ANALYSIS OF SETUP VARIATION IN TOMOTHERAPY BASED IMAGE GUIDED RADIOTHERAPY.

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ABSTRACT :

TO EVALUATE INTERFRACTION SETUP UNCERTAINTIES ACROSS DIFFERENT ANATOMICAL SITES IN PATIENTS TREATED WITH HELICAL TOMOTHERAPY-BASED IMAGE-GUIDED RADIOTHERAPY (IGRT) AND TO DERIVE OPTIMAL PLANNING TARGET VOLUME (PTV) MARGIN GUIDELINES.

AIM : TO ANALYZE SETUP VARIATION FOR VARIOUS ANATOMICAL SITES DURING TREATMENT ON TOMOTHERAPY

OBJECTIVE: TO PROVIDE OPTIMAL MARGIN FOR VARIOUS ANATOMICAL SITE DURING TREATMENT ON TOMOTHERAPY TO IMPROVE ACCURACY OF PATIENT POSITIONING AND REDUCE TUMOUR MARGIN DURING TREATMENT PLANNING ON TOMOTHERAPY.

IndexTerms – TomoTherapy MVCT IGRT PTV margin Setup error Systematic error Random error Image guidance.

INTRODUCTION

Tomotherapy delivers intensity-modulated radiation therapy (IMRT) by rotating a narrow fan beam around the patient, similar to the acquisition pattern of a CT scanner. Helical Tomotherapy is a volumetric, image-guided IMRT system. It incorporates on-board megavoltage computed tomography (MVCT) for daily verification, allowing tumor position and geometry to be confirmed immediately
before each treatment fraction.The broad adoption of IMRT has highlighted the critical role of image guidance. Due to the steep dose gradient at the edge of the planning target volume (PTV) and adjacent organs at risk, there is a significant risk of target underdosage[(1)].
For IMRT Because IMRT plans are highly sensitive to setup uncertainties, strict patient immobilization is required to ensure positional accuracy throughout the treatment course. Helical Tomotherapy (HT) was developed to integrate both intensity-modulated delivery and volumetric image-guided radiotherapy (IGRT). IGRT uses on-treatment imaging to maximize conformance between the delivered dose and the original plan.[(1,3)]Volumetric image guidance represented a major advancement in radiotherapy practice.
In treatment planning, the planning target volume (PTV) is typically generated by expanding the clinical target volume (CTV) with a uniform margin. The CTV itself is derived by adding a margin to the gross tumor volume (GTV),[(4)] which is visible on diagnostic imaging. The size of the PTV margin depends on the

immobilization and localization systems employed. Its purpose is to account for both systematic geometric errors and random residual uncertainties, thereby minimizing target miss.[6]

MATERIALS & METHOD

- A total of 93 patients were included in this study. The cohort was categorized based on treatment sites: 44 patients with head and neck (H&N) cancers, 22 with thoracic tumors, 14 with pelvic malignancies, 12 with brain tumors, and one with an extremity lesion. All patients underwent helical TomoTherapy (HT) with daily image-guided radiation therapy (IGRT).
- For each individual, setup correction data were recorded, including translational displacements along the lateral, longitudinal, and vertical axes. Among the rotational components, only roll corrections were implemented, whereas pitch and yaw adjustments were not applied. The patients were grouped by treatment site to assess systematic and random setup errors, and calculated margins were compared against standard clinical practice.

H & N CASES -TOTAL 44

- 11-CARCINOMA TONGUE ,
- 8 -CARCINOMA BUCCAL MUCOSA ,
- 4 -CARCINOMA NASAL CAVITY ,
- 5- CARCINOMA NASOPHARYNX AND ALVEOLUS ,MAXILLA BRAIN
- 4 -ASTROCYTOMA ,
- 5- GLIOMA , MENINGIOMATHORAX
- 13-CARCINOMA BREAST , ESOPHAGUS
- 7-LUNG ,HODGKINS LYMPHOMAPELVIS
- 6-CARCINOMA CERVIX ,
- 4- NEUROBLASTOMA ,EWINGSSARCOMA -2, PROSTATE -1.

