Evaluating setup accuracy of a positioning device for supine pelvic radiotherapy

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Johannesburg, 2011

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any University.

Sign: ....

Eskadmas Yinesu Belay

Date: ...Sep 28, 2011...

ABSTRACT

Aim: This study aimed at evaluating the accuracy of the treatment setup margin in external beam radiotherapy in cervical cancer patients treated supine with or without the CIVCO "kneefix and feetfix"^{TM} immobilizing devices.

Methods and materials: 2 groups of 30 cervical cancer patients each, who were treated supine with two parallel opposed fields or a four-field "box" technique were selected randomly. The treatment fields were planned with a 2 cm setup margin defined radiographically. The first group was treated without any immobilization and the second group was treated with the "kneefix and feetfix"^{TM} immobilization device. Both groups of patients were selected from the patients treated on one of two linear accelerators (linac), which had weekly mechanical quality control (QC). All patients had pre-treatment verifications on the treatment machine in which a megavoltage X-ray film was taken to compare with the planning simulation film. Both films were approved by the radiation oncologist managing the patient. In this study the position of the treatment couch as at the approved machine film was taken as the intended or planned position for the immobilized patients. The digital readouts of the daily treatment position of the couch were recorded for each patient as the absolute X (lateral), Y (longitudinal), and Z (vertical) position of the couch from the record and verify system interfaced to the treatment machine.

A total of 1241 (582 for the immobilized and 659 for the non-immobilized patient group) daily treatment setup positions were recorded in terms of the X, Y and Z coordinates of the couch corresponding to the Medio-lateral (ML), Supero-inferior (SI) and Antero-posterior (AP) directions of the patient, respectively. The daily translational setup deviation of the patient was calculated by taking the difference between the planned (approved) and daily treatment setup positions in each direction. Each patient's systematic setup error (m_i) and the population mean setup deviation (M), was calculated. Random (σ) and systematic ($\sum$) setup errors were then calculated for each group in each direction. The translational setup variations found in the AP,

ML, SI directions were compared with the 2 cm x 2 cm x 2 cm Planning Target Volume (PTV). Couch tolerance limits with the immobilization device were suggested based on the ± 2SD (standard deviation) obtained for each translational movement of the treatment couch.

Result: The random and systematic errors for the immobilized patient group were less than those for the non-immobilized patient group. For the immobilized patient group, the systematic setup error was greater than the random error in the ML and SI direction as shown in Table I.

Table I: The random and systematic errors in the setup in the Antero-posterior (AP), Medio-lateral (ML) and Supero-inferior (SI) directions and the suggested couch tolerance limits for both patient groups.

	Immobilized patient group			**Non-immobilized patient group**		
	AP (cm)	ML (cm)	SI (cm)	AP (cm)	ML (cm)	SI (cm)
Random error (σ)	0.30	1.35	1.26	0.37	2.74	7.83
Systematic error (∑)	0.19	1.55	1.64	0.33	1.70	8.11
Suggested couch tolerance limits (±2SD)	0.70	4.04	4.08	0.88	4.76	N/A

Almost all treatment setup positions had less than 2 cm variation in the AP setup for both patient groups however; one third of the immobilized positions had more than 2 cm variation in the setup in the ML and SI directions.

Conclusion: The "kneefix and feetfix"^{TM} immobilizing device resulted in a minor improvement in both the random and systematic setup errors. The systematic setup errors need to be investigated further. There are measurable patient rotations of more than 2 cm in the setup margin with the immobilizing device and this should be confirmed with an imaging study. The 2 cm margin in the ML and SI directions established at simulation should not be changed for these patients. A 1 cm tolerance in the AP setup margin could be introduced at this institution.

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DEFINITION OF TECHNICAL TERMS, ACRONYMS AND SYMBOLS

AAPM: American Association of Physicists in Medicine.

AP: Antero-posterior.

cm: centimeter.

CMJAH: Charlotte Maxeke Johannesburg Academic Hospital.

CT: Computed Tomography.

CTV: Clinical Target Volume

EPID: Electronic Portal Imaging Device

IAEA: International Atomic Energy Agency

ICRU: International Commission of Radiological Units and Measurements

IM-WPRT: Intensity Modulated-Whole Pelvic Radiotherapy

LANTIS: "Local Area Network Treatment Information system"™

Linac: Linear accelerator

ML: Medio-lateral.

ODI: Optical Distance Indicator

PTV: Planning Target Volume.

QA: Quality Assurance.

QC: Quality Control.

SAD: Source to Axis Distance.

SD: Standard deviation

SI: Supero-inferior.

∑: Systematic Setup error of the population. This is the standard deviation of the individual systematic errors in the specified direction.

σ: Random setup error of the population. This is the standard deviation of the daily treatment setup variations in the specified direction.

3D-CRT: Three Dimensional Conformal Radiotherapy.

1. INTRODUCTION

1.1 Background

Accuracy and reproducibility of the patient's position is fundamental to the successful delivery of radiation therapy[1]. However many aspects of radiotherapy are subject to uncertainty. The most common uncertainties in external beam radiotherapy are the position of the target to be treated, its clinical margin and the position of the surrounding patient anatomy with respect to the treatment beams[2,3]. These uncertainties lead to delivery errors, *i.e.*, differences between the dose distribution as intended by a treatment plan and the actual dose distribution delivered to a patient during a course of treatment sessions.

Pelvic cancer is an umbrella term applied to any cancer occurring in the pelvis. This includes cervical, ovarian, bladder, uterine, vaginal, endometrial and prostate cancers. Many studies have proven that positioning of patients for pelvic radiotherapy is relatively inaccurate and subject to set up variations that are probably greater than other sites in the body[4, 5]. Motion of external skin marks relative to internal structures, the non rigid nature of the area, patient rotation and day to day variations in rectal and bladder filling for instance, make the pelvis relatively difficult to set up accurately[6].

Patient set up error has a component of random and systematic variations. Hurkmans *et al.*[7] suggested that the main sources of errors are mechanical shortcomings (e.g. laser misalignment), patient related (e.g. skin mark movement) or fixation related (e.g. patient mobility). In addition to these, the precision with which the radiation technologists are able to position the patient using anatomical reference marks and the physical and mental state of the patient also influences the set up accuracy.

Patient immobilization is proposed by many authors as the first solution to reduce setup errors[8], however immobilization devices do not always eliminate all errors and some institutions have failed to find evidence of significant improvement in setup with the use of immobilization devices[8, 9].

Patient setup deviations depend on the immobilizing device and the techniques used in each radiation oncology department. Errors reported in the literature should not be translated into daily practice, as each institution should evaluate its own setup techniques and immobilization devices in order to assure adequate patient immobilization and establish the setup margin that should be included in the local Planning Target Volume (PTV) [6, 10].

