. This process is known as verification. Once the correct patient position and setup had been confirmed, treatment commenced.

The institutional treatment protocol followed during the study did not demand that an initial online patient position verification was performed at the treatment unit. EPI image quality at Livingstone Hospital was not adequate and it was decided to verify most of the patients offline, except if the Simulator was unavailable, in which case online verification was done. For this research, the on-line verification session, was used as the "true" patient position. For patients that were verified off-line, the first fraction of treatment was used as the "true" patient position.

3.2.2 DATA COLLECTION AND PROCESSING:

Record and verify system data was collected in the form of the vertical (z), lateral (x) and longitudinal (y) treatment couch position absolute values for each daily treatment fraction of 58 head and neck patients. 20 of these patients were treated with the base plate localized to the table top. z, x and y values are the anterior-posterior (AP), medio-lateral (ML) and superior-inferior (SI) couch position displacements respectively.

Using the data collected, the difference between the verified couch position of each patient's treatment and the average couch position was calculated to establish the systematic single patient setup error. A distribution of couch position differences from day to day was also calculated to establish the random single patient setup error. The group random and systematic errors were then calculated from the patient population.

The following equations were used to calculate the setup errors. These formulae have been used in literature [7,16,19,30,41]. σ_i and m_i are the individual patient random and systematic errors respectively and σ and Σ are the population random and systematic errors respectively.

$$\sigma_i=\sqrt{\frac{1}{F_i-1}\sum_{i=1}^{F_i}(t_{if}-m_i)^2}$$

$$\sigma=\sqrt{\frac{1}{N}\sum_{i=1}^{N}\sigma_i}$$

$$m_i=\frac{1}{F_i}\sum_{i=1}^{F_i}t_{if}$$

$$\Sigma=\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(m_i-M)^2}$$

With:

t_{if}: The difference between the actual couch position and the planned couch position for a specific principle direction.

N: Total number of patients.

F_i : Fractions per patient i.

F: Total number of fractions for all patients.

M: Mean translational deviation.

$$M=\frac{1}{N}\sum_{i=1}^{N}\sum_{i=1}^{F}m_i$$

Using the population random and systematic setup errors, CTV- PTV and OARV-PRV margins were calculated using the following margin recipes found in literature as discussed in section 2.4:

CTV-PTV margins:

$$2.5\ \sigma_{systematic}+1.64(\sigma_{random}-\sigma_p)$$

$$\sigma_{systematic}+\sqrt{(\sigma_{random}{}^2+\sigma_{systematic}{}^2)}$$

$$\sqrt{(1.6^2\sigma_{random}{}^2+2.7^2\sigma_{systematic}{}^2)}\ -2.8mm$$

$$2\sigma_{systematic}+0.7\sigma_{random}$$

OARV-PRV margin: $1.3\sigma_{systematic}$+/- $0.5\sigma_{random}$

4 RESULTS AND DISCUSSION:

4.1 SETUP ERRORS OF PHOTON FIELDS TREATED WITH THE BASE PLATE NOT LOCALIZED TO THE TREATMENT COUCH:

4.1.1 DAILY TREATMENT COUCH POSITIONS AND SYSTEMATIC SETUP ERROR VARIATIONS:

Daily couch position variations in the three principal directions for two patients treated with the base plate not localized to the treatment couch and verified offline and online respectively, can be seen in figures 4.1 and 4.2.

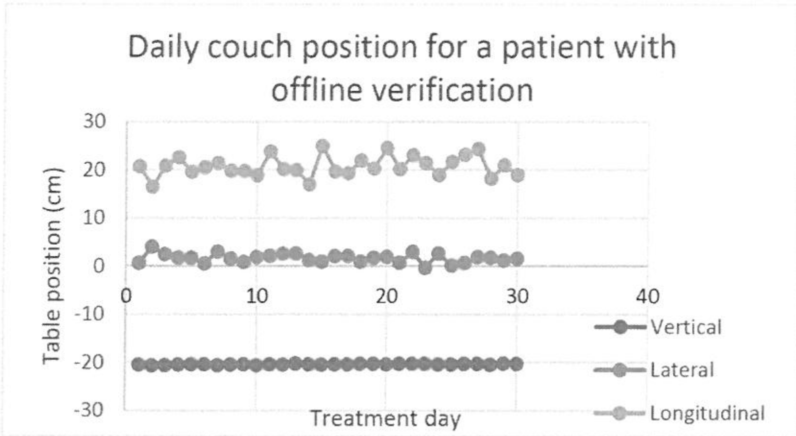

Figure 4.1 Daily couch position variation in the three principal directions for a single patient verified offline.