Immobilization Techniques:

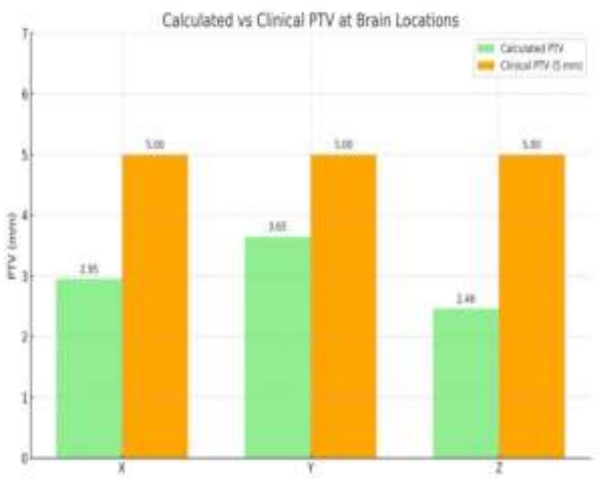
Brain: Patients with intracranial tumors were immobilized using customized thermoplastic masks (Orfit). The masks were secured to a base plate with rigid L-shaped polymer clamps and fixation blocks. Wedged headrests were used to tilt the chin inferiorly, thereby reducing radiation exposure to the eyes.
Head & Neck: A four-point thermoplastic mask was combined with a headrest and shoulder traction using rubber straps. This configuration achieved shoulder depression and minimized overlap of the shoulders with the treatment field.[6]
Thorax: Lung cancer patients were positioned supine using a four-point body mask. A headrest was used, with both arms abducted and raised above the head to maximize exposure of the thoracic region and avoid beam attenuation.[5]
Pelvis: For pelvic radiotherapy, patients were positioned on a custom knee support fabricated from thermocol and plaster of Paris. An abdominal mask and pillow were added for stability. Abdominal compression was applied selectively in cases requiring enhanced immobilization, especially in obese patients who are more prone to lateral setup errors.

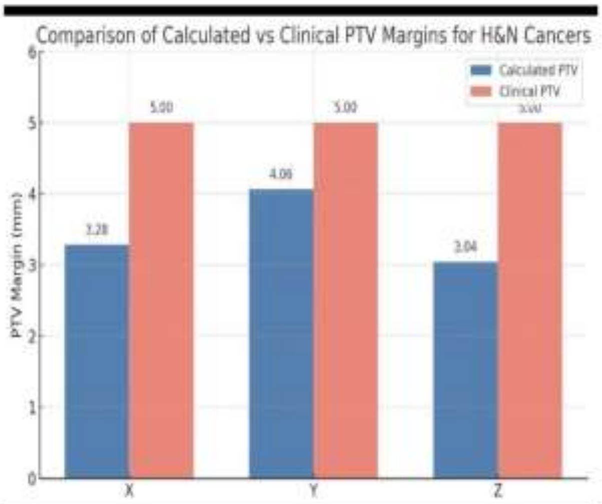
Patients were positioned on the Hi-Art treatment couch using site-specific immobilization devices, and the entire planning target volume (PTV) was contoured as the region of interest. For brain tumors, especially small lesions, MVCT imaging was acquired in fine mode with 2 mm slice thickness. The MVCT scans were rigidly registered to the planning CT images. On the first treatment day, initial alignment was performed by the radiation oncologist; thereafter, daily setup corrections were managed by radiation therapy technologists. Registration was guided by anatomical landmarks relevant to each treatment site.For initial setup verification, kilovoltage cone-beam CT (kV-CBCT) was obtained with the patient in treatment position. Following alignment of bony and soft tissue structures between the CBCT and planning CT, the isocenter was marked on the thermoplastic mask. Couch coordinates in the lateral (x), vertical (y), and longitudinal (z) directions were documented as reference positions for subsequent verifications.

