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**Original Research Article**

# Determination of clinical target volume to planning target volume margins and set up errors in image guided radiotherapy for head and neck and prostate cancer patients treated in helical tomotherapy: an institutional study

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## ABSTRACT

**Background:** Appropriate immobilization and accurate target delineation is imperative in radiotherapy planning and treatment. To achieve optimum target volume coverage with reduced dose to organs at risk, variability in set up should be minimized. This study was an attempt to determine the translational errors and corresponding planning target volume margins in head and neck and prostate cancer patients treated with helical tomotherapy.
**Methods:** This is a retrospective observational study of a total of 29 patients of head and neck cancer and 7 patients of prostate cancer treated in helical tomotherapy with image guided radiation therapy. The shifts in the translational directions were recorded and the systematic and random errors were calculated to obtain the corresponding clinical target volume (CTV) to planning target volume (PTV) margins using Van Herk formula.
**Results:** A total of 945 CBCT images were acquired for the head and neck region and 237 images for the pelvic region. The corresponding CTV-PTV margins in the X, Y and Z directions were 3.5 mm, 3.7mm and 3.4mm respectively for the head and neck region and 4.4mm,8.7mm and 5.8mm in the prostate cancer patients.
**Conclusions:** Image guided radiation therapy is an effective method for ensuring adequate coverage of the target in IMRT technique. Thus, proper imaging will lead to less chances of geographic miss.

**Keywords:** Image guided radiation therapy, PTV margin, Random error, Systematic error

## INTRODUCTION

In radiotherapy planning and treatment proper immobilization and accurate target delineation plays a key role. With newer radiotherapy techniques being introduced, more conformal dose delivery to the target with maximal sparing of Organs at Risk (OARs) is achievable.[1] To attain adequate coverage of the target volumes, set up errors should be minimal as these can lead to geographic miss. As per International Commission on Radiation Units and Measurements Reports 50 and 62, margin is given to the clinical target volume (CTV) to create a planning target volume (PTV) which account for treatment motion and patient set up uncertainties.[2]

Image Guided Radiation Therapy (IGRT) includes acquisition of two-dimensional and three-dimensional imaging during radiation therapy using treatment co-ordinates to verify treatment accuracy.[3] Helical tomotherapy is a form of Intensity Modulated Radiation

Therapy (IMRT) with ability to acquire Megavoltage Cone Beam CT(MV CBCT) images of patient before treatment delivery allowing not only bone matching but also to visualize the target volume and organs at risk enabling appropriate soft tissue matching.[4]

This study was an attempt to assess the translational shifts using MV CBCT images acquired before radiation therapy in head and neck cancer and prostate cancer patients to obtain an optimal CTV to PTV margin as an institutional standard.

## METHODS

This study is a retrospective observational study conducted in the Department of Radiation Oncology, State Cancer Institute, Gauhati Medical College for a period of 1 year from April, 2023 to March, 2024. A convenience sampling technique was used for this study.

A total of 29 head and neck cancer and seven prostate cancer patients evaluated in the outpatient department and planned for radical treatment with intensity modulated radiotherapy using image guidance in radixact helical tomotherapy machine were recruited for the study. The number of Cone Beam CT (CBCT) images acquired were 945 for head and neck cancer patients and 237 for prostate cancer patients. The study was approved by the Institutional Ethics Committee.

Immobilisation for treatment planning was done in the supine position using customized thermoplastic mould. For head and neck region five-clamp mould and for prostate cancer patients six-clamp pelvic mould were used. CT Simulation was conducted by taking three-millimeter (mm) slice on Siemens SOMATOM AS CT Simulator machine. The images were transferred to the treatment planning system (Accuray Precision TPS, Version 3.3.1.3).[2] Contouring for head and neck cancer was done as per the standard guidelines using an isotropic margin of five-mm from Clinical Target Volume (CTV) to create the corresponding Planning Target Volume (PTV). For the pelvic region, a symmetric margin of 10 mm was given to the corresponding CTV. The organs at risk (OAR) were also delineated. On each day of treatment, the patients were positioned using treatment room lasers and marks on the immobilization device. MV-CBCT using 3.5 MV energy was derived prior to each treatment fraction with a spatial resolution of 512 x 512 pixel and field of view of 39 cm diameter.