In order to determine the margins required around the Clinical Target Volume (CTV), the magnitudes of each type of error likely to be encountered during a fractionated course of radiotherapy must be assessed. If the sources and magnitudes of these errors are understood, treatment margins can be adjusted to account for the errors[11].

Most studies have been done to evaluate the setup accuracy and establish the setup margin for pelvic external radiotherapy using prostate cancer cases. However, no published study has been reported on the setup margins for cervical cancer cases in Africa, even though 80% of world's cervical cancer cases occur on this continent[12].

One of the aims of this study was to evaluate the patient setup accuracy during external beam radiotherapy of cervical cancer patients at the CMJAH. Since January, 2010 pelvic patients who are positioned supine are treated using the CIVCO "kneefix and feetfix"™ immobilizing devices at CMJAH. The "kneefix and feetfix"™ moulded cushions are locatable on the tabletops of all the Linear accelerators (Linac), cobalt-60 teletherapy units, simulators and the Computed Tomography (CT) scanner available at CMJAH. The immobilizing devices were introduced to improve reproducibility and comfort of these patients. Figure 1 shows the device located to the tabletop of a linac at CMJAH.

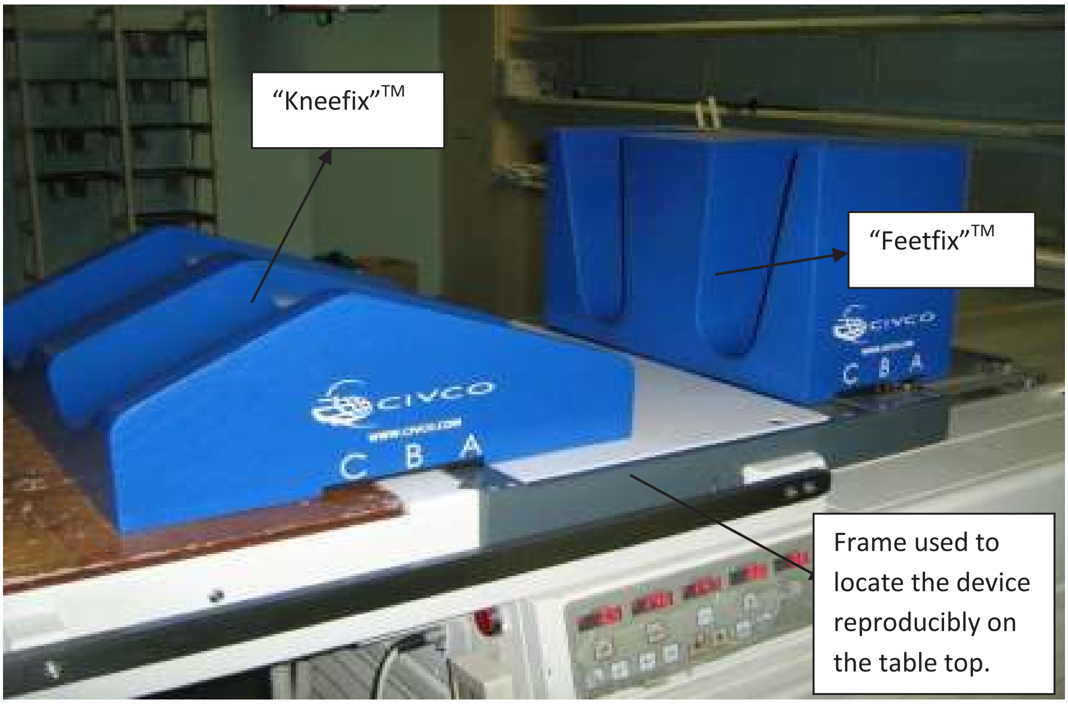

Figure 1: The "kneefix and feetfix"TM immobilizing device is shown located to the couch of a linac treatment machine. During patient simulation, the patient's knees and feet are positioned with appropriate positions (A, B or C) on both the knee and feet fix devices. These positions are recorded as setup parameters on the patient's electronic file in order to assist the setup on the treatment machine.

CMJAH has a record and verify system interfaced to all treatment units. At present all beam and field parameters are verified but only the couch angle is verified with a tolerance of ± 2 degrees. Lateral, longitudinal and vertical treatment couch positions are recorded but they are not verified and tolerance limits are not assigned to them. This study retrieved the daily digital records of the couch positions in order to establish suitable tolerance limits for the lateral, longitudinal and vertical couch movements.

With enough supporting data it is possible that daily verification and electronic recording of the couch co-ordinates, which represent the actual predicted position of the patient on the tabletop, can be introduced into the electronic patient chart. In addition, should the absolute position of the patient on the tabletop be predictable exactly, an automated set-up using a couch control function, which positions a patient relative to a known reference position, is also possible.

1.2 General Objectives

The general objective of this study was to obtain a measure of the setup deviations for supine positioned cervical cancer patients by using the digital readout of the couch position captured at each treatment session. In so doing the current setup margin (2 cm) in the Medio-lateral (ML), Supero- inferior (SI) and Antero-posterior (AP) directions that is included in the PTV could be evaluated quantitatively. Tolerance limits for verification and possible control of the translational movements of the couch were suggested.

1.2.1 Specific Objectives

1. Measure the systematic setup errors (Σ) in the ML, SI and AP position of the immobilized and non-immobilized groups of patients corresponding to the X, Y and Z co-ordinates of the treatment couch, respectively.
2. Measure the random setup errors (σ) in the ML, SI and AP position of the immobilized and non-immobilized groups of patients corresponding to the X, Y and Z co-ordinates of the treatment couch, respectively.
3. Evaluate whether the "feetfix and kneefix"™ immobilizing device improves the reproducibility of patient positioning on the couch.
4. Suggest tolerance limits for the horizontal (X), longitudinal (Y), and vertical (Z) couch movements.
5. Evaluate whether the current PTV of 2 cm x 2 cm x 2 cm can be reduced based on the direction and magnitude of the setup variations found from patients treated with the immobilizing device.

2. PRELIMINARY LITRATURE REVIEW

2.1 Patient setup errors

In 2-dimensional radiotherapy a patient typically has one planning session followed by multiple treatment sessions. In the planning phase the patient's CT or simulator image is used to construct a treatment plan. The intention is to deliver this plan in all treatment sessions[13]. However there are sources of uncertainties that may impact on the exact reproducible delivery of the plan in each treatment session. The International Commission of Radiation Units and Measurements (ICRU)[14] considers patient setup variation, organ motion and deformation, and machine related errors as sources of geometric uncertainties. With modern radiotherapy equipment, the latter sources of error are generally considered small compared to other sources if a quality control programme is in place[13].