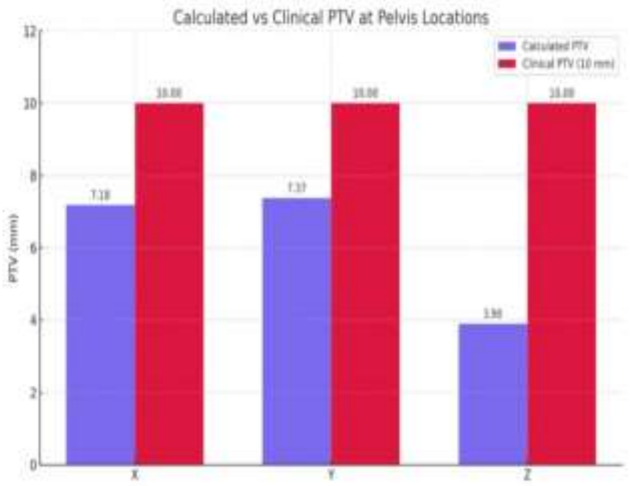
Data Collection and Margin Calculation.Setup correction data, including translational and rotational shifts, were recorded from each MVCT session. Patients were stratified by treatment site to analyze systematic (Σ) and random (σ) errors. Systematic error was calculated as the standard deviation of mean displacements for each patient group. Random error was computed as the root mean square of intra-patient standard deviations. PTV margins were estimated using the formulas proposed by Bijhold et al.[18], Stroom et al.[18], and Van Herk et al.[19], and were compared with the margins routinely used in clinical practice.

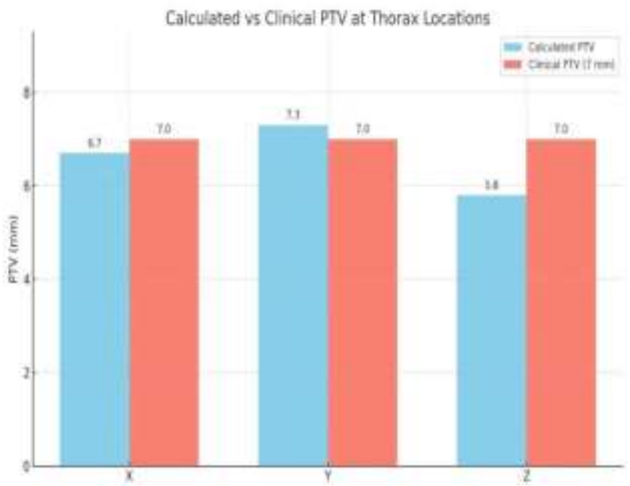
Margin calculation followed the van Herk formula:

- Margin = $2.5\Sigma + 0.7\sigma$,
- where Σ represents systematic error and σ the random error. This formula ensures that 90% of patients receive at least 95% of the prescribed dose to the CTV.Systematic errors vary between patients and are influenced by factors such as post- surgical edema or misalignment during simulation. Random errors arise from daily variations in setup and internal organ motion. The average of the standard deviations of individual patients' means quantified systematic errors per direction, while random errors were computed as the root mean square of patient-specific variations.