The CBCT images were then registered with the planning CT images using appropriate bony and soft tissue matching and visually verified. After registration, only the shifts in the translational directions; lateral (left-right), longitudinal (superior-inferior), and vertical (anterior-posterior) along the X, Y, and Z axes, respectively were recorded.

Analysis was done as- Anterior, superior and left sided shifts were considered positive shifts and posterior, inferior and right sided as negative shifts. For individual patient recorded errors the mean and standard deviation (SD) were calculated in the X, Y and Z axes.

Set-up error along the three translational directions was used to calculate the systematic and random set-up errors for each individual patient and the patient group.

### *Systematic set up error*

The systematic error of the population ($\Sigma_{\text{set up}}$) is defined as the SD of the individual mean set up error about the overall population mean (M pop). This is calculated by summing up of the squares of the differences of the overall population mean (M pop) and each individual patient mean ($m_n$) divided by number of total patients minus one.[5]

### *Random set up error*

The Random (daily) set-up error ($\sigma_{\text{individual}}$) is the SD of the set-up errors around the corresponding mean individual value. $(\sigma_{\text{individual}})^2$ is calculated by summing up of the squares of the differences between the mean and the set-up error from each image divided by the number of images minus one.

$$\Sigma^2_{\text{set up}} = (m_1\text{-Mpop})^2+(m_2\text{-Mpop})^2+\ldots\ldots(m_p\text{-M pop})^2/(p-1)$$

$$\sigma^2_{\text{individual}}=(\Delta_1\text{-m})^2+(\Delta_2\text{-m})^2+\ldots\ldots(\Delta_n\text{-m})^2/n-1$$

$\sigma_{\text{set up}}= \sigma_1+ \sigma_2+\ldots\ldots+ \sigma_p/p$; where p=No. of patients and n=No. of images.[5]

The patient set-up error measurements were then used to calculate the three-dimensional CTV-to-PTV margins using Van Herk's formula, where the PTV margin is given by the formula: $2.5\Sigma+0.7\sigma$.[5]

## RESULTS

The translational displacements in all the three axes: X (Medio-lateral), Y (Supero-inferior) and Z (Anterior-posterior) were recorded for 945 MV CBCT images in 29 patients. The systematic ($\Sigma$) and random ($\sigma$) errors were calculated along with the corresponding margins and are depicted in Table 1 for head and neck cancer patients and in Table 2 for prostate cancer patients respectively.

For head and neck cancer patients the margins in the medio-lateral, supero-inferior and anterior-posterior were 3.5 mm, 3.7mm and 3.4 mm respectively. However, the corresponding margins were 4.8 mm, 8.7mm and 5.8mm for prostate cancer patients.

**Table 1: The systematic (Σ) and random (σ) errors were calculated along with the corresponding margins and are depicted for head and neck cancer patients.**

| Directions | Systematic error (Σ) (mm) | Random error (σ) (mm) | Van Herk's formula (2.5Σ + 0.7σ) (mm) |
|---|---|---|---|
| **X (Medio-lateral)** | 0.98 | 1.51 | 3.5 |
| **Y (Supero-inferior)** | 1.01 | 1.67 | 3.7 |
| **Z (Anterior-posterior)** | 0.99 | 1.33 | 3.4 |