Setup errors are separated into two main components, systematic (Σ) and random (σ). Systematic errors (Σ) are defined as variations that are persistent during the whole course of treatment. For individual patients, it is defined by the mean value of displacements along a specified coordinate. For the whole group, the distribution of systematic deviations is determined by the standard deviation of the values of the mean shifts of individual patients along a specified coordinate. Random errors (σ) are defined as variations that may occur by chance. The random displacements, correspond to day-to-day setup variations during the course of treatment, and are represented by the amount of dispersion of individual points around the mean[4, 13, 15].

Numerous setup error studies have measured both systematic and random errors using different techniques. Some studies measured setup errors by taking megavoltage films or performing electronic portal imaging during patient treatment sessions. Kasabasic *et al*.[4] measured patient positioning errors in the pelvic area using variations in field positioning relative to bony landmarks obtained from daily images of orthogonal portal films. Systematic and random setup errors in the ML, SI and AP directions were calculated. In the study the daily setup deviations were defined as the distance from the centre of the treatment field to the visible bony anatomical landmarks along each axis. The daily setup deviations of each patient in the ML and SI directions were determined using film taken in the AP field, and the deviation in the AP direction was determined from the lateral film[4, 10, 11].

Haslam *et al*.[15] evaluated setup errors in patients treated with Intensity Modulated Whole Pelvis Radiotherapy (IM-WPRT) for gynecological malignancies by comparing portal images to simulation images. Fiorino *et al*.[16] also used an imaging technique in order to compare the setup accuracy of two different immobilizing systems for supine positioned prostate patients.

Imaging techniques are usually employed to correct patient positioning errors[17]. The use of an EPID or megavoltage film combined with visual inspection can lead to large intra and inter-observer variations and it is a time consuming process to use in resource-constrained radiotherapy departments[7, 17, 18]. In addition to this, some radiation therapy departments do not use imaging at all for verifying patient positioning. For these situations, a record and verify system is recommended to ensure correct daily patient treatment parameters[17].

Hadley *et al*.[17] set tolerance limits for the treatment couch to detect mistakes in patient setup by using the couch digital position readout. The daily recorded patient treatment couch positions in the ML (X), SI (Y), and AP (Z) directions were used to determine the variation in the couch location for different treatment sites and immobilizing devices. The ability of immobilization to reduce variation in the digital readout of the treatment couch was investigated by calculating standard deviations from mean couch positions over the course of treatment. The calculated standard deviations were set as tolerance limits for the treatment couch.

Vanlin *et al.*[19] compared patient setup accuracy using a "couch height set up" method with a "laser setup" method. In the study two groups of prostate cancer patients were investigated. The first group of patients were setup on the treatment couch using skin marks aligned with lasers and in the second group the patient's simulation couch (digital read out) position was taken and the treatment couch was set at the same height as defined during simulation. The "couch height set-up" method was found to reduce the systematic and random errors compared to the "laser setup method". This indicates that the daily setup of the patient should be performed using the digital readout of the couch.

2.2 Patient Immobilization

A number of techniques have been developed to immobilize patients treated in the pelvic region. Some studies showed inconclusive and contradictory results on the efficiency of immobilizing devices in different institutions[16, 20]. More recently, Fiorino *et al.*[16] compared the positioning accuracy of prostate cancer patients who were treated with leg immobilization, pelvic immobilization or without any immobilization. It was reported that the leg immobilization technique improved patient set up accuracy in the AP, ML, and SI directions. When considering major deviations (defined as >5 mm), patients with pelvic immobilization showed a significantly higher number of major shifts compared to patients with leg immobilization in the AP direction (21.6% versus 4.4%) and in the ML direction (7% versus 1.7%). In contrast, patients with pelvic immobilization showed a slightly worse setup accuracy compared to patients with no immobilization device in the AP direction and an improved setup in the ML direction.

Soffen *et al.*[21] reported that the daily setup margin for prostate cancer patients was 3.3 mm with no immobilization and 1 mm when immobilized in the supine position using a personalized low density alpha-cradle™ cast. Catton *et al.*[9] investigated positional accuracy for lateral fields using a leg immobilization device and showed a decrease in the number of large (defined as >5 mm) PA shifts from 17% without immobilization to 8% with immobilization. Similar results were found by Mubata *et al*.[22] who reported a significant reduction of large (>5 mm) shifts for prostate patients immobilized with a VacFix bag™ (from 18% without immobilization to 4% with immobilization). In the study daily portal images were acquired and compared with the Digital Reconstructed Radiographs (DRRs) or simulator films in ordered to calculate the systematic and random errors.

Song et al.[20] compared five groups of prostate patients treated with three-dimensional conformal radiotherapy (3D-CRT). The first group had with no immobilization and while the other 4 groups had immobilization devices. The second to fifth groups were immobilized with an alpha cradle™ from the waist to the upper thighs; an alpha cradle from the waist to below the knees; a styrofoam leg immobilizer below the knees; and an aquaplast™ cast encompassing the entire abdomen and pelvis to midthigh together with an alpha cradle™ immobilization to their lower legs and feet, respectively. The results showed that "insignificant" differences were found in the rate of serious displacements. Fiorino *et al*.[16] concluded that not all immobilizing systems can improve the set up accuracy, and therefore, it is recommended that the performance of a new immobilization device should be evaluated.

2.3 Set up margin

ICRU[23] defined CTV as "the demonstrable tumor including the volume of suspected subclinical microscopic malignant disease that should receive the prescribed dose". To account for uncertainties, this volume must be extended with a 3D margin (CTV-PTV), thereby yielding the PTV.

Many researchers have defined a formula to calculate this margin using clinical data. ICRU[14] states that systematic (Σ) and random errors (σ) should be added in quadrature ($\sqrt{\Sigma^2 + \sigma^2}$) to calculate the setup margin. However, many authors agree that this approach is an ideal situation because it assumes that random and systematic errors have an equal effect on the dose distribution, which may not necessarily be the case. Van Herk *et al.*[24] found that systematic errors lead to a much larger under dosage to the CTV compared with large random errors. Systematic errors cause a shift of the cumulative dose distribution whereas random errors blur the dose distribution relative to the target[17]. In other words, systematic errors have a major impact on the magnitude of the required planning margins[24].

Van Herk *et al.*[24] provided a formula for calculating a margin to ensure that a minimum dose of 95% of the prescribed dose to the CTV over the course of all treatment sessions in 90% of the patients, which is given by $2.5\Sigma + 0.7\sigma$. Stroom *et al.*[26] suggested a similar formula ($2\Sigma + 0.7\sigma$) to ensure that on average, 99% of the CTV receives more than or equal to 95% of the prescribed dose.

