

Analysis of Set-up Parameters in Head and Neck Patients at the Charlotte Maxeke Johannesburg Academic Hospital (A Review of Current Clinical Practice)

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Abstract

This study aimed to collect and analyze the recorded daily setup parameters of the bed as incidentally captured on an integrated record and verify system. This was done on some radical head and neck patients treated from 2008 to 2010 at Charlotte Maxeke Johannesburg Academic Hospital (CMJAH) in South Africa. Most of these patients had anterior neck fields that were set-up using fixed couch longitudinal movements (meaning more than one treatment isocentre). It was hoped that the ideal absolute position of the patient on the bed relative to the isocentre of the treatment machine, for a course of head and neck radiotherapy at CMJAH, could be established. Knowledge of the set-up margin achievable could also assist in defining the tolerance assigned to couch parameters on the electronic record and verify system, such that setup is restricted accordingly.

Keywords: Head and neck; Set-up error(s); CMJAH; Virtual simulation; IMRT

Introduction

All patients with head and neck tumours usually undergo a full Ear, Nose and Throat (ENT) examination, to define the local extent of the tumour. A chest x-ray is also conducted to exclude lung disease, which is the most common site of distant metastasis. Other sites of distant metastasis for head and neck tumours include the mediastinal lymph nodes, liver, brain and bones. Tumours may also spread along the nerves, such as high-grade parotid tumours, which are known to involve the facial nerve and cause paralysis.

The “standard” treatment for head and neck tumours could either be surgery (with preoperative or postoperative radiotherapy) and chemotherapy. The advances made in surgical reconstruction of the head and neck region has led to more patients being treated with a combination of primary surgery and postoperative radiation, rather than primary radiation with surgery for salvage. The “general” consensus is to include the entire operative bed for radiotherapy treatment and to start as soon as the surgical wound has healed, usually three to four weeks after surgery. A combination of chemotherapy and radiotherapy may also be used for inoperable and unresectable tumours (stage three and four).

Radiotherapy is a standard non-surgical treatment for locally advanced head and neck cancers. Radiotherapy therefore plays an important role in the management of head and neck cancer patients. The decision to irradiate postoperative tumours will depend on the presence of perineural invasion, lymph node involvement, pattern of spread, etc. Patients who had neck dissections may receive post-operative irradiation if there was an incomplete excision, nodal involvement at more than one level, or extra-capsular spread. The aim of radiotherapy is to deliver a radiation dose to a well-defined target volume whilst sparing the surrounding normal tissue, thereby achieving an optimal therapeutic ratio with the minimal level of morbidity. Patients can either be treated with a linear accelerator (LINAC) or a Cobalt teletherapy unit, based on the target volume in question. A cobalt unit may be preferable for patients with superficial lesions, because part of the volume is immediately adjacent to the skin; and a linear accelerator may be preferred for deeper seated tumours.

“Standard” radical (curative intent) fractionation to the primary tumour and/or lymphadenopathy is 1.8-2 Gray (Gy) per fraction. Both the tumour and the associated lymphadenopathy are included in the treated volume but the variability of the body contour in the head and neck region poses a challenge to dose uniformity [1-10].

A shrinking field technique is often used, whereby the clinical target volume (CTV) is sterilized and the known gross disease (GTV) is then further “boosted” to the final dose as prescribed by the radiation oncologist. Tolerance of the spinal cord is critical to this treatment technique. Several radiation side effects are known to the head and neck area which may include loss of appetite, sore mouth, skin reactions, weight loss, acute laryngeal oedema (larynx cases), etc. In some cases re-planning during treatment may be necessary. Vigilance is needed by the radiation oncology team to ensure that the best possible quality in the daily treatment delivery is maintained in spite of the changes in the target volumes and the challenges posed by the side effects experienced by the patient [11-20].

