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VMAT Treatment Evaluation in Patients with Head-And-Neck Cancer (HNC): Analysis of Systematic, Random Errors and Evaluation of CTV-PTV Margin.

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KEYWORDS

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ABSTRACT:

This study focuses on refining the accuracy of treatment setup and delivery for patients with advanced head-and-neck cancer (HNC) undergoing Volumetric Modulated Arc Therapy (VMAT). VMAT allows rapid, dynamic delivery of highly targeted radiation doses, making precise error control essential to avoid unnecessary radiation exposure to healthy tissue. We evaluated 40 patients with stage III or IV HNC who received VMAT at our center, delivering a simultaneous integrated boost (SIB) of 70 Gy to the primary tumor and 57.75 Gy to the nodal regions. This research specifically assessed variations in patient setup along the vertical, longitudinal, and lateral axes. The study relied on data from the Monaco Treatment Planning System (Version 5.11.02, Elekta) and the Mosaiq software (Version 2.0), integrated with iViewGT and XVI onboard imaging systems on the Elekta Versa-HD machine. Before treatment, we conducted quality assurance and quality controls (QA/QC) and dosimetric verification using the MyQA platform and a high-resolution Matrixx Universal detector array. This allowed us to create a database capturing treatment setup variations to ensure consistency and reliability across all treatment fractions. The results emphasize the importance of understanding both systematic and random errors to enhance treatment precision. Following the International Commission on Radiation Units (ICRU-51 and 62) recommendations, we calculated systematic errors in the X, Y, and Z directions to be 0.93 mm, 0.9 mm, and 0.88 mm, respectively, while random errors were 0.98 mm, 0.82 mm, and 0.92 mm in these same directions. Using Van Herk's margin formula, we determined the Clinical Target Volume to Planning Target Volume (CTV-PTV) margins as 3.011 mm, 2.824 mm, and 2.844 mm for each axis. QA/QC results also confirmed a high dose accuracy with a gamma index average of 99.5% across treatments. In conclusion, managing systematic and random errors in external beam therapy is critical, especially for complex regions like the head and neck, where anatomy can vary significantly. Despite

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advancements in VMAT, errors remain inherently unpredictable, underscoring the need for precise margin calculations to maintain treatment quality. Accurate CTV-PTV margins are crucial for minimizing radiation exposure to healthy tissue while ensuring that the tumor receives the prescribed dose, ultimately improving treatment outcomes for patients with large tumor volumes in radiosensitive areas.

1. Introduction

Head-and-neck cancers (HNC) account for nearly 6% of all malignancies, with almost half of patients presenting in a locally advanced stage [1]. Cancer treatment using radiation therapy, more precisely Volumetric Modulated Arc Therapy (VMAT) has emerged as a powerful technique in radiation therapy, allowing for the precise delivery of highly conformal dose distributions. Due to the large and often complex shapes of target volumes in HNC, heterogeneity of HNC region and the sensitivity of the organs located in the HNC location. VMAT enhances the therapeutic ratio by enabling better coverage of the target while sparing nearby healthy tissue. This technique has gained widespread adoption in radiotherapy centers, thanks to its precision, efficiency, and treatment efficacy. With VMAT, the multileaf collimator continuously adjusts both shape and fluence (dose rate), optimizing the radiation dose across the target and ensuring a more homogenous isodose distribution while reducing treatment time. For HNC cancers, this precision has allowed physicists to achieve excellent target coverage and minimize dose to surrounding organs at risk (OARs) [2-3].

As with all radiation therapy techniques, however, VMAT is not without limitations. Systematic and random errors can occur, impacting treatment accuracy. The primary goal of radiation therapy is to deliver the maximum dose to the tumor while minimizing exposure to surrounding healthy tissue and critical structures. This requires high accuracy during planning and treatment delivery. Therefore, achieving reproducibility of the patient's setup from simulation to treatment is critical, as setup errors and patient movement are inherent to the process. These errors may lead to slight variations in target localization, potentially compromising the treatment outcome. The planning target volume (PTV) includes the clinical target volume (CTV) plus an additional margin to account for these setup uncertainties, patient motion, and other factors that could reduce treatment effectiveness or increase toxicity to nearby organs [4].