**Table 2: The systematic (Σ) and random (σ) errors were calculated along with the corresponding margins and are depicted for prostate cancer patients.**

| Directions | Systematic error (Σ) (mm) | Random error (σ) (mm) | Van Herk's formula (2.5Σ + 0.7σ) (mm) |
|---|---|---|---|
| **X (Medio-lateral)** | 1.25 | 2.52 | 4.8 |
| **Y (Supero-inferior)** | 2 | 3.03 | 8.7 |
| **Z (Anterior-posterior)** | 1.71 | 2.29 | 5.8 |

## DISCUSSION

The variations arising in radiotherapy treatment planning can be due to internal organ motion or due to set up inaccuracies. Thus, both intra and inter fraction variations are to be taken into account for a proper treatment implementation.[6] The modern radiotherapy techniques equipped with image guidance helps to minimise the errors in treatment delivery thus providing adequate coverage of the target volumes with minimal normal tissue complications.

The assessment of set up errors is particularly important in head and neck and pelvis regions as there are critical structures that need to be optimally spared. This study was conducted in patients who were treated with Intensity Modulated Radiotherapy (IMRT) in helical tomotherapy machine using MV CBCT images. The traditional methods lack proper soft tissue contrast which resulted in discrepancy when based on bony structures. The benefit of MV CBCT is that it allows for soft tissue matching which carries importance in pelvic cancer patients.[7-9] Previous studies showed that bone matching required PTV margins of 4.7-10.5 mm, 7.4-12 mm, and 1.4-4.4 mm in the AP, SI, and LR dimensions, respectively.[10] But with soft tissue matching this margin can be further minimised as seen from the results of this study. A study by Iwama et al in prostate cancer patients treated with helical tomotherapy found that a margin of 5 mm was sufficient for adequate coverage of the PTV.[11] Melancon et al reported that a 3-mm intra-fractional margin was adequate for prostate dose coverage but the caveat was that a significant number of patients lost seminal vesicle dose coverage because of the change in rectal volume.[12] Another study by Mutanga et al found that a 5-mm margin provided sufficient dose coverage for the prostate. However, an 8-mm seminal vesicle margin was still insufficient due to deformations.[13] Compared to the above- mentioned studies, in the present study, the CTV to PTV margins were 4.8mm, 8.7 mm and 5.8 mm in the X, Y and Z axes respectively which resulted in adequate coverage of the PTV despite of unplanned variations in internal organ motion. The results from our study suggest that differential margins for patients undergoing pelvic radiotherapy with emphasis laid on proper set-up.

Zhou et al, in their study evaluated the set-up errors with calculation of CTV to PTV margins for five different anatomical sites in patients treated with helical tomotherapy. For head and neck region they suggested margins of 4.2 mm, 5 mm and 2.5 mm in the X, Y and Z-axes respectively. Similarly, for prostate cases, the corresponding directional margins were 7.4mm, 6.6mm and 5.4 mm respectively. Thus, they concluded that pre-treatment MV CBCT can be used to increase the accuracy of the treatment.[14] Another study by Leitzen et al, conducted in head and neck cancer patients treated with helical tomotherapy concluded that frequent patient positioning is necessary which can be achieved by focussing on a very limited region based on appropriate landmarks.[15]

In this study, while evaluating the translational errors it was seen that in head and cancer patients a uniform margin can be applied, but in prostate cancer patients the maximum shift was seen in the Y axis (supero-inferior/longitudinal) direction which can be minimized using daily image guidance. Thus, it can be considered that a uniform margin of 5 mm from CTV in head and neck cancer patients and a differential margin of 5 mm, 9 mm and 6 mm approximately in the medio-lateral (X axis), longitudinal (Y axis) and vertical (Z axis) would be appropriate to cover the corresponding target volume for prostate.

A major limitation was the limited number of patients recruited in this study. Continuation of the study with more number of patients will further validate our findings.

## CONCLUSION

Use of pre-treatment CBCT serves as an important measure to increase the accuracy of radiation therapy delivery. The knowledge of set up errors can provide useful information for determination of optimal CTV to PTV margins and thus ensure coverage of the target volumes.

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