Precise target coverage according to radiation treatment planning depends on the reproducibility of the patient position on a day-to-day basis throughout the course of treatment. Depending on the intent, target position or the precision required for beam delivery, patients may or may not require an external immobilization device for their treatment. For instance, cases of the central nervous system require rigid immobilization whereas cases for total body irradiation may not. Prior to an immobilization device being made, it is essential that the physician, physicist, mould room technologist and therapist agree on the optimal

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patient position for treatment planning. Immobilization devices have two fundamental roles: to immobilize the patient during treatment and to provide a reliable means of reproducing the patient position from simulation (or Computed Tomography (CT)) to treatment, and from one treatment to another. Moreover, a well-constructed immobilization system may reduce the daily positioning time of the patient and make the patient feel more secure and less anxious. The construction of an effective immobilization device requires a thorough understanding of the extent of the target anatomically, and the device should extend beyond the treatment volume. It is also important for an immobilization device to be rigid and durable enough to a course of radiotherapy treatment. There are two classifications of immobilization devices, namely simple and complex. Simple immobilization devices restrict “some” patient movement and therefore patient movements will not be entirely deterred [21-27].

Some examples of such immobilization are masking tape, large rubber bands or a bite block. Complex immobilization devices restrict the patient’s movement entirely, and ensure reproducibility in positioning. These devices are usually made of plaster, plastic and Styrofoam. Both these immobilization techniques require the patient’s voluntary co-operation.

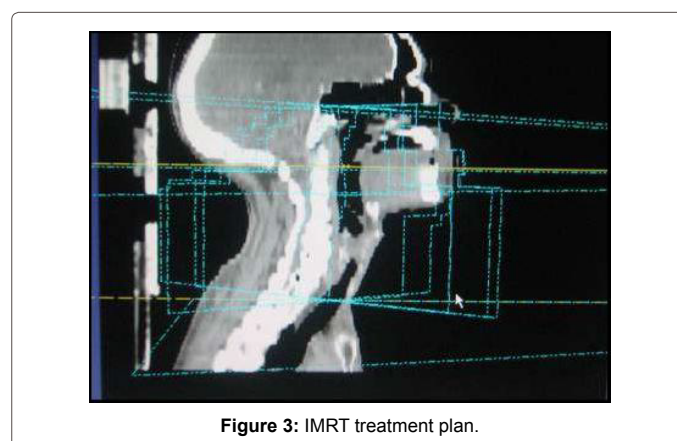
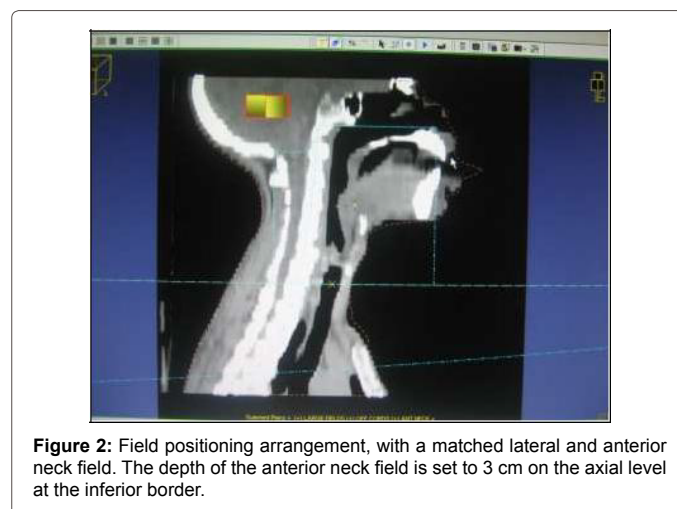
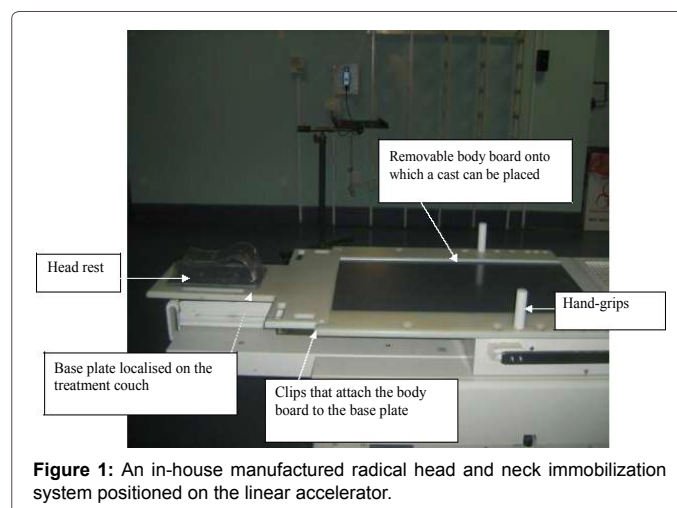
Complex immobilization devices are very important for the treatment of head and neck cancers. The basic immobilization device used for head and neck treatments is the head rest, shaped to fit snugly under the patient’s head and neck area, allowing the patient to lie comfortably on the treatment couch. The head rests also locate to a base plate positioned on the treatment couch. The combination of the head rest and mask prevent movement from that position on the couch during a treatment session [27-31].

