Measuring Radiotherapy Setup Errors in IMRT and VMAT Treated Head and Neck Cancer Patients on a Ring based LINAC

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Abstract: ***Objective**: Our study aimed quantify the magnitude of setup errors in intensity - modulated radiotherapy (IMRT) and Volumetric Arc therapy treated Head and Neck cancer patients and recommend appropriate PTV margin. **Materials and Methods**: 65 patients with head and neck cancer at Father Muller Medical College who underwent radical or postoperative radiotherapy with bilateral neck irradiation were planned and treated with IMRT or VMAT technique. All Patients underwent image - guided radiotherapy (IGRT) with daily cone beam computed tomography (CBCT). The 3D displacements, systematic and random errors were calculated and PTV expansion was determined using Van Herk's formula. **Results**: Mean 3D displacement was 0.219 cm in the vertical direction, 0.215 cm in the horizontal direction and 0.218 cm in the longitudinal direction. **Conclusion**: Daily CBCT allows the planning target volume (PTV) expansion to be reduced. The newly derived clinical target volume (CTV) - PTV margin for our linear accelerator is 0.219 cm, 0.215 cm, and 0.218 cm in the vertical, horizontal and longitudinal directions, respectively.*

Keywords: setup error, IMRT, VMAT

1. Introduction

The goal of image - guided radiation therapy (IGRT) is to minimise the amount of organ at risk (OARs) exposed to ionising radiation by precisely delivering the therapeutic radiation following image - based target relocalization. Determination of the discrepancy between the intended and actual treatment position with the aid of cone - beam computed tomography (CBCT) is an integral part of IGRT.1 The digitally reconstructed radiographs (DRRs), which serve as a corresponding reference for the CBCT images, are used to compute the disparity as a shift in treatment field location. Set - up error is measured over a horizontal axis, or right - left (X), longitudinal axis, or superior - inferior (Y), and depth, or anterior - posterior (Z), and consists of a systematic and random component.

The systematic error is a reproducible consistent deviation that occurs in the same direction and magnitude throughout the treatment course. At any stage of the treatment chain, including localization, planning, and beam delivery, systematic errors may occur. Possible reasons for systematic errors[2, 3] are (1) target delineation error which represents the difference between the delineated and ideal clinical target volume (CTV); (2) target position and shape error which is due to the tumor regression or growth, hair loss etc.; and (3) phantom transfer error[4] which occurs during image transfer from initial localization through the treatment planning system (TPS) to the linear accelerator (LA). Several factors which might lead to such errors are differences in laser alignment between CT simulator and LA, minor changes in CT simulator couch longitudinal position, image resolution, isocenter location, source to surface distance (SSD) indication, margin growing algorithm, field edge and multileaf collimator (MLC) leaf position, gantry, and collimator angle accuracy. Many of these parameters are expected to be detected by the routine quality assurance program of the machines.5 For every administered treatment fraction, there is a deviation known as the random component that can change in magnitude and direction. It happens during the execution or administration of treatment, and there may be several causes, are (1) patient set - up error which is varying, unpredictable changes due to variation in patient's daily position, treatment equipment like immobilization devices, or set - up methodology between each delivered fraction; (2) change in target position and shape between fractions due to motion and breathing. These errors are influenced by the immobilization system, patient compliance, and department protocols.

The random error component in the ensuing fractions cannot be fixed by anything other than an offline correction. Online correction[6] of CBCT is necessary to rectify the random error component. Errors in setup, the use of immobilisation devices, beam delivery strategies, and geometric margins for CTV - planning target volume (PTV) are all related. The daily online correction protocol's significant treatment duration increase may result in intrafractional variance for both random and systematic errors. Longer treatment durations also require more skilled staff and resources, which may be in short supply in India's busy radiation centres. Volumetric arc therapy (VMAT), a single - or multiple - arc treatment, can reduce intrafractional set - up mistakes by delivering radiation with a shorter beam on time and fewer monitor units (MU).

Our study aims to assess the three - dimensional set - up errors in image - guided fractionated radiotherapy at our tertiary radiation center in Father Muller Medical College, Mangaluru and to establish the departmental protocol of PTV margins for cancer in Head and Neck.

2. Materials and Methods

Patient Selection

Sixty Five patients with Head and Neck Cancer who were treated with curative intent in a Linear accelerator (Halcyon Elite V 3.1) at the department of Radiation Oncology, Father Muller Medical College, Mangalore, were enrolled retrospectively.