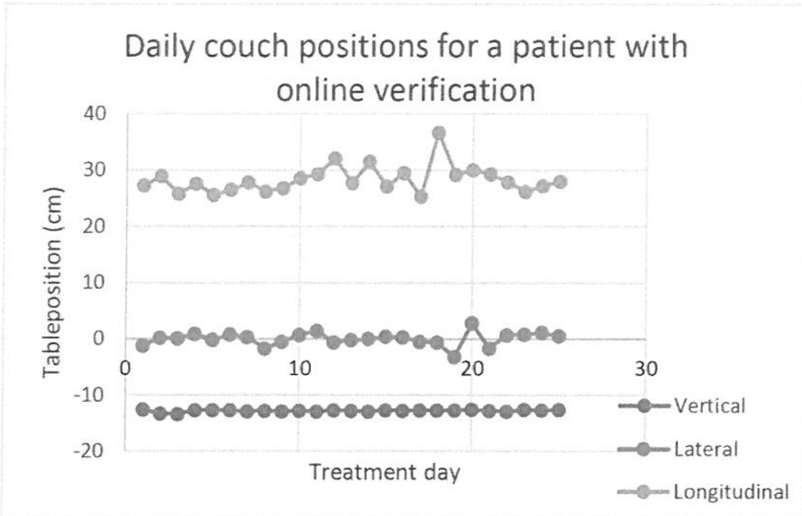

Figure 4.2 Daily couch position variation in the three principal directions for a single patient verified online.

An individual patient systematic setup error is the average of the difference between the planned couch position and the actual couch position for all fractions of a patient's treatment in each principle direction. As every patient setup was different, the variation of the actual couch position for all patients is irrelevant. Thus the individual systematic setup error variation in each principle direction for the 38 patients treated with the base plate not localized to the treatment couch, is shown in Figures 4.3 to 4.5. Negative values indicate posterior, right lateral and inferior displacements of the patient from the isocenter position respectively. The data set are divided between patients with verification done online and patients with verification done offline.

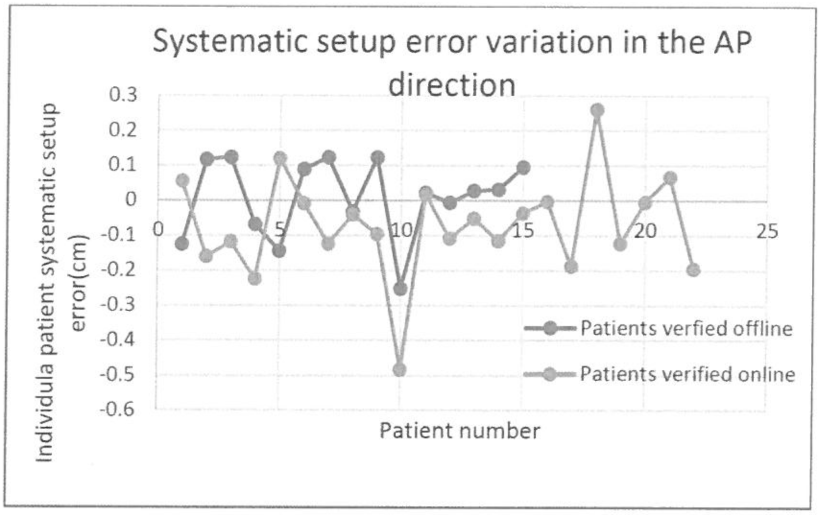

Figure 4.3: Variation in the individual patient systematic setup errors (m_i) in the AP direction.

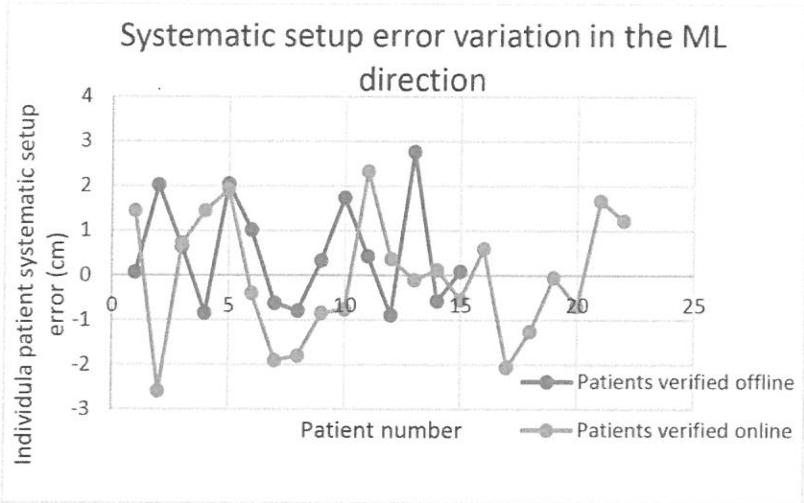

Figure 4.4: Variation in the individual patient systematic setup errors (m_i) in the ML direction.

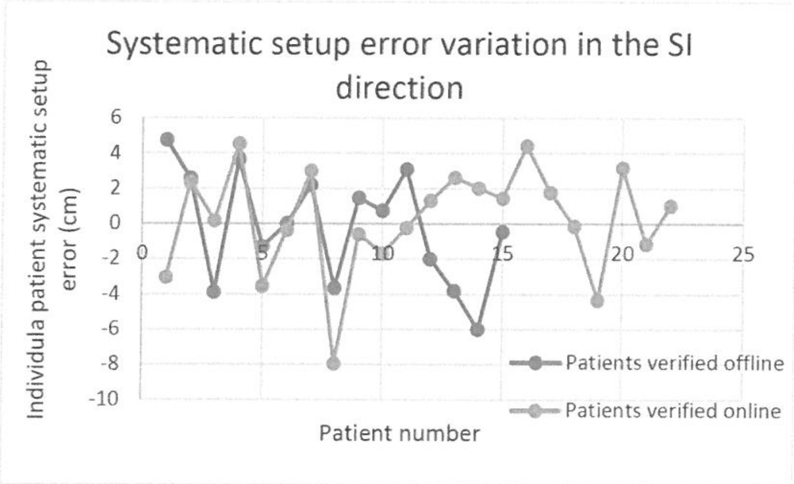

Figure 4.5: Variation in the individual patient systematic setup errors (m_i) in the SI direction.