At CMJAH in South Africa all the patients with head and neck cancers, who are treated with curative intent (radical) have individualized Perspex shells (masks) to prevent movement during treatment. The mask and head rest is secured to a base plate. The head and neck base plate clips onto a removable body board. The entire system was developed locally. The superior underside of the head and neck base plate fits into the centre spine of the couch. The table top inserts are therefore removed and this increases clearance around the head and neck area during treatment, which is important for the treatment of lateral posterior neck electron fields without removing the mask or Intensity Modulated Radiotherapy (IMRT) fields with multiple beam ports. Clearance between the patient and the treatment head is therefore improved and treatment using an electron applicator that extends to the patient is expedited, for instance. There are “lips” at the shoulder level that fit around the sides of the table top to centre and secure the entire system. Adjustable hand grips are used to keep the patient’s shoulders out of the field of treatment. Further reproducibility can also be achieved by using a body cast. Figure 1 shows the in-house manufactured head and neck immobilization system.

Methods and Materials

Two population groups were studied, namely virtual simulated and Intensity Modulated Radiotherapy (IMRT) cases. All cases were treated with the in-house immobilization system, which located centrally, but not longitudinally, to the treatment couch. Verification of the couch position, other than the isocentric angle, was not activated. The virtual simulated cases consisted of two lateral fields with a matched anterior neck field. The borders of these fields were chosen by the radiation oncologist as illustrated in Figure 2. The IMRT cases were planned by a

medical physicist and consisted of 6-9 fields of 3-4 intensity levels each as illustrated in Figure 3. Digitally Reconstructed Radiographs (DRRs) of the 2 lateral fields and the anterior neck field for the virtual simulated cases, and the 2 lateral and anterior composite fields at the same isocentre for the IMRT cases, were printed and represented the ideal patient position. On the first day of treatment, megavoltage verification films were taken of the treated or positioning fields respectively. These



verification films were compared to the DRRs and approved by a radiation oncologist [31-34].

The absolute bed position in the vertical (Y), lateral (X) and longitudinal (Z) directions at the time of film approval, was used as the reference or ideal position. An example of the couch positions are given in Figure 4. The absolute readings of the couch position that were captured daily over the course of treatment were then compared to the initial couch position to give an indication of the systematic and random errors. One linear accelerator was used in this study and weekly mechanical Quality Control (QC) was performed on it (Figure 4).

The systematic error is the deviation between the simulated or planned patient position and the average patient position. This is the deviation that occurs in the same direction and is of a similar magnitude for each fraction throughout the treatment course. In this study the population systematic error was also studied. This was the spread of individual mean errors for the group of patients. Systematic errors may occur at localization, planning or treatment delivery. Systematic errors during treatment delivery were looked at in this study. Possible causes for this error could include changes in the patient's position, shape or size (weight loss, hair loss, etc.). Other systematic errors not studied during this study included target delineation, position and shape errors. Another quite frequent systematic error (also not studied here) is the phantom transfer error. This occurs when transferring image data from its initial location through the treatment planning system to the linear accelerator. This "end to end" testing of the treatment planning system has been performed and validated at CMJAH [35].

The random and systematic errors in this study were calculated according to the method employed by Hurkmans et al. [6]. This method is similar to the one used by Hong et al., however, it has been adjusted to account for small sample sizes [7]. Equations 1 and 2 show how the random and systematic errors were calculated.

In all equations, N is the total number of patients, Fi is the number of fractions for patient i, and F is the total number of fractions for all patients. The measurement of the translation of patient i during fraction f along one of the principal axes is denoted by σ_i ; m_i is the individual systematic error, M being the mean translation deviation (Figures 5 and 6).



Figure 4: The digital reading as displayed on the couch control panel. Each value can be zeroed in order to assist setup, but the absolute values are captured and stored by the LANTISTM for each treatment.