Part of the CTV-PTV margin depends on setup deviations; its width is not unique for all institutions because of the differences in positioning methods, treatment techniques and Quality Assurance (QA) standards. Therefore it is advisable to use local data from institutional protocols to propose one's own set up margin[27].

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Ethics approval

The study has been approved by the research ethics committee at the University of the Witwatersrand and approval number is M10629.

3.1.2 Patients group

A random selection of cervical cancer patients, who were treated at CMJAH in the period between April 2009 and June 2010, were included in the study. The population sample size was determined by statistical computation and therefore, a total of sixty patients treated in a supine position on one of two Linacs (Siemens Primus^{TM}) were investigated retrospectively. Out of the sixty patients, thirty were selected who were treated with no immobilization, and the rest were treated with the "kneefix and feetfix"^{TM} immobilization device.

3.1.3 Treatment technique

All patients were simulated in the supine position on a Toshiba LX50^{TM} simulator. Five skin marks, one at the center of the anterior field and two anti-rotational tattoos on both the lateral sides of the patient were marked and simulation films were taken. Treatment fields of Antero-posterior (AP) and Postero-anterior (PA) fields or a four field technique (AP, PA, right and left lateral fields) were planned with 2 cm margins defined by the clinician from bony anatomy. All patients' treatment parameters were recorded on the patients file and transferred to the treatment machine using the LANTIS^{TM} (record and verify system). Patients were treated with a 100 cm Source to

Axis Distance (SAD) isocentric technique. Each treatment session of a patient was therefore carried out at one couch position.

3.1.4 Immobilizing device

A new immobilizing device "kneefix and feetfix"^{TM} was implemented at CMJAH in January, 2010. A localizer system was developed to locate the device reproducibly on the simulator or treatment couch. The "kneefix and feetfix"^{TM} device is made up of light weighted closed cell foam, which is easy to clean. The knee and feet cushions have three possible positions (A, B, and C), which are located in absolute coordinates on the table top as shown in Figure 2. The treatment couch location is not currently absorbed into the patient's digital file as a setup parameter, which is then verified. The couch position during treatment is however, captured and recorded on LANTIS^{TM}.

Figure 2: The supine positioned patient with the "kneefix and feetfix"^{TM} immobilizing device setup on a linac. The patient's knee is at position A and the feet are at position C.

3.1.5 Treatment machines

The data from two of the LINACs, where most of cervical cancer patients are scheduled for treatment in the department, were used for this study. The treatment machines had weekly mechanical quality control in which isocentric couch, collimator and gantry rotations, vertical, lateral and longitudinal couch movements; the accuracy of the Optical Distance Imaging (ODI), lasers, back pointer and treatment field light indicator were checked based on the Task Group 40 protocol published by the American Association of Physicists in Medicine (AAPM) [28].

3.2 Methods

3.2.1 Data collection

All patients had a portal imaging pre-treatment verification film on the treatment machine. This film was compared with the simulator image and approved by the radiation oncologist. The treatment couch digital readout of this verified patient position was taken as the intended or planned setup position in the study.

Using LANTIS^{TM}, the digital daily treatment couch absolute positions of each patient in terms of the X, Y, and Z position were recorded. These corresponded to the ML, SI and AP position of the patient respectively. A total of 1241 treatment setup positions (659 for the non-immobilized and 582 for the immobilized patient group) in each axis were collected and analyzed.

3.2.2 Statistical Analysis

The daily treatment couch digital readout of each patient (i) was compared with the couch digital readout of the planned (verified) position to determine the daily translational setup deviation (t_{if}) of each treatment fraction number (f) in each axis.

The random set up error (σ) of each patient group was calculated as the deviation of the setup position occurring between the different daily treatment sessions, while the systematic set up error (∑) was defined as the deviation between the verified (planned) patient position and the average daily treatment position of patient. The random and systematic errors for both groups of patients treated with and without immobilization were determined according to equations (1) and (2) [29].

$$\sigma = \sqrt{\frac{N}{F-N}\sum_{i=1}^{N}(F_i - 1)\sigma_i^2} \quad \text{……………………………………………….(1)}$$

$$\Sigma = \sqrt{\frac{N}{F(N-1)}\sum_{i=1}^{N}F_i(m_i - M)^2} \quad \text{…………………………….……….(2)}$$

where,

- *N* is the total number of patients in each group (in this case N = 30 for both immobilized and non-immobilized patient groups).
- *F* is the total number of fractions for each patient group which was 582 and 659 for the immobilized and non-immobilized patient groups, respectively.
- F_i is the total number of fractions received by any one patient (patient i), which varied between patients depending on the prescribed total number of treatment fractions.

- m_i is the average translational setup variation of patient i in one of the principal axes or it can be defined as the individual systematic setup error in the specified direction and is given by equation (3).

$$m_i = \sum_{f=1}^{F_i} \frac{t_{if}}{F_i} \quad \text{......(3)}$$

Where,

- t_{if} is the displacement (translational shift) between the daily patient treatment position and the planned (verified) position of patient i during fraction f along one of the principal axes.

M is the mean translational deviation, which is the average value of the overall fractions of all patients in each principal axes for each patient group, and is given by equation (4).

$$M = \frac{1}{F} \sum_{i=1}^{N} \sum_{f=1}^{F} t_{if} \quad \text{......(4)}$$

If the systematic setup error (∑) is the unknown standard deviation of the individual systematic setup error (m_i) for N patients in the group and t is the constant for the t-distribution with (N-1) degrees of freedom (at the 95% confidence limit), then an absolute value of M $> t\frac{\Sigma}{\sqrt{N}}$ indicates statistically significant overall systematic deviation at the 95% confidence limit[30].

The individual patient random error σ_i, is given in equation (5).

$$\sigma_i = \sqrt{\frac{1}{F_i - 1}\sum_{f=1}^{F_i}(t_{if} - m_i)^2} \quad (5)$$

This provides the standard deviation of the translational setup variations (t_{if}) around the mean (m_i) for each patient in each axis.

The set-up errors, Σ and σ, were defined as the standard deviations of the individual systematic and random set-up deviations for all patients, respectively. The reliability of the above statistical approach was dependent on the number of patients N and the setup positions F_i taken for each patient. All patients in each group were assumed to be coherent in terms of set-up technique. The calculation method assumes that both random and systematic components are normally distributed. Numerous studies of patient setup error support this assumption[31].

A large setup variation in the X and Y coordinates for non-immobilized patients was expected. Similar results were expected between the two patient groups in the couch height (Z).