The mean ± one standard deviation of the individual systematic setup errors of patients treated with the base plate not localized to the treatment couch is shown in Tables 4.1 and 4.2 for online and offline verification respectively.

Mean ± standard deviation of individual systematic setup errors of patients with online verification(cm):		
AP	ML	SI
-0.1± 0.1	-0.1± 1.4	0.2± 3.0

Table 4.1: Mean ± one standard deviation of the individual systematic setup errors in all three principle directions for patients with online verification done.

Mean ± standard deviation of individual systematic setup errors of patients with offline verification(cm):		
AP	ML	SI
0± 0.1	0.5± 1.2	-0.2± 3.0

Table 4.2: Mean ± one standard deviation of the individual systematic setup errors in all three principle directions for patients who had offline verification done.

Since the base plate is not localized to the treatment couch, the largest individual patient systematic setup errors are in the SI and ML directions. The base plate can thus essentially be placed anywhere on the treatment couch, and the couch merely moved to compensate for this so that the lasers once again line up with the correct markings on the treatment mask. The individual patient setup error in the ML direction is smaller than the error in the SI direction because it is easier to centre the base plate laterally on the couch top by visual inspection. The largest individual patient setup error was -7.95 cm in the SI direction for a patient verified online.

4.1.2 OVERALL MEAN VARIATION:

The overall mean systematic setup errors for photons are shown in tables 4.3 and 4.4.

Overall mean variation of photon fields treated with online verification (cm):		
AP	ML	SI
-0.06	-0.09	0.04

Table 4.3: Overall mean systematic setup variation (M) of patients that had online verification done.

Overall mean variation of photon fields treated with offline verification (cm):		
AP	ML	SI
-0.01	0.23	0.11

Table 4.4: Overall mean systematic setup variation (M) of patients that had offline verification done.

The overall mean variations in the ML and SI directions are larger, and in the AP direction is smaller, for patients whose treatment was verified offline as opposed to online.

4.1.3 POPULATION RANDOM ERROR:

The population random error is equal to 0.15 cm and 0.1 cm in the AP direction for online and offline verified patient groups respectively. The calculated population random errors in the ML and SI directions, are not a true reflection of the random setup error. This is due to the fact that the base plate can be placed anywhere on the couch top laterally and longitudinally and the couch position changed to accommodate this. The population random setup error in the AP direction is comparable to previously cited random population setup errors in the AP direction. [7,15,17,19,42–44]

4.1.4 POPULATION SYSTEMATIC SETUP ERROR:

The population systematic setup errors are 0.14 cm and 0.11 cm in the AP direction for online and offline verified patients respectively. Only the population systematic setup errors in the AP direction were comparable to that found in literature.

4.1.5 CTV-PTV AND OARV-PRV MARGINS:

From the random and systematic setup errors calculated it is apparent that only the errors calculated in the AP direction are an indication of the true setup error size. Tables 4.5 and 4.6 show margin sizes in the AP direction that was calculated for photon fields using various margin recipes (equations) as found in the literature.

CTV-PTV margin (cm)	
AP	Reference for equation:
0.48	20
0.34	37
0.15	19
0.38	43
OARV-PRV margin (cm)	
AP	
0.18+/-0.07	33

Table 4.5: CTV-PTV margins and an OARV-PRV margin of patients treated with photon fields that had online verification done.

CTV-PTV margin (cm)	
AP	Reference for equation:
0.36	20
0.25	37
0.04	19
0.28	43
OARV-PRV margin (cm)	
AP	
0.14+/-0.05	33

Table 4.6: CTV-PTV margins and an OARV-PRV margin of patients treated with photon fields that had offline verification done.

100 Percent of patients had individual systematic setup errors in the AP direction within 0.5 cm, which is the current isotropic CTV-PTV margin size used at Livingstone Hospital. The calculated OARV- PRV margins in the AP direction also fell within the isotropic 0.5 cm OARV-PRV margin used at Livingstone Hospital.

4.2 SETUP ERRORS OF PHOTON FIELDS TREATED WITH THE BASE PLATE LOCALIZED TO THE TREATMENT COUCH:

4.2.1 DAILY TREATMENT COUCH POSITIONS AND SYSTEMATIC SETUP ERROR VARIATIONS:

Daily couch position variations in the three principal directions for two patients treated with the base plate localized to the treatment couch and verified offline and online respectively, are shown in figures 4.6 and 4.7. Outlier variations in the longitudinal direction due to the base plate not being placed into the same slot along the treatment couch for every fraction was corrected for.