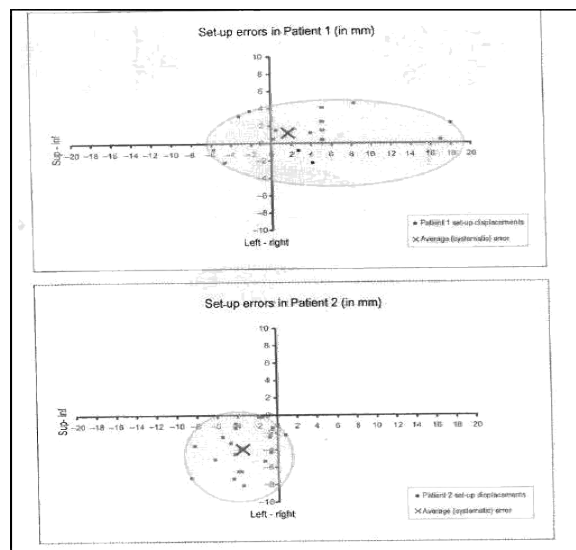


Figure 5: Difference between a large systematic and a large random error.

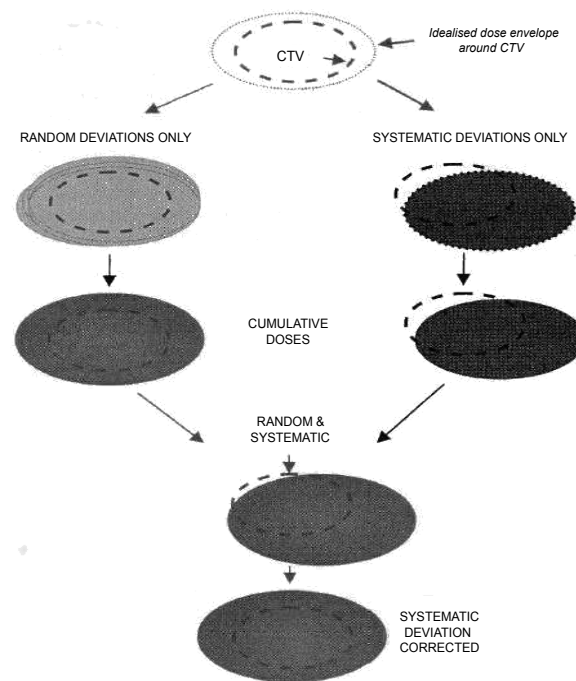


Figure 6: Demonstration of how systematic and random errors are linked to the volumes.

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

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

At the time of the study, CMJAH had a QA radiotherapist tasked to further check treatment plans, prescription, final simulation movements, etc. Thus ensuring that no obvious mistakes were made

before the actual treatment of the patient. This QA procedure formed part of the management of all the patients in this study.

Results and Discussion

The total number of patients studied (N) was 110; 100 were virtual simulated and 10 were IMRT cases. The total number of daily fractions (F) for these cases were 5644 and 600 respectively. The virtual simulated cases had 3321 daily fractions for the lateral fields and 2323 fractions for the anterior neck fields. The IMRT cases had 350 daily fractions for the intensity modulated fields and 250 daily fractions for the anterior neck fields (Figure 7).

Lateral fields for the virtual simulation cases

The individual set-up variations for the lateral and anterior neck fields for each patient are shown in Figures 8A-8E.

Anterior neck fields for the virtual simulation cases

The individual set-up variations for the anterior neck fields for each patient are shown in Figures 8D-8E.

The vertical (Y) individual set-up variation of the lateral fields seems to have the smallest variation, followed by the match point (Z) variation, with the lateral (X) having the largest variation. This is a “strange result” given that the system is centered. One of the reasons for this large variation in the X-direction could be due to the fact that CMJAH do not use the same thickness “marker pen” to mark the treatment position on the patient mask. The markers used are usually larger than the laser lines that can be seen on the mask. This can result

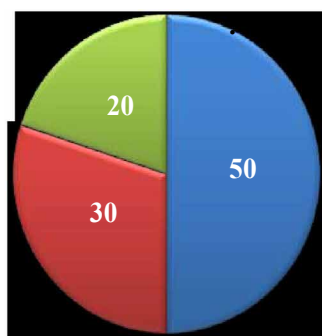


Figure 7: The number of virtual simulated cases studied.