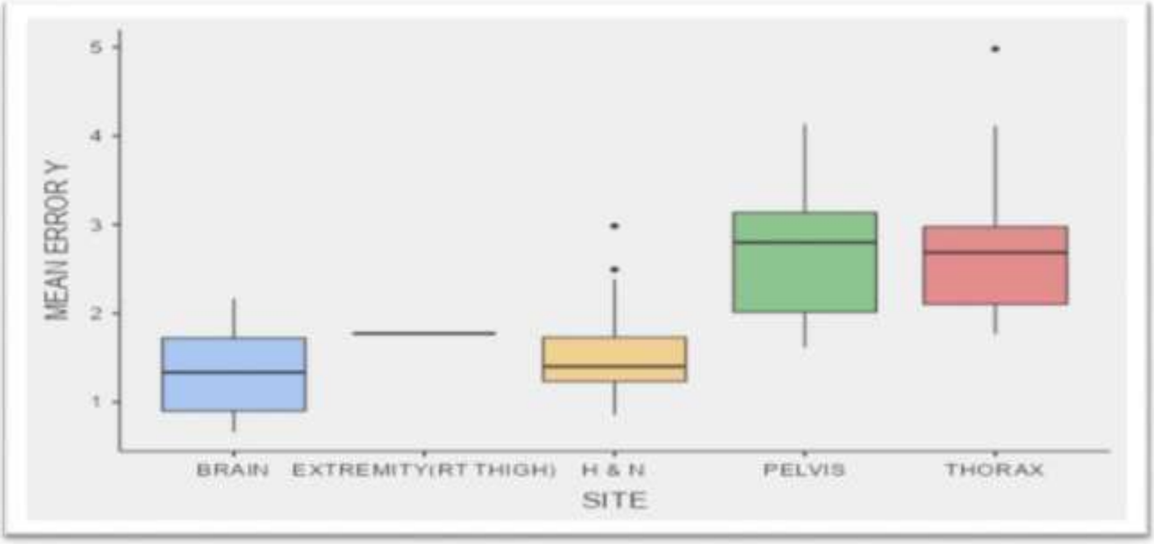


OVERALL RANDOM & SYSTEMATIC ERRORS OF X, Y & Z

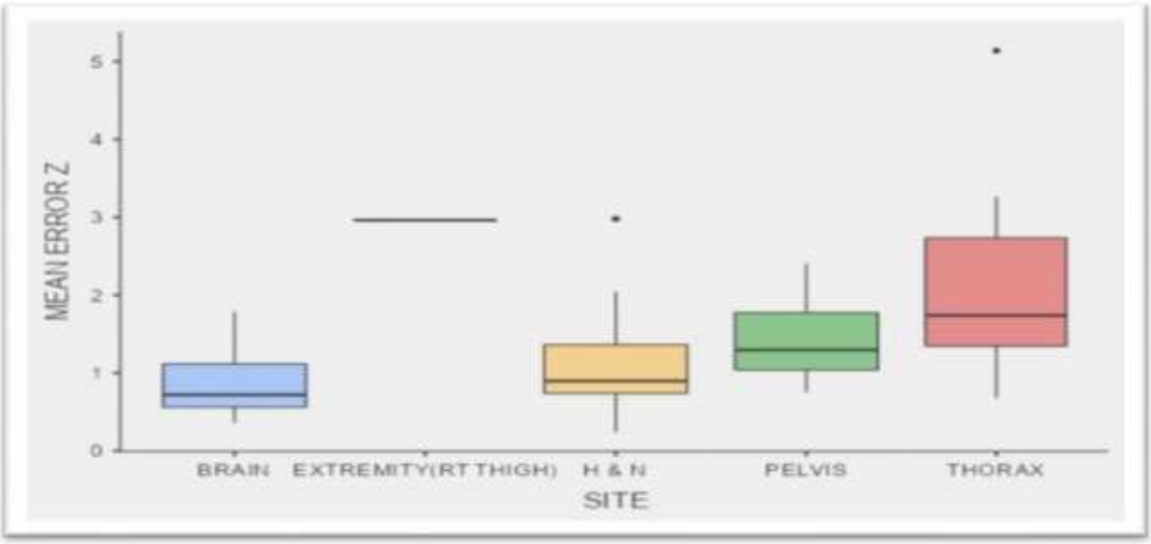
- The systematic error along the lateral, longitudinal, and vertical directions for all sites ranges from 1.04mm to 2.63mm, 1.33to mm 2.73mm, and 0.87mm to 2.96mm respectively
- All the random errors were within 1 mm except for lung with an error of 1.05mm along the vertical direction.
- The systematic error was found to be 1.42mm and 2.06mm along the vertical direction for pelvis and lung patients respectively, which was the highest.
- Similarly, among the random error, it was observed that the highest error of 1.05 mm found for lung in the vertical direction.
- Calculated PTV margin site wise by a formula
- It was found that the clinical isotropic margin of 4mm is adequate for brain patients.
- In H and N, the calculated margins were well within the isotropic margin of 5 mm which is in clinical use.

In pelvis, the calculated margins were well within the isotropic margin of 10 mm which is in clinical use In the lung, all the calculated lateral and vertical margins were well within the margins used clinically 6.7 mm vs 7 mm and 5.8 mm vs 7 mm respectively however in longitudinal direction the calculated margin were out of clinical margin 7.33 mm vs 7 mm.