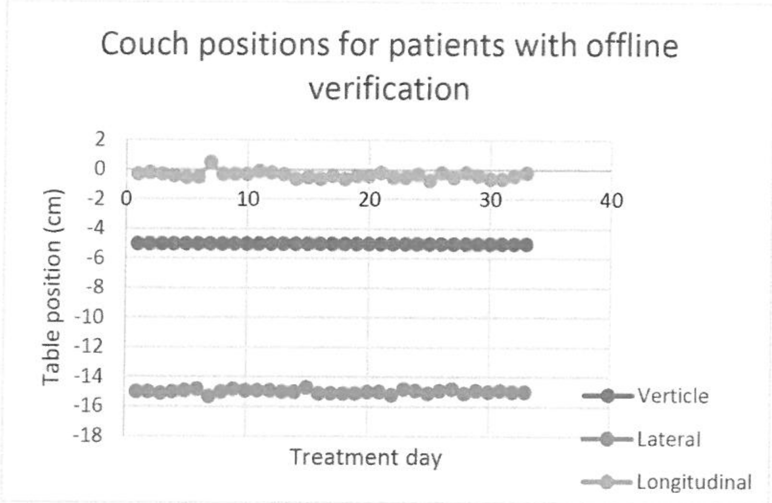

Figure 4.6 Daily couch position variation in the three principal directions for a single patient verified offline

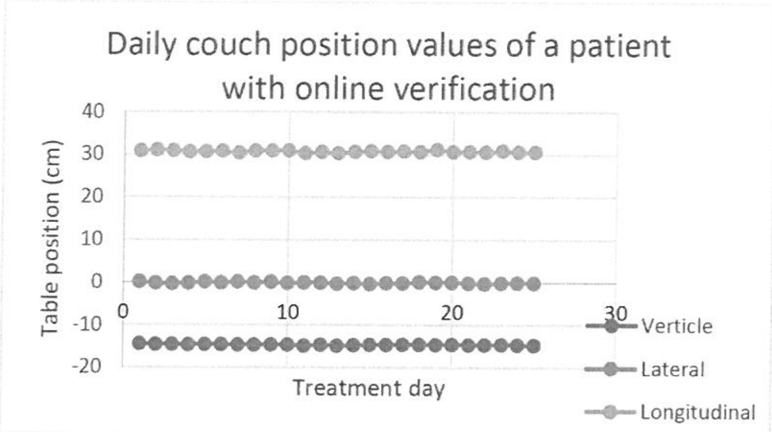

Figure 4.7 Daily couch position variation in the three principal directions for a single patient verified online.

Individual systematic setup error variations, in all three principle directions, for the 20 patients treated with the base plate localized to the treatment couch, are shown in Figures 4.8 to 4.10. Negative values indicate posterior, right lateral and inferior displacements of the patient from the isocenter position respectively. The data set are divided between patients with verification done online and patients with verification done offline.

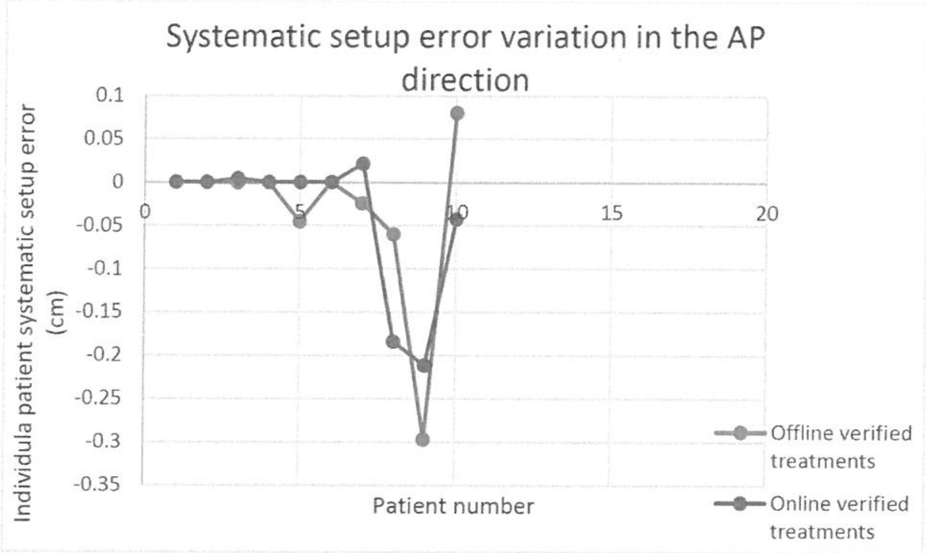

Figure 4.8: Variation in the individual patient systematic setup errors (m_i) in the AP direction.

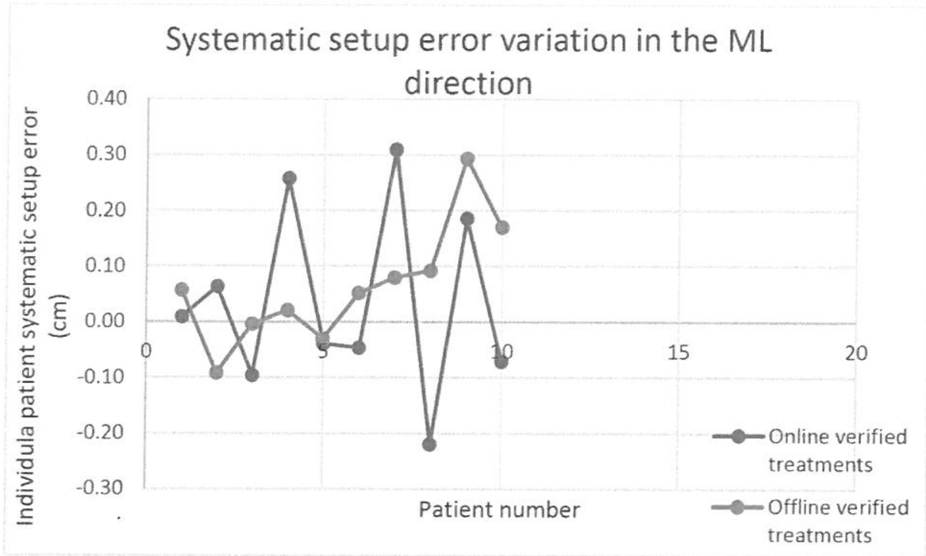

Figure 4.9: Variation in the individual patient systematic setup errors (m_i) in the ML direction.