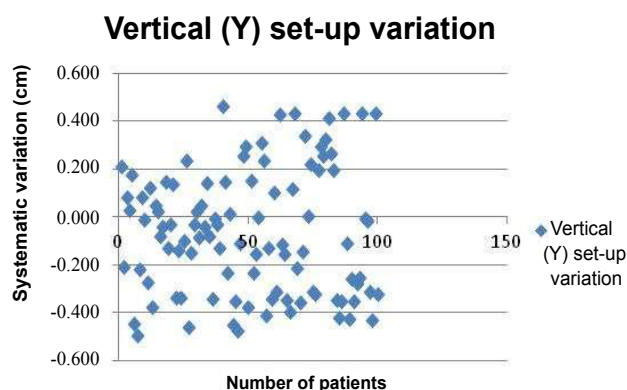


Figure 8A: The individual patient systematic variation of the lateral fields in the Y-direction.

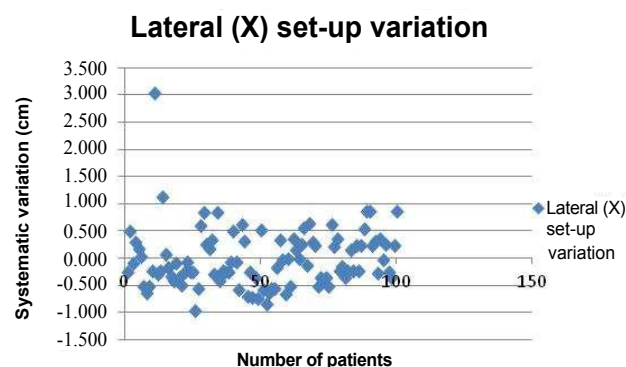


Figure 8B: The individual patient systematic variation of the lateral fields in the X-direction.

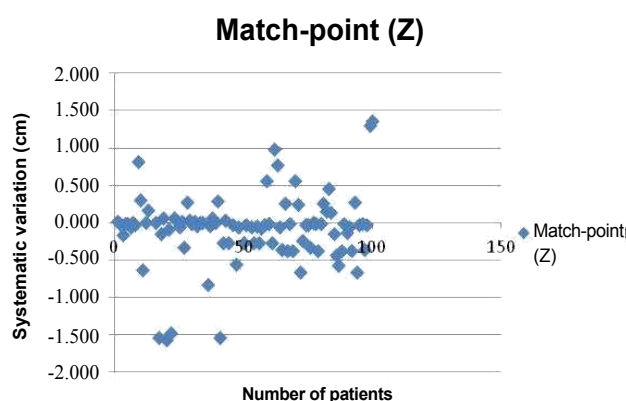


Figure 8C: The individual patient systematic variation of the match point of the lateral and anterior neck fields in the Z-direction. A zero result implies that the patient's lateral fields were on average perfectly matched to the anterior neck field.

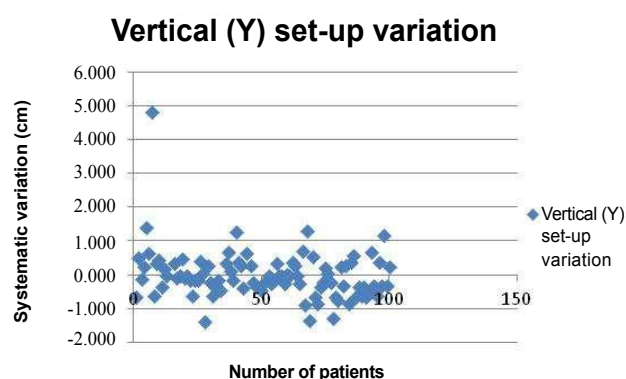
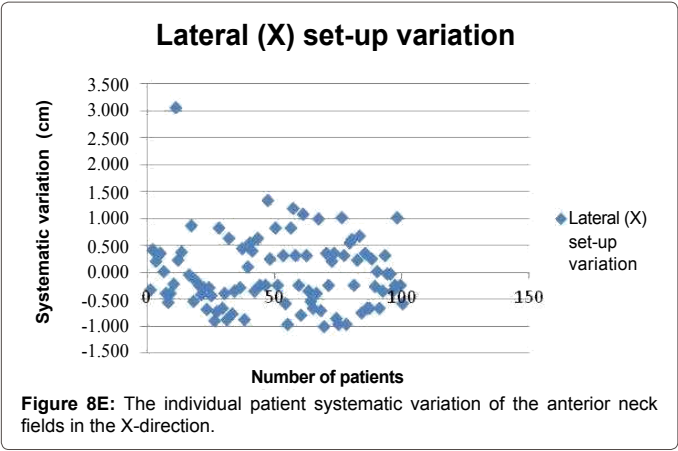