4. RESULTS AND DISCUSSION

4.1 Translational setup variations

4.1.1 Ranges of setup variations

The range of setup variations measured in each direction for both patient groups are given in Table 1. A negative value indicates a setup shift from the isocenter in the posterior, right lateral and inferior direction of the patient.

Table 1: The overall range of setup variation for both patient groups in the AP, ML and SI directions.

Patient group	AP (cm)	ML (cm)	SI (cm)
Non-immobilized	-1.7 to +2.7	-7.9 to +6.3	-19.4 to +21
Immobilized	-1.4 to +2	-6 to +6.4	-8 to +6.5

In the non-immobilized patient group the highest range of translational setup variation of -19.4 to 21 cm was found in the SI direction. This variation in the SI direction was expected because patients without the immobilizing device had arbitrary daily setup positions along the longitudinal direction of the treatment couch. This variation reduced for the immobilized patient group and ranged between -8 and +6.5 cm.

In general, the range in couch position for the immobilized patient group reduced in all directions with respect to the other group. The highest translational setup variation is the left direction and is almost the same for both groups (+6.3 cm for the non-immobilized and +6.4 cm for the immobilized group).

4.1.2 Individual systematic setup variations (m_i)

For both patient groups, the individual systematic setup variation (average setup variation of each patient for all treatment fractions) was analyzed and is shown in Figure 3. 93.30%, 50% and 13.33% of the non-immobilized patients and 100 %, 43.33% and 53.33% of the immobilized patients had average setup variations of less than ±1 cm in the AP, ML and SI directions, respectively. All immobilized patients setup to within ±1cm in the AP direction only.

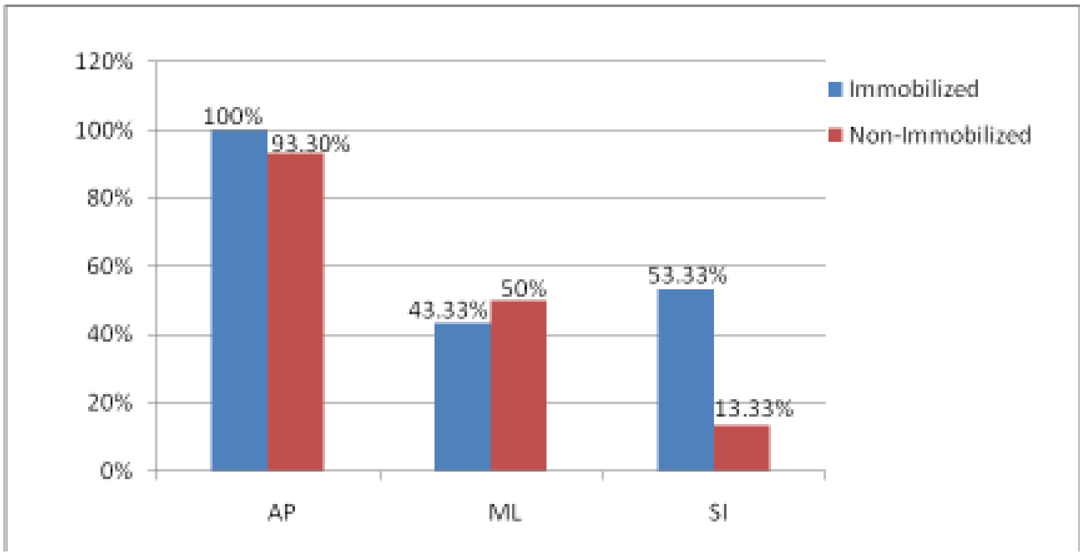

Figure 3: The percentage of patients with average setup variations of less than ±1 cm.

The number of immobilized patients with less than 1 cm average setup variation in each direction was more than the number in the non-immobilized group except in the ML direction. In the ML direction more non-immobilized patients had better setup accuracy, which implies that patients are generally centered better on the couch without an immobilization device. However the highest individual systematic setup variation of +4.87 cm was found for one patient in the non-immobilized group in the left lateral direction.

The individual systematic setup variations for both groups of patients are shown in Figures 4 to 6 in each direction.

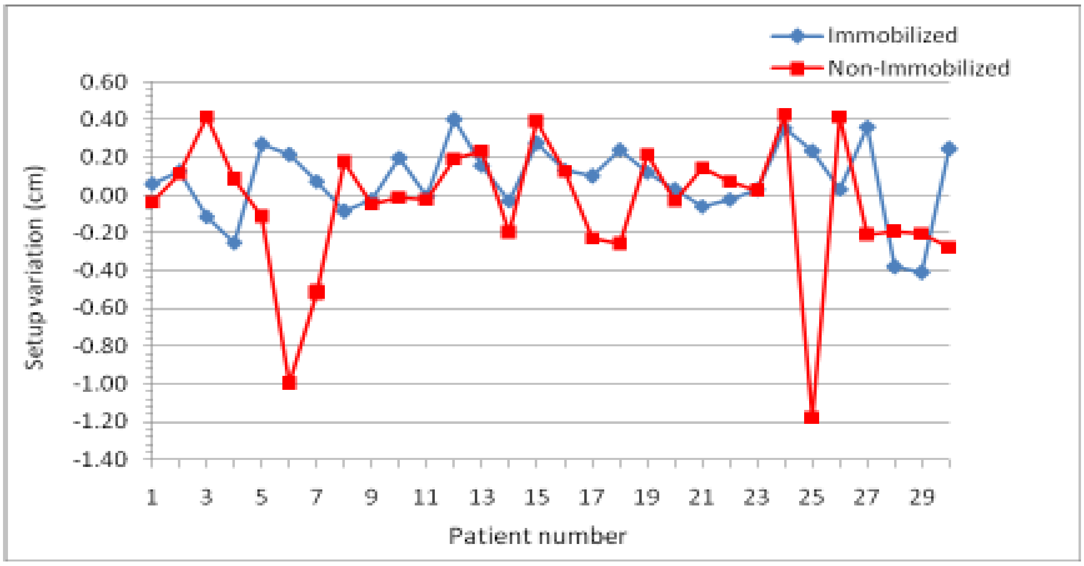

Figure 4: The distribution of individual patient systematic setup variations in the AP direction.