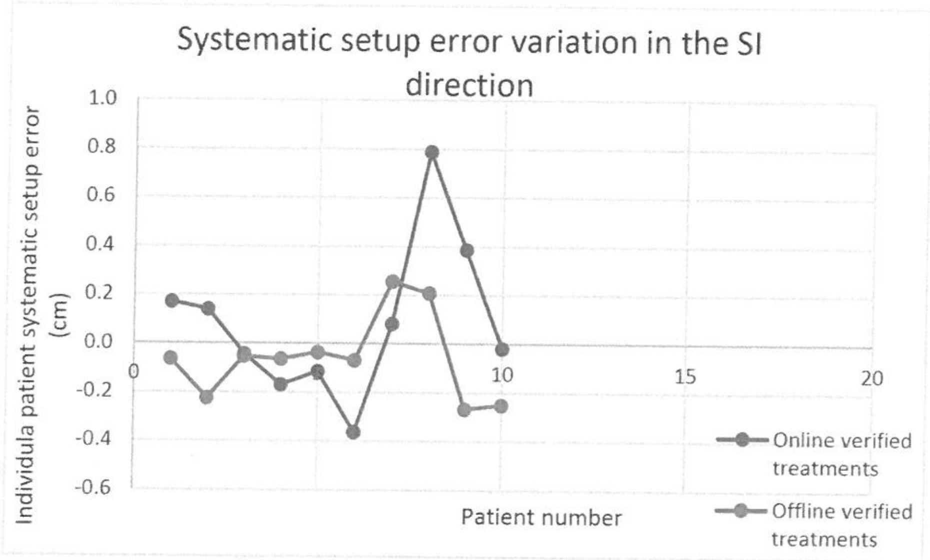

Figure 4.10: Variation in the individual patient systematic setup errors (m_i) in the SI direction.

The mean ± one standard deviation of the individual systematic setup errors of patients treated with the base plate localized to the treatment couch is shown in Tables 4.7 and 4.8 for online and offline verification respectively.

Mean ± one standard deviation of individual systematic setup errors of patients with online verification(cm):		
AP	ML	SI
-0.01± 0.20	0.00 ±0.05	-0.08 ± 0.06

Table 4.7: Mean ± one standard deviation of the individual systematic setup errors in all three principle directions for patients with online verification done.

Mean ± one standard deviation of individual systematic setup errors of patients with offline verification(cm):		
AP	ML	SI
-0.01 ± 0.20	0.00 ± 0.05	-0.08 ± 0.06

Table 4.8: Mean ± one standard deviation of the individual systematic setup errors in all three principle directions for patients who had offline verification done.

The absolute scalar displacement of the individual systematic setup errors was calculated using the following formula:

Absolute scalar displacement= $\sqrt{m_{i_{Vrt}}^2 + m_{i_{Lat}}^2 + m_{i_{Lat}}^2}$

With:

$m_{i_{Vrt}}$ is the individual systematic setup error in the AP direction.

$m_{i_{Lat}}$ is the individual systematic setup error in the ML direction.

$m_{i_{Long}}$ is the individual systematic setup error in the SI direction

The absolute scalar displacement of the individual systematic setup errors of patients treated with the base plate localized to the treatment couch is shown in Figure 4.11.

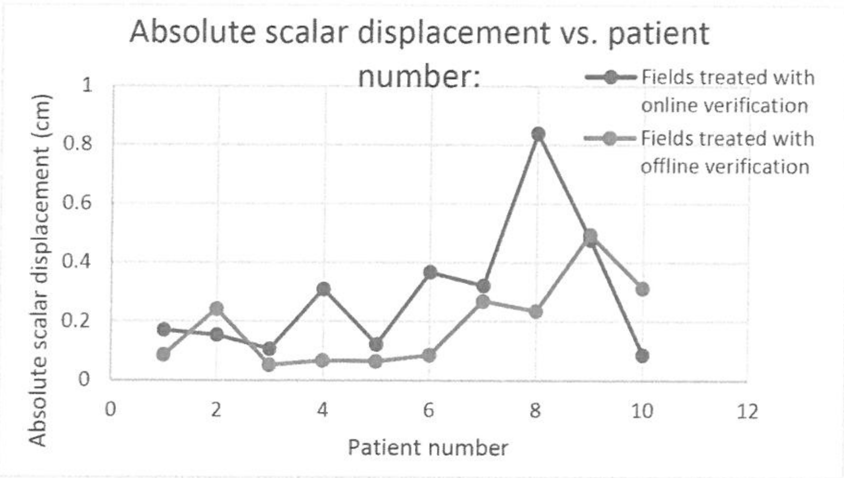

Figure 4.11: Absolute scalar displacement of the individual systematic setup errors.