Figure 8D: The individual patient systematic variation of the anterior neck fields in the Y-direction.

in the radiotherapist aligning the lasers on the mask “where they see fit”, resulting in a large variation systematically. The lateral fields’ individual systematic variation was found to be as large as 0.49 cm, 3.03 cm and 1.5 cm in the Y, X and Z – directions respectively. The anterior neck field individual systematic variation was found to be as large as 4.81 cm and 3.07 cm in the Y and X directions respectively. These results are for patient number 7 and 11, on two different days of treatment. The mechanical Q.C results were looked at for these two



days and it showed that the lasers were within 2 mm for those days. So again this error could be due to the laser alignment to the mask markings. Another reason for these large errors could be the “rotation” of the upper body relative to the head [36-38].

Overall mean set-up variation (m) for the virtual simulation cases

The population’s mean set-up variation is given in Table 1.

Random errors for the virtual simulation cases

The random errors calculated from the standard deviation of set-up from the mean in each direction are given in Table 2.

The population studied had a large overall random error (0.7 cm for the laterals and 1.24 cm for the anterior neck fields), when compared to a random error of 0.2 cm (for lateral fields) by Hurkmans et al. (using a similar immobilization devices). The anterior neck variation was not given in their study.

The vertical random error for the anterior neck field is very large; the mechanical couch position was within mechanical tolerance during this period, which leads the investigators to question the comprehension of the set-up of the individual fields by the radiotherapists. This question could be a follow-up study in the near future, comparing the set-up variations of the different radiotherapists at CMJAH, looking at years of experience in the field as well as the vigilance of the radiotherapists in question, radiotherapist training and regular QA of the setup.

Systematic error for the virtual simulation cases

The systematic error calculated from the mean shifts in the standard deviation is given in Table 3.

The population studied had an overall systematic error of 0.47 cm for the laterals and 0.75 cm for the anterior neck fields. The lateral fields compare well to a systematic error of 0.46 cm reported by Hurkmans et al. again the systematic error for the anterior neck was not given for their study [39-41].

IMRT fields

The individual set-up variations for the IMRT cases are shown in Figures 9A-9C in each direction (X, Y and Z).

The individual set-up variations for the IMRT cases anterior neck fields are shown in Figures 9D-9F in each direction (X, Y and Z).

Overall mean set-up variation (m) for the IMRT cases

The population’s mean set-up variation is given in Table 4.

There was a large variation in the longitudinal (Z) direction, and this was expected because of the arbitrary placement of the base plate on the table in the longitudinal direction.

Random errors for the IMRT cases

The random errors calculated from the standard deviation of set-up from the mean in each direction are given in Table 5.

Fields	Vertical (Y)	Lateral (X)	Match point (Z)
Laterals	-0.091 cm	-0.021 cm	-0.109 cm
Anterior neck	0.205 cm	-0.015 cm	

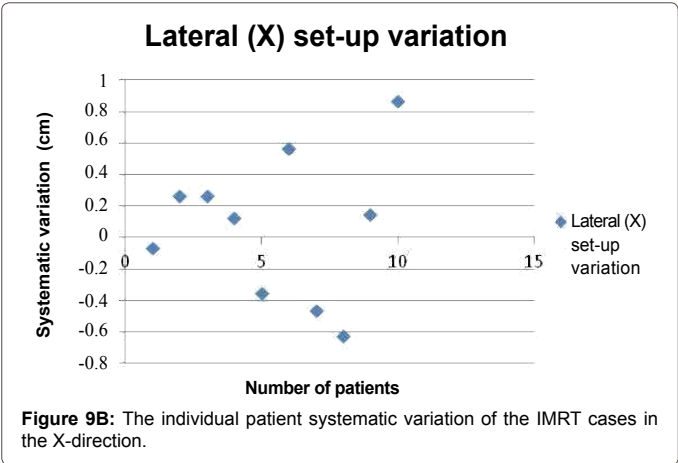
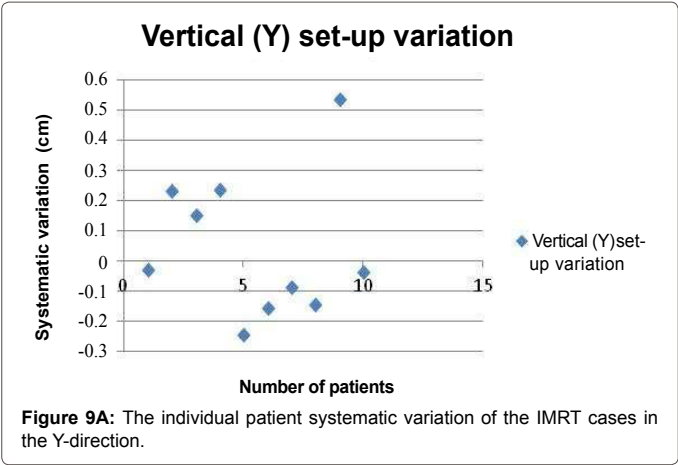
Table 1: The mean set-up variation of the lateral and anterior neck fields.