Geometric uncertainties during radiation delivery can result in insufficient dose coverage of target volumes and unintended exposure of critical organs. These uncertainties, which can arise from factors like patient positioning, mechanical variations in equipment (such as gantry, multileaf collimator, or treatment couch), data transfer from computed tomography (CT), or human error, must be managed with care. Systematic errors are consistent, usually occurring in the same direction and with similar magnitude across treatment fractions, while random (day-to-day) errors vary in direction, magnitude, and predictability [4-5]. Therefore, precise setup margins and reproducibility are essential in VMAT to ensure optimal dose coverage and minimize the risks associated with positional uncertainties that remain unpredictable [5].

2. Materials and Method

2.1. Patient Selection

Since September 2021 to December 2022, about 251 patients with HNC were treated using VMAT in our center, in order to evaluate and analyze our quality of treatments, we analyzed data of a randomly selected consisting 40 patients suffering from HNC for this study being treated at Mohammed VI oncology center [Table 1], For assessing time burden, the entire and delivery process was divided into two major specific steps, each step is a well-defined entity allocating Human Resources based on prevalent departmental experience and practice to verify every step during the can-CT session and simulation. First, these patients underwent a mold room procedure for precise immobilization and set-up using a headrest and a 5-points fixation thermoplastic mask (Civco Medical Solutions, Kalowa, IA), followed by the CT scanning protocol for head-and-neck cancer (HNC). Keeping the headrest and shoulder traction, metal micro spherical fiducially were placed after patient's alignment to the scan-CT lasers making precise alignment to reduce misplacement of the head, at this point the scan-CT therefore were verified, approved and sent to the simulation unit. The planning CT

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scan was done on a flat couch six slices CT scanner (Optima CT-660, General Electric Medical Healthcare, Boston, Massachusetts, USA), high resolution images of the verse to 10 cm below the carina following the tree his of space (axial, sagittal and coronal) were taking using 2.5 mm slices thickness. Second, the approved scan-CT is uploaded on the treatment planning for volume delineation. The Gross Tumor Volume (GTV) was outlined on a contrast-enhanced planning CT scan with a 2.5-mm slice thickness. In most patients, target volumes were defined by co-registering diagnostic MRI scans with planning CT (or PET/CT as needed). The GTV encompassed the primary tumor along with involved lymph nodes as identified on both imaging modalities. The ‘‘boost’’ clinical target volume (C$\boldsymbol{TV_{boost}}$) comprised the gross tumor volume with a margin of 1 cm, and was corrected for anatomical boundaries. The elective CTV (C$\boldsymbol{TV_{elect}}$) included the C$\boldsymbol{TV_{boost}}$ and bilateral elective lymph nodes: at least levels II-V, and level I-VI or retropharyngeal nodes when indicated and in accordance with published guidelines.

Table 1. ***Patients Characteristics.***

patient	site	Age)	Vol $\boldsymbol{PTV_{elect}}$ (mL)	Vol $\boldsymbol{PTV_{boost}}$ (mL)
1	Larynx	55	665	150
2	Larynx	57	684	132
3	Cavum	60	710	122
4	Oropharynx	49	515	214
5	Larynx	61	705	186
6	Hypopharynx	68	560	178
7	Nasopharynx	56	814	452
8	Larynx	67	801	230
9	Cavum	66	722	152
10	Larynx	58	789	210
11	Hypopharynx	68	620	184
12	Cavum	64	447	176
13	Hypopharynx	47	610	217
14	Larynx	53	522	187
15	Cavum	56	588	213
16	Cavum	68	760	206
17	Oropharynx	49	643	170
18	Larynx	54	657	231
19	Cavum	69	763	210
20	Cavum	54	594	167
21	Larynx	70	692	185
22	Hypopharynx	57	739	155
23	Nasopharynx	63	583	173
24	Larynx	58	695	125
25	Cavum	61	739	221
26	Hypopharynx	69	679	186
27	Larynx	55	712	204
28	Hypopharynx	57	652	175
29	Cavum	51	717	233
30	Oropharynx	68	594	180
31	Larynx	61	497	169
32	Larynx	69	630	171
33	Hypopharynx	65	566	187
34	Cavum	57	940	154
35	Cavum	59	870	206
36	Cavum	63	833	223
37	Cavum	47	794	194
38	Oropharynx	65	691	179
39	Cavum	60	760	157
40	Cavum	63	709	212
average	40 cases	58.5 (47-70)	650	270