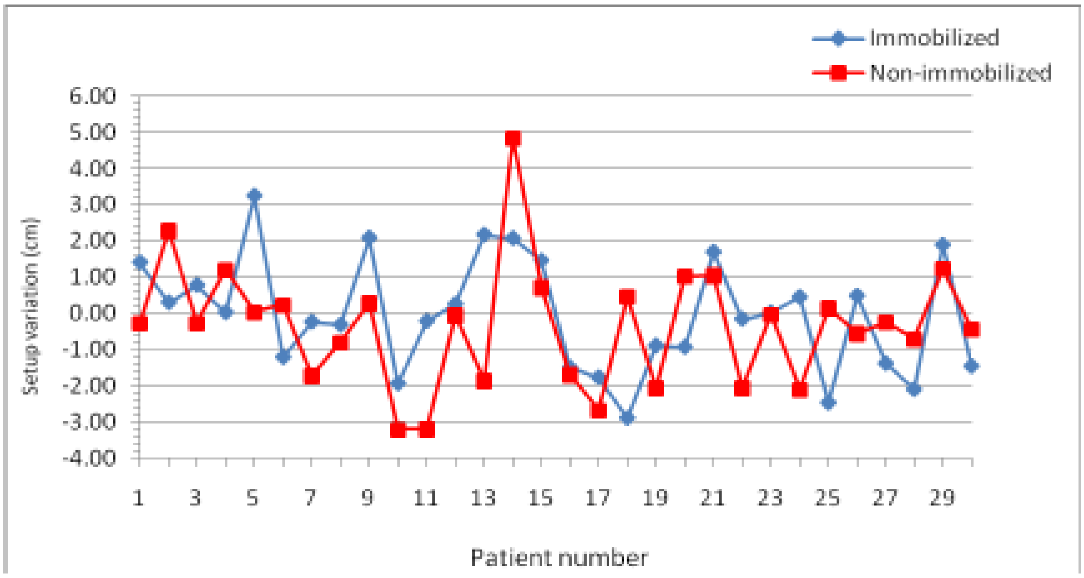

Figure 5: The distribution of individual patient systematic setup variations in the ML direction.

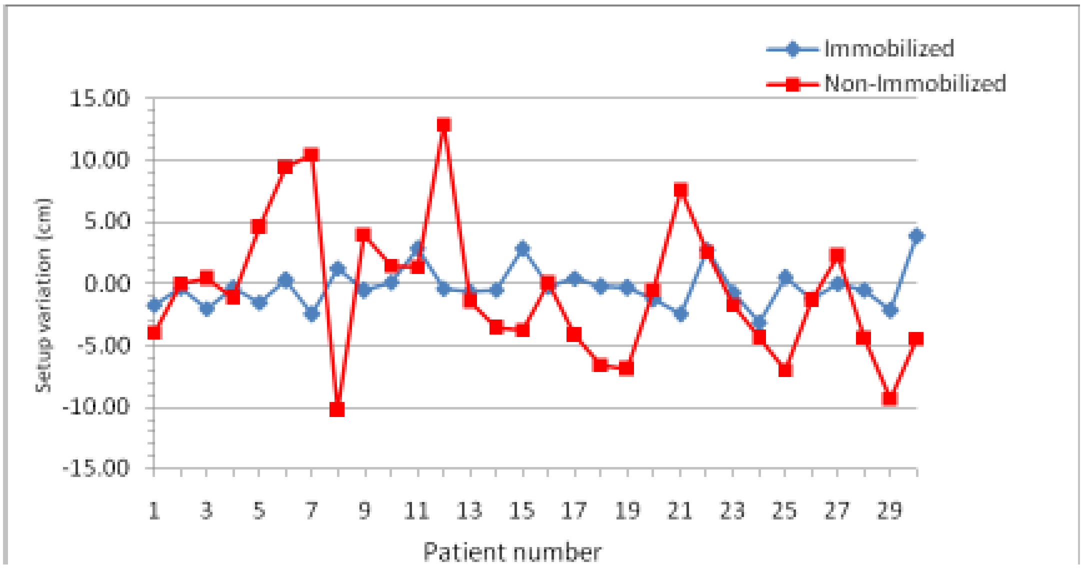

Figure 6: The distribution of individual patient systematic setup variations in the SI direction.

The highest individual systematic variation for immobilized and non immobilized patients was found to be 0.41 and 1.2 cm, 3.2 and 4.8 cm, and 3.8 and 12.9 cm in the AP, ML and SI directions, respectively.

Two non-immobilized patients had large systematic setup variations of 1 and 1.2 cm in the posterior direction. In the ML direction, 50% of immobilized and 60 % of non-immobilized patients had a systematic shift towards the right side of the patient regardless of the magnitude of the setup variation. Equivalently, 50 % of immobilized and 40 % of non-immobilized patients had a systematic shift towards the left direction. Due to the equal numbers of immobilized patients with shifts to the right and left sides, the magnitude of the overall mean systematic ML shift (M) is +0.03 cm which was calculated as the average of individual systematic setup variations in the ML direction.

As expected, the individual SI systematic setup variations are reduced for immobilized patients.

4.1.3 Overall mean variation (M)

The population mean setup variation (overall mean variation, M) of each patient group in each direction was determined as the average of the individual systematic variations (m_i) in each direction for all patients in the group. The results are shown in Table 2.

Table 2: The overall mean setup variation (M ± 1SD) of both patient groups in each direction.

Patient group	AP (cm)	ML (cm)	SI (cm)
Non-immobilized	-0.04 ± 0.48	-0.33 ± 2.30	0.56 ± 7.33
Immobilized	0.07 ± 0.35	0.03 ± 2.02	-0.32 ± 2.40

In order to conclude whether the immobilized patient group's overall mean systematic deviation (*M)* was statistically significant, a t-test was performed. The 30 (N=30) mean deviations *(m_i)* were assumed to follow a t-distribution with standard deviation equal to Σ. The degrees of freedom were 29 (N-1). For a 95 % confidence level and 29 degrees of freedom, the tabulated t-constants are 2.07, 0.135 and 0.845 for the AP, ML and SI directions, respectively. Since the absolute value of $M < t\frac{\Sigma}{\sqrt{N}}$. in the AP and ML directions, there was no indication of significance in the overall systematic deviation at the 95 % confidence level. The result did show however, that there was a statistically significant difference in the overall systematic deviation in the SI direction with immobilization as expected.

4.1.4 Patients' setup accuracy

All patients' treatment fields were initially planned with a 2 cm x 2 cm x 2 cm CTV-PTV margin. The setup accuracy of the daily treatment setup in each direction was evaluated by comparing it to this setup margin. As shown in Figure 7, the percentage of daily treatment setup positions less than or equal to 2 cm were 100%, 68.5 % and 63.8% in the AP, ML and SI directions for the immobilized group and 99.7% and 62.8% for the non-immobilized patient group in AP and ML directions, respectively.