Fields	Vertical (Y)	Lateral (X)	Match point (Z)
Laterals	±0.77 cm	±0.58 cm	±0.74 cm
Anterior neck	±1.79 cm	±0.69 cm	

Table 2: Random error for the virtual simulation population studied.

Fields	Vertical (Y)	Lateral (X)	Match point (Z)
Laterals	±0.21 cm	±0.72 cm	±0.53 cm
Anterior neck	±0.88 cm	±0.62 cm	

Table 3: Systematic error for the virtual simulation population studied.



Longitudinal (Z) set-up variation

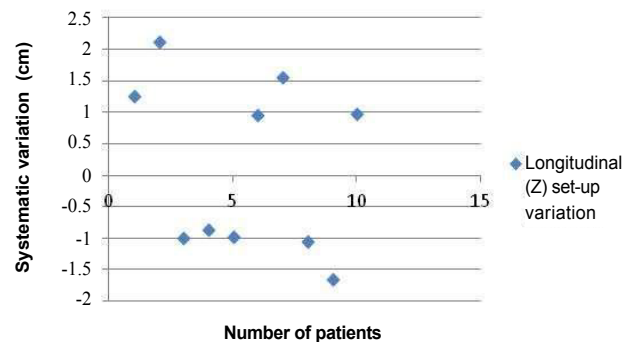


Figure 9C: The individual patient systematic variation of the IMRT cases in the Z-direction.

Vertical (Y) set-up variation

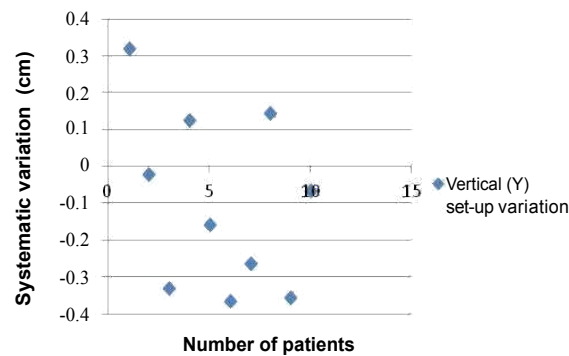


Figure 9D: The individual patient systematic variation of the IMRT cases anterior neck field in the Y-direction.

Lateral (X) set-up variation

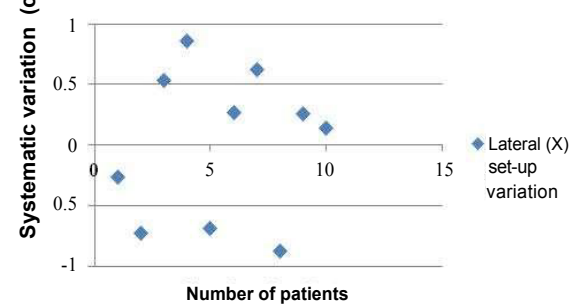


Figure 9E: The individual patient systematic variation of the IMRT cases anterior neck fields in the X-direction.

The IMRT results were similar to the virtual simulation results, excluding the longitudinal direction (again for the base plate reason) the random error for the IMRT set-up was 0.61 cm.

Systematic error for the IMRT cases

The systematic error calculated from the mean shifts in the standard deviation is given in Table 6 for the IMRT cases.

Once again excluding the longitudinal result (for reasons

mentioned above) the IMRT cases had a good systematic error of 0.44 cm, which again is similar to the virtual simulated results.