2.2. Planning objectives and techniques:

The treatment planning and simulation of treatment aiming to create an optimized plan with the best dose distribution possible giving maximum dose to the target volume and

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rotating the healthy tissue as possible as the optimization stage can give by giving the planning system the OARs constraints that should be respected. For this study we realized an integrated boost treatment up to 70Gy during 35 fractions delivering 2Gy per fraction. Patients were irradiated once per day, five times per week [6]. The quantitative evaluation of plans was done on the histogram dose-volume to appreciate the coverage of the target volume by the prescribed dose more. precisely on the Areas where the PTV approaches the surface, a local virtual build up was recommended on 6 mm (the aim was to overcome dose build up under the skin) was applied to optimize and quantify the PTV coverage. Therefore, Optimization and radiation dosage calculations were performed using the Monaco (Version 5.11.02, Elekta, Stockholm Sweden) treatment planning system with 6 MV photon beams from an Elekta Versa-HD Treatment Machine (Elekta Ltd, Crawley, UK).

2.3. Quality assurance (QA) and quality assurance (QA):

n dynamic treatments like VMAT, accurate dose delivery requires synchronization between the gantry position, multileaf collimator (MLC) leaf positions, and dose rate. Maintaining this coordinated alignment throughout treatment is essential to ensure a uniform dose distribution. For our study, using a VERSA-HD machine, the treatment planning system assigned specific MLC shapes and precise dose rates for each gantry position; segments are defined during the second stage of optimization. Pretreatment quality assurance and quality controls (QA/QC) verifications enabled us to confirm that all dosimetric parameters were accurately set. VMAT pretreatment quality assurance requirements of dosimetric verification, plans analysis and control of homogeneity, coverage and conformity of PTV before treatment was done by using a Matrixx (IBA dosimetry Gmbh, Brabant Wallon, Belgique) to verify the gamma index and dose homogeneity and distribution. Patient Setup required a high level of precision which led to the need of a tool for image analysis, these approaches were applied by comparing the reference images with KV-CBCT current treatment images, systematic and random errors are unpredictable parameters, before treatment patient's setup must be confirmed by the presence of a RO and a RTT to make sure the setup reproducibility according to the simulation setup (reference setup). For this issue a board imaging system is installed in the treatment machine that allow us to make KV-CBCT images and KV-2D images using XVI R5.0.3 and iViewGT R3.4.0 on board imaging systems to keep the precision and efficiency of the reproducibility. The resulting images were registered to create a 3D volume reconstruction following space axis and compared to reference simulation-CT by changing the contrast, at this stage the matching between references images and current images is important following bony landmark matching due to the importance of this step to reduce the maximum of systematic errors possible during the setup specially for cases such as head and neck cancer (HNC). After the radiation therapist approved the image registration, couch corrections were applied in the X, Y, and Z directions. These adjustment data were recorded in a log sheet to calculate the appropriate margin from CTV to PTV using the Van Herk formula. (1).

$$\text{CTV-PTV} = 2.5 * \sum + 0.7\ \sigma \qquad (1)$$

$\sum$ = systematic error and σ = random error.

For the documentation and evaluation purpose superior, anterior and right-side shifts are taken as positive shifts and posterior, inferior and left side shifts are taken as negative shifts. Routine shifts assurance of the radiation therapy machine was done in the recommended conditions with the minimum impact on daily setup position [6-4]. In this study XY software is used for data collection and statistical analysis. The general workflow starting from mold room procedure to radiation treatment setup verification for HNC radiation therapy is shown in [Figure 1].

3. Results and Discussion

3.1. Optimization & pretreatment verification:

Clinically accepted single arc VMAT treatments plans were achieved in all cases. Although the exact times for optimization and planning were not registered, VMAT optimization clearly were faster than other Radiotherapy modalities due to the advanced technology especially that Monaco TPS in uses on Monte-Carlo (MC) algorithms to execute photons interaction with the irradiated part, adding the computer good performance and the fast sequencing on the TPS. The conformity index (CI) was calculated for all treatment plans as the ratio of the patient volume receiving at least 95% of the prescribed boost dose to the volume of the PTV_{boost}. Additionally, we recorded the percentage of boost and elective volumes receiving at least 95% ($V_{95\%}$) and 107% ($V_{107\%}$) of the prescribed doses. The doses delivered to 99% and 95% of the target volumes, noted as $D_{99\%}$ and $D_{95\%}$, were also calculated. Dose homogeneity to PTV_{elect} and PTV_{boost} was largely approved using the