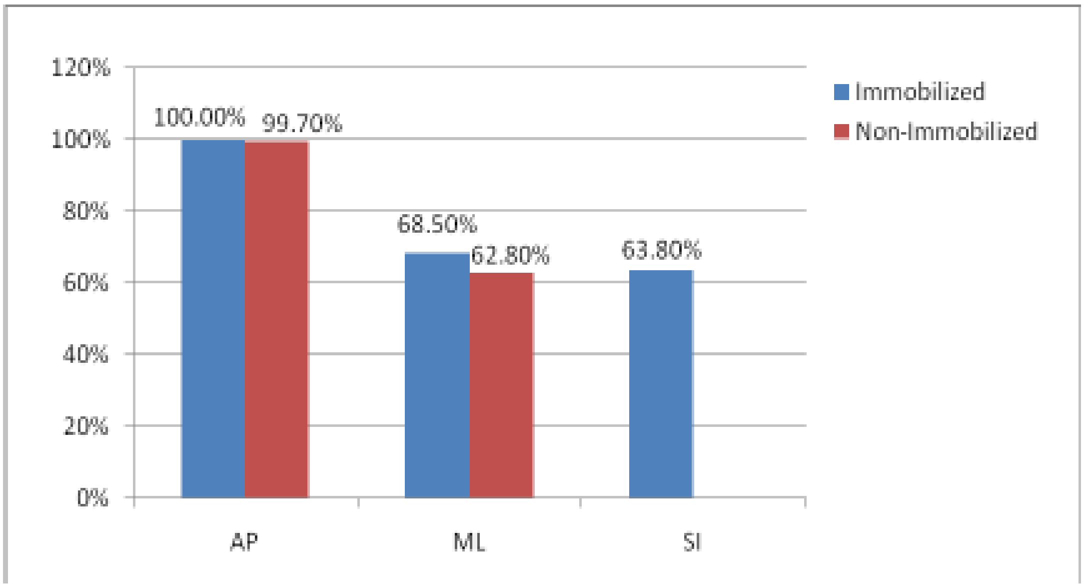

Figure 7: The percentage of daily treatment setup variations with in the setup margin (≤ 2 cm) in each axis.

The setup accuracy in the SI without immobilization was not determined because patients had arbitrary daily setup positions along the longitudinal direction of the treatment couch for each treatment session. For patients with immobilization, the daily lateral and longitudinal position of the patient on the couch was poorly reproduced by the knee and feet position locator (A, B and C) of the immobilizing device.

4.1.5 Random setup error (σ)

For all patients in each group, the random setup error was calculated as the standard deviation of the setup from the mean in each specified direction. The results are shown in table 3 in each direction for both patient groups.

Table: 3 The random setup variations of both patient groups in each direction.

Patient group	AP (cm)	ML (cm)	SI (cm)
Non-immobilized	± 0.37	± 2.74	± 7.83
Immobilized	± 0.30	± 1.35	± 1.26

The random setup errors reduced for the immobilized patient group by almost one half and one sixth compared with the non-immobilized patient group in the ML and SI directions, respectively. The results confirmed that the "kneefix and feetfix"™ device improved the random setup variation, which was expected.

4.1.6 Systematic setup error (∑)

The systematic setup error for all patients in each group was determined from the standard deviation of the values of the mean shifts (individual systematic setup variations) along a specified direction. The systematic setup variations reduced for the immobilized group in all directions. There was a statistical significance of systematic setup error only in the SI direction at the 95% confidence interval. Results are shown in Table 4 for both patient groups in each direction.

Table: 4 The systematic setup errors of both patient groups in each direction.

Patient group	AP (cm)	ML (cm)	SI (cm)
Non-immobilized	± 0.33	± 1.70	± 8.11
Immobilized	± 0.19	± 1.55	± 1.64

4.2 Couch tolerance limits with immobilization

Based on the results, couch tolerance limits could be suggested. Two standard deviations (± 2SD) of the translational setup variations (±0.7 cm, ±4.0 cm and ±4.8 cm) are suggested as couch tolerance limits to include 95% of the setup positions in the vertical (Z), Lateral (X) and longitudinal (Y) couch position, respectively. This implies that the treatment would be prohibited if the patient does not setup within these tolerances.

Tolerance limits in the Z and X axes of the couch are similar to those of Hadley who published ± 0.7 cm, ± 4.0 cm and ± 6.2 cm in the vertical (Z), lateral (X) and longitudinal (Y) axes, respectively for prostate cancer patients[19]. Daily digital readouts of the treatment couch position were also used in that study.

Couch tolerance limits of ± 0.9 cm and ± 4.8 cm were calculated similarly for the non-immobilized patient group in the Z and X axis, respectively.

4. CONCLUSIONS

1. The CIVCO "kneefix and feetfix"™ immobilizing device improved reproducibility of patient setup in the SI (longitudinal) direction.

2. The immobilizing device reduced the range of couch position in the AP and SI directions over which a patient was setup.

3. The random setup variations reduced for the immobilized patient group in all directions.

4. There was less setup variation using the immobilizing device; however the systematic setup errors were larger than the random errors. Therefore there is a need for further investigation such as correlation to patient size, treatment machine, treatment setup procedures, QA checks of the treatment setup process, and competence of treating radiotherapy technologists.

5. There are measurable patient setup variations which are more than the 2 cm in the ML and SI directions with the immobilizing device. Therefore it is not advisable to introduce full couch verification and control on the treatment machines.

6. The 2 cm margin in the ML and SI directions established at simulation should not be changed for these patients. A 1 cm tolerance in the AP setup margin could be introduced at this institution.

7. Regardless of patient comfort, the "kneefix and feetfix"™ immobilizing device has not shown significant improvement in the reduction of the setup margin.

8. A system that records the digital readout of the treatment couch positions can be used as an alternative offline method to evaluate treatment setup accuracy and suggest couch position tolerance limits.

6. REFERENCES

1. Kneebone A, Gebski V, Hogendroorn N and Turner S. A Randomized Trial Evaluating Rigid Immobilization for Pelvic Irradiation. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 56, No. 4, pp. 1105–1111, 2003*.