Graphical Distribution of site & Error of Y -FIG 8



Graphical Distribution of site & Error of Z – FIG 9



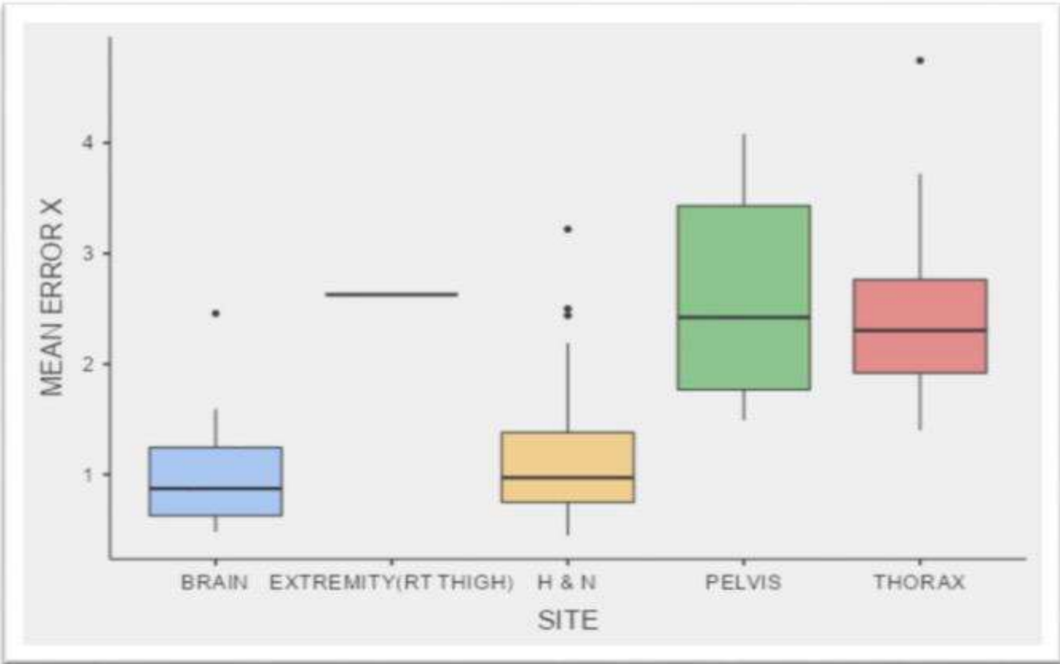
DISCUSSION

The aim of this study was to quantify setup uncertainties across different anatomical sites using TomoTherapy megavoltage computed tomography (MVCT), and to derive optimal PTV margin recommendations for each site. In TomoTherapy, dose delivery is achieved by translating the treatment couch through a continuously rotating gantry. Intensity modulation is performed using binary multileaf collimators driven by high-pressure pneumatic systems. Ninety-three patients with tumors in the head and neck, brain, thorax, pelvis, and extremities were enrolled. MVCT imaging was performed before each fraction to verify patient positioning and target localization. Using the integrated anatomy registration tool, MVCT provided real-time measurements of tumor displacement relative to the simulation CT position.Interfraction setup variations were analyzed for five anatomical regions. Setup deviations were consistently smaller for intracranial sites, specifically head and neck and brain, compared to extracranial sites including thorax, pelvis, and abdomen. The largest deviations were observed in lung cancer patients, likely due to respiratory-induced tumor motion. Such motion can be mitigated using breath-hold techniques or respiratory gating devices.

CONCLUSION

- PTV margins were evaluated for multiple disease sites in patients treated with helical Tomotherapy-based IGRT. The findings validate the clinical margins currently in use at our institution. For brain, head and neck, and lung tumors, the applied margins were found to be adequate across all axes, except for the longitudinal Y margin in lung cases where the calculated margin of 7.33 mm slightly exceeded the clinical 7 mm margin. Since daily MVCT image guidance was employed, there is potential to reduce PTV margins for selected sites without compromising target coverage. Conversely, in the absence of daily IGRT, the clinical margins used in this protocol, along with the immobilization devices, would maintain setup errors within acceptable limits. The calculated margins from this study may also serve as a reference for centers using non-IGRT setups.For brain, head and neck, and pelvic tumors, the clinically implemented margins proved sufficient along all axes. It is well established that advanced platforms like TomoTherapy combined with IGRT improve the therapeutic ratio by escalating tumor dose while sparing normal tissues. However, these benefits can be offset by uncertainties inherent to the radiotherapy chain. Each step—from immobilization and imaging to contouring, planning, dose calculation, delivery, and verification—contributes its own potential sources of error.Limitations
- This study has several limitations that should be considered:Sample size: The cohort included 93 patients, which is relatively small for deriving site-specific margin recommendations.Immobilization variability: Despite using advanced immobilization systems, inter-fraction patient motion and repositioning differences could still introduce setup errors.Respiratory motion: For thoracic and abdominal tumors, breathing-related movement affects reproducibility, particularly when motion management techniques were not used.Laser alignment errors: Initial positioning using room lasers may be inaccurate if skin tattoos or reference marks are poorly visible or inconsistently applied.Machine calibration drift: Over time, mechanical components of the TomoTherapy unit may drift from calibration, leading to systematic discrepancies..

Graphical Distribution of site & Error of X- FIG 7



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