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single ARC plans. The Mean PTV coverage, CI, D_{max} In the spinal canal, target volumes 95% and 107% for all 40 patients are summarized in [Table 2]. The mean volumes of P PTV_{elect} and PTV_{boost}were 650 cm^3, and 270 cm^3, respectively. Coverage of both PTV_{elect} and $PTV_{boost}$was excellent on an average superior to 99% of both PTVs receiving a dose superior to 99% of the prescribed dose. QA verifications were using Matrixx resolution and MyQA platform presented by IBA Dosimetry. Dose distribution Results for one representative patient are shown in [Figure 2] with a 95% does distribution of the ail and Gamma criteria of 2mm in 2%, coronal and sagittal slices, Dose-volume histogram (DVH) of PTV_{elect} and PTV_{boost}next to dose variation of the spinal cord and the brainstem, also [Figure 3] shows us QA results of the gamma index was 99.8% of matching dose distribution of a representative patient treated for Larynx Cancer. Mean value for all 40 patients was on an average of 99.5% [7].

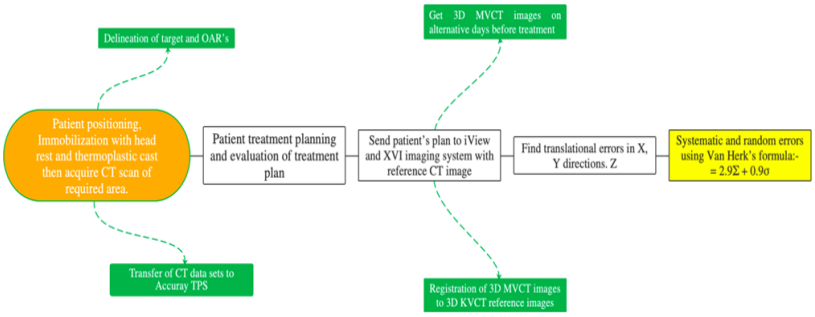

Figure 1. ***Standard protocol and workflow for HNC patients in Mohammed VI radiotherapy department.***

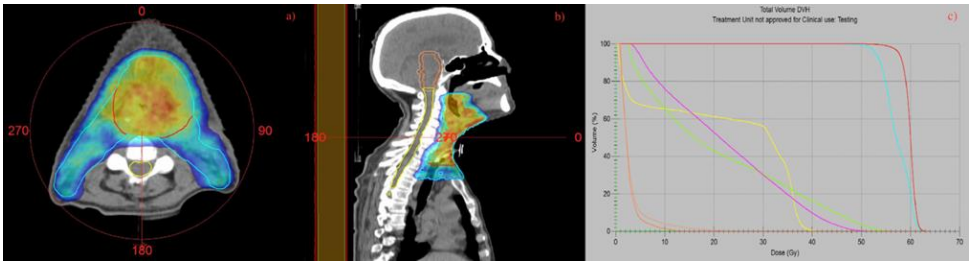

Figure 2. ***a), b) and c) are respectively the Axial and sagittal Dose ($D_{95\%}$) distribution and dose- volume histogram (DVH) for a typical patient oropharynx tumor. DVH of planning target volume elective nodal region (PTV_{elect}) in blue Cyan, PTV_{boost} in red, spinal cord in yellow and brainstem in Orange.***

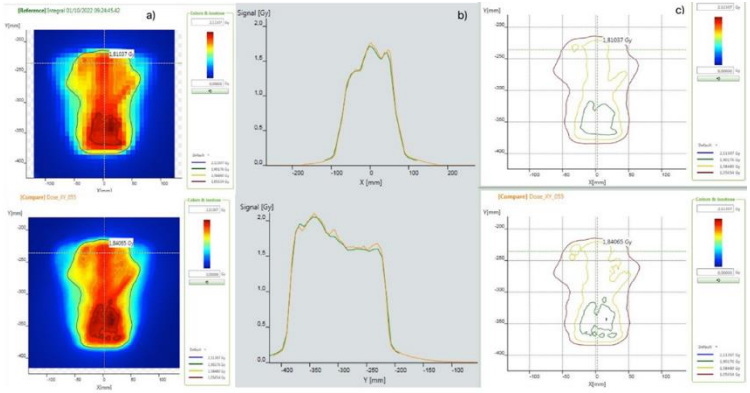

Figure 3. ***QA results from comparing dose coverage Gamma index by using MATRIXX Resolution and MyQA (IBA dosimetry).***