The online and offline individual patient systematic setup errors are comparable. Reasons for this could be that:

- It is much easier to see bony land marks with offline verification and adjust patient position accordingly due to the imaging being done with kV x-rays on the simulator as opposed to MV photons online.
- The radiotherapists verifying the patient position are possibly more accurate when using the simulator as it does not take treatment session time.

4.2.2 OVERALL MEAN VARIATION:

The overall mean systematic setup errors of patients treated with the base plate localized to the treatment couch are shown in tables 4.9 and 4.10.

Overall mean variation (cm):		
AP	ML	SI
-0.04	0.04	0.09

Table 4.9: Overall mean systematic setup variation (M) of patients that had online verification done.

Overall mean variation (cm):		
AP	ML	SI
-0.03	0.06	-0.06

Table 4.10: Overall mean systematic setup variation (M) of patients that had offline verification done.

The overall mean variations are comparable for online and offline verified patients.

4.2.3 POPULATION RANDOM ERROR:

Population Random Setup error (cm):		
AP	ML	SI
0.04	0.14	0.79

Table 4.11: Population random setup error (Σ) of patients that had online verification done.

Population random setup error (cm):		
AP	ML	SI
0.06	0.17	0.39

Table 4.12: Population random setup error (Σ) of patients that had offline verification done.

The population random setup errors are comparable to those found in literature for this group of patients. Since the population random error is the mean of the individual random errors and the individual random error is the standard deviation of the difference in couch position from fraction to fraction, the verification method should not have had an impact on it, the random errors are however comparable for offline and online verification. The population random error is smallest in the AP direction and largest in the SI direction [7,15,17,19,42–44].

4.2.4 POPULATION SYSTEMATIC ERROR:

Population Systematic Setup error (cm):		
AP	ML	SI
0.10	0.17	0.33

Table 4.13: Population systematic setup variation (σ) of patients that had online verification done.

Population systematic setup error (cm):		
AP	ML	SI
0.10	0.13	0.18

Table 4.14: Population systematic setup variation (σ) of patients that had offline verification done.

The population systematic setup errors are comparable to those found in literature for this group of patients. Since an individual systematic setup error is the mean displacement from the planned patient position for all fractions treated and the population systematic error is the standard deviation of the distribution of individual patient setup errors, it would be expected that the online population systematic setup error would be smaller than the offline error. They are in fact, comparable, and even slightly larger than the offline verified patient group. The population systematic setup errors are smaller than the random errors. The setup process is therefore adequate.

4.2.5 CTV-PTV AND OARV-PRV MARGINS:

Tables 4.14 and 4.15 shows margin sizes in every principal direction that was calculated using various margin recipes (equations) as found in the literature.

CTV-PTV margin (cm)			Reference for equation:
AP	ML	SI	
0.28	0.55	1.53	20
0.20	0.39	1.18	37
-0.03	0.22	1.07	19
0.22	0.44	1.21	43
OARV-PRV margin (cm)			
AP	ML	SI	
0.024+/-0.007	0.075+/-0.0.79	0.09+/-0.126	33

Table 4.15: CTV-PTV margins and an OARV-PRV margin of patients that had been online verified.

CTV-PTV margin (cm)			Reference for equation:
AP	ML	SI	
0.31	0.48	0.80	20
0.22	0.35	0.61	37
0.00	0.15	0.42	19
0.25	0.38	0.63	43
OARV-PRV margin (cm)			
AP	ML	SI	
0.024+/-0.007	0.075+/-0.0.79	0.09+/-0.126	33

Table 4.16: CTV-PTV margins and an OARV-PRV margin of patients that had been offline verified.

Factors that would also influence the margin sizes such as rotational setup errors and internal organ movement are not included here. These margin sizes should thus not be used to adjust margin sizes used at Livingstone Hospital.

4.3 SETUP ERRORS OF ELECTRON FIELDS:

4.3.1 DAILY TREATMENT COUCH POSITIONS OF A SINGLE PATIENT TREATED WITH ELECTRON FIELDS:

All electron fields were treated with the base plate not localized to the treatment couch. Electron and photon field treatments formed part of the same fraction and the base plate was in one position for the entire fraction of treatment.

Daily couch position variations in the three principal directions for a right lateral posterior neck electron field from a single patient can be seen in figure 4.12.