Immobilization and Simulation
Before the treatment, all the patients underwent CT scan in head first and supine position. Contrast dye was used as per clinician's discretion. Patients with squamous cell carcinoma head and neck region (HNSCC) malignancy were immobilized with four clamps thermoplastic cast. Suitable size of head rest (HR) was used for all patients with HNSCC which were comfortable, reproducible, and fit for the patients.

Fiducial Markers The external markers for patients and HNSCC were placed on the surface of the fixation masks with the aid of CT simulation in - room laser in three directions (right, left, and roof).7

Image Acquisition and Registration of Planning CT to CBCT
The CT simulation of all patients is undergone with GE Bright speed full - rotation helical 16 - slice CT scanner.
Head and neck images are taken with 5 - mm slice thickness. These CT images were transferred to the Eclipse v17.0 TPS. For a more accurate delineation of the gross tumour volume (GTV), positron emission tomography (PET) and magnetic resonance imaging (MRI) for any subsites were registered with CT simulation images, if available.

Using an in - room set - up laser, the patients were positioned for the first day of therapy in accordance with the fiducial marker. After that, the gantry - mounted X - ray volume imaging system was used to obtain kV - CBCT pictures. The registration between the acquired CBCT images and planning CT images (DRR) was performed by bone and/or soft tissue grey value automatching followed by a manual correction if required. The translational position correction vectors were calculated after the whole matching procedure for lateral, longitudinal, and vertical axis.8 The clinical threshold level at our institution is 5 mm and 3 degrees for both translational and rotational directions. In cases of larger deviations, the patient was repositioned and online registration was performed again.

Methods of Data Analysis
The translational vectors for total 2200 kV CBCTs images were collected from the treatment record. For every patient, a unique three - axis shift average and standard deviation (SD) were determined. For each treatment site, the overall average of the SD, minimum, and maximum values were examined. The mean (M) and standard deviation (SD) of errors best characterise setup errors, which are normally distributed. The average of all individual means is called M, and it should ideally be closer to zero. S is the standard deviation of each patient's mean, and σ is the root mean square of each patient's unique standard deviation. According to the literature of The Royal College of Radiologist, Institute of Physics and Engineering in Medicine and Society and College of Radiographers are on target, ensuring geometric accuracy in radiotherapy.3 The errors are categorized as follows.

Systematic Error
Individual Mean Set - up Error
Individual mean set - up error (m_{ind}) is the mean set - up error for an individual patient:

$$m_{ind} = \frac{\sum_{i=0}^{n} \Delta_i}{n},$$

where Δi is the set - up error for each imaged fraction and n is the number of imaged fractions.

Overall Population Mean Set - up Error
The overall mean set - up error (M_{pop}) is the overall mean for the analyzed patient group and should ideally be zero. Significant deviation from zero indicates an underlying error common to the patient group and requires corrective measurements.

The equation to calculate the overall population mean set - up error is as follows:

$$M_{pop} = \frac{\sum_{i=0}^{p} (m_{ind})_p}{p},$$

where m_{ind} is the individual mean set - up error and p is the number of patients.

Population Systematic Error
The systematic error for the population ($\sum_{set\text{ - }up}$) is defined as the SD of the individual mean set - up errors about the overall population mean (M_{pop}). It is calculated from the following equation:

$$\Sigma_{set-up} = \sqrt{\frac{\sum_{i=0}^{p} [(m_{ind})_i - M_{pop})]^2}{(p-1)}},$$

where m_{ind} and M_{pop} are individual and overall population systematic set - up error respectively and p is the number of patients.

Random Error

Individual Random Error
For each individual, the interfractional random (daily) set - up error (σ_{ind}) is the SD of set - up errors around the corresponding mean individual value (m_{ind}) derived from equation (01).

It is calculated from the following formula:

$$\sigma_{ind} = \sqrt{\frac{\sum_{i=0}^{n} (\Delta_i - m_{ind})^2}{(n-1)}},$$

where σ_{ind} and m_{ind} are the individual random error and individual mean set - up error. Δi is the set - up error for each imaged fraction and n is the number of imaged fraction.

Population Random Error
The population random error ($\sigma_{set\text{ - }up}$) is the mean of all the individual random errors.

$$\sigma_{set-up} = \frac{\sum_{i=0}^{p} (\sigma_{ind})_i}{p},$$

where σ_{ind} is the individual random error and p is the number of patients.