Weekly verification random and systematic error for the IMRT cases

The systematic and random errors for the weekly IMRT verifications are similar to the daily errors, and were found to be 0.43 cm and 0.59 mm respectively. However in investigating the weekly film verifications further, it was noted that the some patients did not have the chin positioned “snugly” in the mask (Figure 10). For these cases the couch position was acceptable, which leads the investigators to suggest that there are limitations to the methodology of using the couch position alone. It is suggested that investigations of set up errors can indeed be complemented by studies of field positioning based on images of the patient. Couch position certainly cannot account for deficient chin or head position. The radiotherapists may also set up a patient (with the mask fitting) and with the correct couch position, but as soon as they

Longitudinal (Z) set-up variation

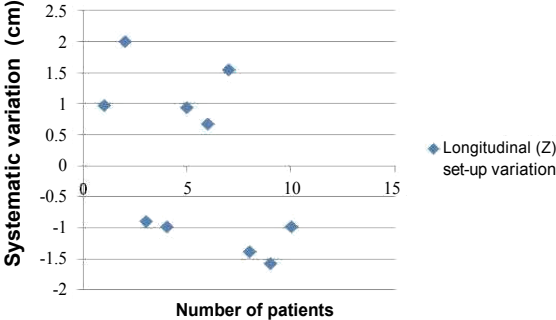


Figure 9F: The individual patient systematic variation of the IMRT cases anterior neck fields in the Z-direction.

Fields	Vertical (Y)	Lateral (X)	Longitudinal (Z)
IMRT	-0.087 cm	0.025 cm	-0.663 cm

Table 4: The lateral and anterior neck fields' mean set-up variation.

Fields	Vertical (Y)	Lateral (X)	Longitudinal (Z)
IMRT	±0.69 cm	±0.52 cm	±1.89 cm

Table 5: Random error for the IMRT cases.

Fields	Vertical (Y)	Lateral (X)	Longitudinal (Z)
IMRT	±0.20 cm	±0.68 cm	±1.10 cm

Table 6: Systematic error for the positioning of the planned fields in the IMRT cases.



Figure 10: Demonstration of the patient chin position not fitting in the mask.

leave the treatment room the patient may drop their chin or snuggle more “comfortably” in the head rest. This error may not be noticed when using the couch or pre-treatment images as a surrogate for the patient’s set-up [41-46].

Conclusion

The following was concluded from this thesis along with the following recommendations made:

- The systematic error of this population was 0.47 and 0.44 cm for the virtual simulated and IMRT cases respectively. This compares well with published results using a similar immobilization system.
- The random error of this population was 0.70 cm and 0.61 cm for the virtual simulated and IMRT cases respectively. This is three times larger than the results reported in the literature (using a similar immobilization device).
- There were individual cases that had systematic deviations larger than 3 cm, the largest recorded value being 4.81 cm. This leaves the investigators to recommend that the radiotherapists need to be more vigilant when setting up head and neck cases, especially the anterior neck field (in the vertical Y-direction). In addition; procedures, training and regular QA of setups need to be improved.
- This study also leads to the question: “Does the set-up error differ when using different methodologies?” For the IMRT cases this question could be partly answered, from the imaging data of the 10 patients in which suboptimal chin or head positioning was observed. It is therefore recommended that a follow-up study be done at CMJAH in which setup errors obtained from different methodologies (such as imaging) are compared with these results. However offline monitoring of couch position provides insight into setup margins and this can contribute to realistic institutional planning target volumes.
- Pre-treatment approval of the weekly verifications, in which the medical physicist and radiation oncologist are present for the setup, may also improve setup errors. This could be concluded from the “better” results obtained in the IMRT cases which could be due to the requirement for weekly verification imaging.
- The investigators recommends more regular verification of the virtual simulated cases, at least four verification throughout the patient’s 35/33 fractions of treatment. This will aid radiotherapist in setting up the patient, by “checking” themselves more regularly and correcting their mistakes.
- The absolute couch position (for this study) was estimated at -1.8 cm, -16.3 cm and +61.5 cm for the lateral (X), vertical (Y) and longitudinal (Z) directions respectively. The tolerance for introducing fully automated couch control should be 1 cm (on either side) for both X and Y positions, and 2 cm (on either side of the absolute position) for the Z direction.

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