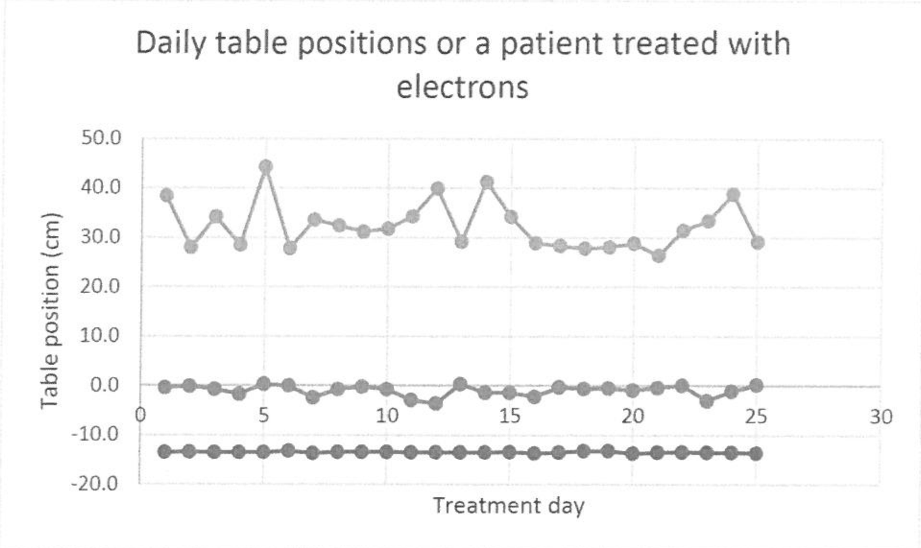

Figure 4.12 Daily table position variation in the three principal directions for a single patient treated with a right lateral posterior neck electron field.

4.3.2 POPULATION RANDOM SETUP ERROR FOR ELECTRON FIELDS:

Population random setup error (cm):		
AP	ML	SI
0.93	1.32	3.36

Table 4.17: Population random setup variation (Σ) of patients treated with electron fields.

The population random errors calculated for electrons, using the couch position as a surrogate for patient position, are comparable to those calculated for photon fields treated with the base plate not localized to the treatment couch in the ML and SI directions and larger in the AP direction.

4.3.3 POPULATION SYSTEMATIC SETUP ERROR FOR ELECTRON FIELDS:

Population Systematic Setup error (cm):		
AP	ML	SI
1.54	2.72	2.87

Table 4.18: Population systematic setup variation (σ) of patients treated with electron fields.

The population systematic errors calculated for electrons, using the couch position as a surrogate for patient position, are comparable to those calculated for photon fields treated with the base plate not localized to the treatment couch in the ML and SI directions and larger in the AP direction.

4.3.4 TRANSLATION FROM THE PHOTON FIELD PATIENT POSITION TO THE ELECTRON FIELD PATIENT POSITION:

To examine the large population setup errors calculated for electron fields, the translation from the photon field patient position to the electron field patient position was also examined. Figures 4.13 and 4.14 show this translation from fraction to fraction for a single patient treated with right and left lateral posterior electron fields respectively.

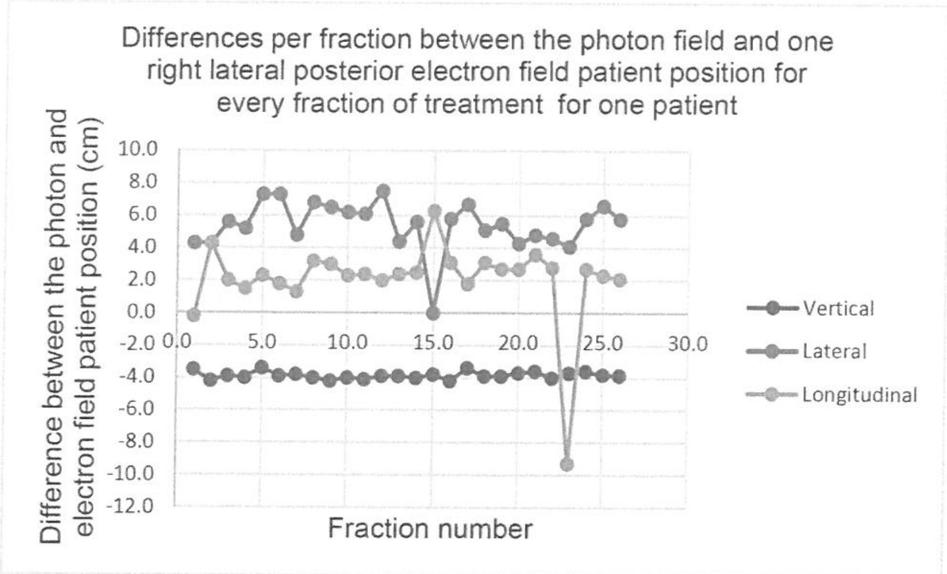

Figure 4.13: Fractional differences in photon field patient position and right lateral posterior electron field patient position.