2. Sir MY, Epelman MA and Pollock SM. Stochastic Programming for Off-line Adaptive Radiotherapy. *http://www.springerlink.com/content/48m0n0378447w365/*

3. Kasabasic M, Faj D, Simlovic R, Svabi M, Ivkov A and Jurkovic S. Verification of the Patient Positioning in the Bellyboard Pelvic Radiotherapy. *Coll. Antropol. 32, Suppl. 2, pp. 211–215, 2008.*

4. Kasabasic M, Faj D, Nenad B, Zlatan F and Ilijan T. Implementing of the offline setup correction protocol in pelvic radiotherapy: safety margins and number of images. *Radiol.Oncol., Vol.41, No. 1, pp.49-56, 2007.*

5. Hunt MA, Schulthesis TE, Desbory GE, Hakki M and Hanks GE. An evaluation of setup uncertainties for patients treated to pelvic sites. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 32, No. 1, pp. 227-233, 1995.*

6. Lynn V. Immobilizing and Positioning Patients for Radiotherapy. *Seminars in Radiat. Oncol., Vol.5, issue 2, pp 100-114, 1995.*

7. Hurkmans CW, Remeijer P, Lebesque JV and Mijnheer BJ**.** Set-up verification using portal imaging; review of current clinical practice. *Radiother. Oncol., Vol. 58, pp.105-120, 2001.*

8. Clippe S, Sarrut D, Malet C, Miguet S, Ginestet C and Carrie C. Patient setup error Measurement Using 3D intensity-Based Image Registration Techniques. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 56, No. 1, pp. 259–265, 2003.*

9. Catton C, Lebar L, Warde P, Hao Y, Catton P, Gospondarowicz M, McLean M, and Milosevic M. Improvement in total positioning error for lateral prostatic fields suing a soft immobilization device. *Radiother. Oncol., Vol. 44, pp. 265-270, 1997.*

10. Creutzeberg CL, Althof VM, de Hoog M, Visser AG, Huizenga H, Wijinmaalen A and Levendag P. A quality control study of the accuracy of patient positioning in irradiation of pelvic fields. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 34, No. 3, pp. 697-708, 1996.*

11. Suzuki M, Nishimura Y, Nakamatsuk, Okumura M, Hashiba H, Koike R, Kanamori S, Shabibata T. Analysis of interfractional set-up errors and intrafractional organ motions during IMRT for head and neck tumors to define an appropriate planning target volume (PTV)- and planning organs at risk volume (PRV)-margins. *Radiother. Oncol., Vol. 78, pp. 283–29, 2006.*

12. Thun MJ, Delancey JO, Center MM, Jemal A and Ward EM. The global burden of cancer: priorities for prevention. *Carcinogenesis vol.31, No.1, pp.100–110, 2010*.

13. Stroom J and Ben J. Geometrical uncertainties, radiotherapy planning margins, and the ICRU-62 report. *Radiother. Oncol., Vol.64, pp. 75–83, 2002.*

14. International Commission on Radiation Units and Measurements. ICRU Report 62. Prescribing, recording, and reporting photon beam therapy (Supplement to ICRU Report 50). *ICRU, 1999.*

15. Haslam JJ, Lujan AE, Mundt AJ, Bonta DV and Roeske JC. Setup Errors in patients treated with Intensity Modulated Whole Pelvic Radiotherapy for Gynacological. *Med. Dosi., Vol. 30, No. 1, pp. 36-42, 2005.*

16. Fiorino C, Reni M, Bolognesi A, Catlaneo M and Calandrino R. Set-up error in supine-positioned patients immobilized with two different modalities during conformal radiotherapy of prostate cancer. *Radiother. Oncol., Vol.49, pp. 133-141, 1998.*

17. Hadley SW, Balter JM, and Lam KL. Analysis of couch position tolerance limits to detect mistakes in patient setup. *J. App. Clin. Med. Phys., Vol. 10, no.4, 2009.*

18. Gupta T, Chopra S, Kadam A, Agarwal JP, Devi PR, Laskar SG and Dinshaw KA. Assessment of three-dimensional set up errors in conventional head and neck radiotherapy using electronic portal imaging device. *Radiother. Oncol., Vol. 2, No. 1, pp. 1-8, 2007.*

19. Vanlin ENJ, Nijenhuis E, Huizenga H, van der Vight L and Visser A. Effectiveness of couch height-based patient set-up an off-line correction protocol in prostate cancer radiotherapy. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 50, No. 2, pp. 569–577, 2001.*

20. Song P, Washington M, Vaida F, Hamilton R, Spelbring D, Wyman B, Harrison J, Chen GTY and Vijayakumar S. A comparison of four patient immobilization devices in the treatment of prostate cancer patients with three dimensional conformal radiotherapy. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 34, pp. 213-219, 1996.*

21. Soffen EM, Hanks GE, Hwang CC, and Chu JCH. Conformal static field therapy for low volume low grade prostate cancer with rigid immobilization. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 20, pp.141-146, 1991.*

22. Mubata CD, Bidmead AM, Ellingham LM, Thompson V and Dearnaley DP. Portal imaging protocol for radical dose-escalated radiotherapy treatment of prostate cancer. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 40, pp.221-231, 1998.*

23. International Commission on Radiation Units and Measurements. ICRU Report 50. Prescribing, recording, and reporting photon beam therapy. *ICRU, 1993.*

24. Van Herk M, Remeijer P, Rasch C and Lebesque V. The probability of correct target dosage: Dose-population histograms for deriving treatment margins in radiotherapy. *Int. J. Radiat. Oncol. Biol. Phys., Vol. 47, pp.1121–35, 2000*

25. Quint S, de Boar C, Van sornsen de Koste R, Heijmen J and Olofsen-van Acht MJ. Set-up verification of cervix cancer patients treated with long treatment fields; implications of a non-rigid bony anatomy. *Radiother. Oncol., Vol. 60, pp. 25-29, 2001.*

26. Stroom J, de Boer H, Huizinga H and Visser A. Inclusion of geometrical uncertainties in radiotherapy treatment planning by means of coverage probability. *Int. J. Radiat. Oncol. Biol. Phys*., *43*, *pp*. 905*–919, 1999*.

27. Duan M. Verification and correction of geometrical uncertainties in conformal radiotherapy. *Arch. Oncol., Vol. 13, issue 3-4, pp.140-144, 2005.*

28. Kutcher GJ, Coia L, Gillin M, Hanson W, Liebel S, Morton R, Palta J, Purdy J, Reinstein L, Svensson G, Weller M, and Wingfield L. Comprehensive QA for

radiation oncology: Report of the AAPM Radiation Therapy Committee Task Group 40. *Med. Phys., Vol. 21, pp. 581–618, 1994.*

29 Remeijer P, Geerlof E, Ploeger L, Gilhuijs K, van Herk M and Lebesque JV. 3-D portal image analysis in clinical practice: An evaluation of 2-D and 3-D analysis techniques as applied to 30 prostate cancer patients. *Int. J. Radiat. Oncol. Biol. Phys*., *Vol. 46, pp***.** *1281–90, 2000*.

30. Ruckman L. Statistik. *http://www.cs.kau.se/stat/statdist/kap9.html.*

31. Bel A, Vos PH, Rodrigus PT, Creutzberg CL, Visser AG, Stroom JC, and Lebesque JV. High-precision prostate cancer irradiation by clinical application of an offline patient setup verification procedure, using portal imaging. *Radiothert. Oncol,Vol., 35, pp. 321-332, 1996.*