Calculation of PTV Margin

The International Commission on Radiation 62 (PTV margin = ∑+0.7σ), Stroom's approach (PTV margin = 2 ∑+0.7σ), and Van Herk's formula (PTV margin = 2.5 ∑+0.7σ) are a few ways to compute the CTV to PTV margin. In this case, the population random error is represented by σ, and the population systematic error by ∑. Van Herk's equation is used to compute the general margin for our institutional processes. Graphs and analysis are performed with Microsoft Office Excel.

3. Results

The average shifts for all the patients in our study including all the treatment sites in three directions are shown in ►**Fig.1**, and the values of Mean, systematic error, and random error for each anatomical subset are shown in ►**Table 1**.

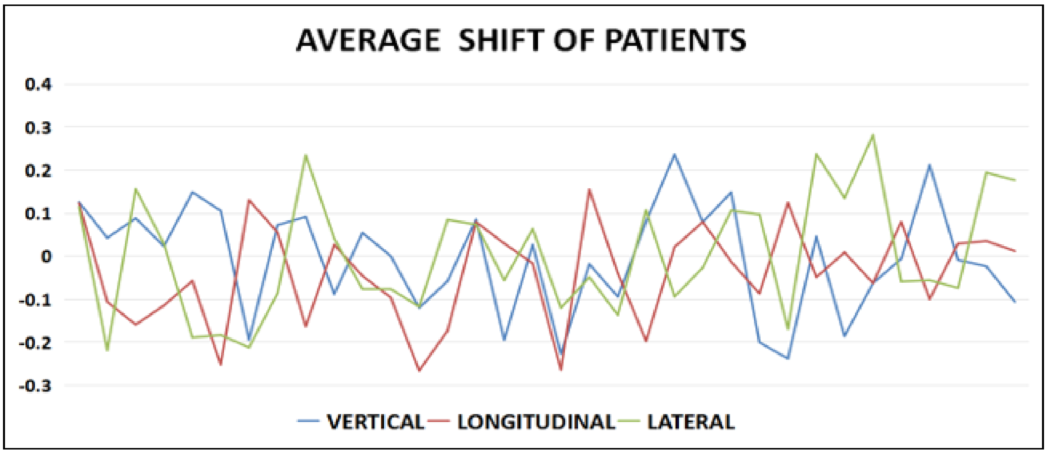

Figure 1

Table 1

PTS	KVC BCT	Mean in CM			Systematic Error (∑) in CM			Random Error in (σ) CM		
		X	Y	Z	X	Y	Z	X	Y	Z
65	2200	0.144	0.110	0.182	0.052	0.052	0.046	0.126	0.126	0.135

In overall, the largest value for systematic error is smaller than 5 mm in all directions and for Head and neck subsets.

4. Discussion

Interfraction set - up errors for Head and neck site for 65 treated patients at our institute were analyzed retrospectively using 2200 CBCT studies. The results of our study showed that the variation was small for Head and neck treatments. Several factors like curved external anatomy, loosening, or tightening of the fixation mask due to changing body contours, tumor shrinkage can also contribute to significant set - up errors. Keeping such changes in mind, rescanning and replanning with new fixation mask were done in our institution if considerable discrepancies occurred.9 [- 11]

Multiple studies[12, 13, 14] have recommended the reduction of PTV margins with the use of CBCT image guidance.

PTV margin without image - guided radiation therapy should be ≥5 mm, whereas, with daily CBCT image guidance, it could be reduced to approximately 3 mm. The calculated PTV margins of approximately 0.219 cm, 0.215 cm, and 0.218 cm in the vertical, horizontal and longitudinal directions, respectively.

Therefore, reduced PTV margins for the Head and neck cancers should be applied under daily CBCT imaging guidance. Gaining more expertise and efficiency by the radiation technologists for patient simulation, molding of thermoplastic casts, patient positioning, and localization in treatment couch and more uniform use of thermoplastic devices and skin markings with ink tattoos can explain this significant improvement.

5. Limitations

One of the limitations which need to be addressed for this study is the unavailability of 6 degrees of freedom robotic couch system in our institute and hence not accounting the rotational changes in the analysis.

6. Conclusion

Daily CBCT allows the planning target volume (PTV) expansion to be reduced. The newly derived clinical target volume (CTV) - PTV margin for our linear accelerator is 0.219 cm, 0.215 cm, and 0.218 cm in the vertical, horizontal and longitudinal directions, respectively.

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