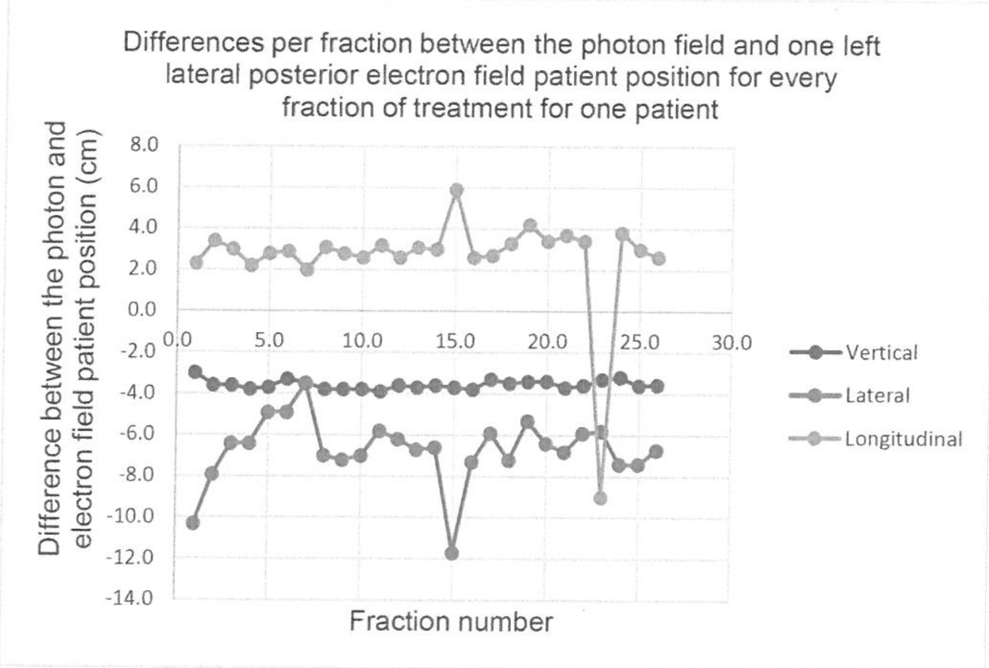

Figure 4.14: Fractional differences in photon field treatment position and the left lateral posterior electron field patient position.

The difference between the photon field patient position and the electron field patient position varies in the AP (couch vertical) direction due to the fact that the personal shielding could be stuck onto either the anterior or posterior sides of the applicator. The difference between the photon field patient position and the electron field patient position varies in the SI (couch longitudinal) direction due to the fact that the personal shielding could be stuck onto either the inferior or superior sides of the applicator. The treatment couch would have to be moved vertically and/or longitudinally respectively, to compensate for this and to once again align the field light up with the electron treatment field position. For two fractions of treatment the difference between the photon field patient position and the electron field patient position in the SI direction is substantially larger than for the other fractions. This could be because the base plate was moved in between the photon and electron field treatments, which would have resulted in a different treatment couch translation.

The differences in the photon field patient position and the electron fields' patient positions in the ML direction, were however unexpected because this would indicate a variation in the source to surface distance (SSD) from fraction to fraction. Table 4.18 shows the minimum and maximum ML distance between the photon and electron fields' patient positions as well as the variance of this distance for all fractions for all electron fields treated.

Minimum and maximum distances and variance between photon field treatment position and right lateral posterior electron field treatment position in the ML direction			Minimum and maximum distances and variance between photon field treatment position and left lateral posterior electron field treatment position in the ML direction		
Minimum (cm)	Maximum (cm)	Variance (cm)	Minimum (cm)	Maximum (cm)	Variance (cm)
-11.70	-3.5	2.4	0.00	7.5	2.1
-8.1	-5.6	0.5	2.3	7.1	1.2
-7.8	-5.5	0.44	5.1	8.5	0.53
-9.9	-5.9	0.64	4.9	7.9	0.36
-7.9	-5.8	0.4	3.6	9.2	1.5
-11.1	-4.3	1.3	No left electron field treated		
No right electron field treated			3.5	12.1	4.7
No right electron field treated			5.5	7.4	0.18

Table 4.19: Minimum and maximum distances between photon field patient position and electron field patient position as well as the variance of the distance for all fractions for the 8 patients treated with electron fields.

The variance should be equal to zero in the ML direction for every electron field. Since the variance does not equal zero, it implies either that the SSD was not consistently set up to the same point on each fraction, or that the entire base plate (patient) was shifted on the tabletop between the photon and electron setups. The population setup error in the ML direction may not therefore be a true reflection of the setup accuracy because the base plate was not fixed to the treatment couch.

The translation from the photon to the electron field patient position differed from fraction to fraction for all patients. The population random and systematic setup errors calculated are thus not a true reflection of reality.

5 CONCLUSIONS AND RECOMMENDATIONS:

- Photon fields treated with the base plate visually centered on the couch resulted in the largest setup errors in the ML and SI directions as the base plate could be placed anywhere along and across the treatment couch, and the couch moved to compensate for this. The CTV – PTV and OARV- PRV margins could only be reliably confirmed in the AP direction. The setup errors calculated for this group are therefore not necessarily a reliable indication of the actual patient position.
- Online and offline systematic setup errors calculated with data taken when the base plate was localized to the treatment couch, were found to be comparable. In some cases patients' verified offline had smaller setup errors. It is recommended that offline patient position verification is performed in departments where online images are of a poor quality or not available.
- Offline verification is recommended in resource-constrained environments in terms of increasing the accuracy of patients treated when online verification is not able to be performed.
- Population systematic setup errors are mostly smaller than the random setup errors. This implies that there was less of an overall shift from the planned patient position than in the day to day setup errors.
- For patients with the base plate localized to the treatment couch the margin sizes are mostly well within the 0.5 cm margin used at Livingstone Hospital. However, rotational setup errors and internal organ movement were not taken into account, hence margin sizes at Livingstone Hospital should not be reduced. A future study could be designed and conducted to determine patient rotation at Livingstone Hospital.
- It is recommended that a pen as thin as possible is used for making reference and isocenter markings on the customized masks.
- Due to intrafraction re-positioning of the patient, setup errors collected during this study could not reliably be determined for patients treated with electrons. As such, it is recommended that the setup accuracy for electron field treatments at Livingstone Hospital be investigated further.
- It is recommended that a similar electron field setup study be conducted at another institution wherein the immobilization system is localized to the treatment couch. Standardized electron field shaping and a fixed SSD that will not result in couch-applicator positioning restrictions in the lateral direction, are also recommended.

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