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a). Dose fluence of the exported integral slice of TPS results and the measured integral slice by the Matrixx.

b). Comparison of the imported fluence signal from the Monaco TPS and the measured signal by the Matrixx.

c). Fluence- dose mapping of the TPS and the Matrixx.*3.2. Systematic and random errors corrections:*

In the absence of simulated errors, the integrated images are almost uniform due to the dynamic modality of treatment and some features are visible when QC are dome by KV-CBCT are done before starting VMAT treatment delivery fraction [12-15]. A statistical analysis was performed on all patient data, with 3D shifts recorded in the X (lateral), Y (longitudinal), and Z (vertical) directions based on the nature of systematic and random errors and their frequencies. Errors for all patients were categorized to calculate the mean (M) and standard deviation (SD). The mean values of systematic errors in the X, Y, and Z directions were 0.93 mm, 0.9 mm, and 0.88 mm, respectively, while random errors (SD) were 0.98 mm, 0.82 mm, and 0.92 mm, respectively. The calculated CTV-PTV setup margin is shown in [Table 3].

Translation shifts in all three directions were calculated individually for each patient, with [Figure 4] displaying the mean directional shift per patient. The displacement range for each direction was also determined. Setup errors were calculated using iView and XVI, confirming their effectiveness in reducing setup margin. The final margin results were compared with previous studies, showing a high level of agreement and acceptability [10-16].

The accuracy of treatment delivery depends upon precision and good immobilization, T simulation and quality of treatment delivery. In this study, spatial attention has been given towards proper mobilization to reduce the setup margins and protect the OARs in the region of the target volume. According to the International Commission on Radiation Units (ICRU) repast 62, these additional CTV-PTV margins are required to include systematic and random errors. According to previous studies such as Stroom et al and Van Herk's Formula, the final CTV-PTV margin must be introduced from both systematic and random errors [11-10]. The final CTV-PTV margins calculated using Van Herk formula we found that 3mm of 3D margin for PTV is sufficient to give uniforms and homogeneous dose distribution to the target area with an adequate target volume coverage. The larger the interval of having errors during radiation treatment delivery affect the target coverage which can result in false treatment causing acute, short term side effect and long-term side effect, in few cases can even cause radio-inducted cancers and destroy the functioning of OARs near the target volume especially in Head and Neck Cancer due to the sensibility of the organs in neighbor [13-14].

Table 2. ***The Mean PTV coverage, Conformity Index (CI), D_{max} in the spinal canal, target volumes $V_{elect\_95\%}$, $V_{boost\_95\%}$ and $V_{boost\_107\%}$ for all 40 patients.***

Site (n patient)	$V_{elect\ 95\%}$	$V_{boost\ (95\%)}$	Conformity Index (CI)	$V_{boost\ 107\%}$	D_{max} (Gy) Spinal cord
Cavum (15)	*99.7*	*99*	*1.13*	*0.0075*	*44.6*
Nasopharynx (2)	*99.4*	*99.3*	*1.1*	*0.0074*	*44.3*
Hypopharynx (7)	*98.5*	*98.9*	*1.14*	*0.0045*	*44.9*
Larynx (12)	*97.8*	*98.6*	*1.12*	*0.0061*	*45.1*
Oropharynx (4)	*98.4*	*99.1*	*1.14*	*0.0055*	*44.8*
Standard deviation range	± 0.96	± 0,38	± 0,026	± 0.0017	± 0,44

Table 3. ***Systematic errors (Mean of deviations values), Random errors (standard deviations values) and Calculated setup margin in mm using Van Herk's formula in Lateral direction (X), Longitudinal direction (Y) and Vertical direction (Z).***

Directions	Systematic errors	Random errors	Calculated setup errors using Van

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	Mean (mm)	SD (mm)	Herk Formula (mm)
Lateral (X)	0,93	0,98	3,011
Longitudinal (Y)	0,9	0,82	2,824
Vertical (Z)	0,88	0,92	2,844

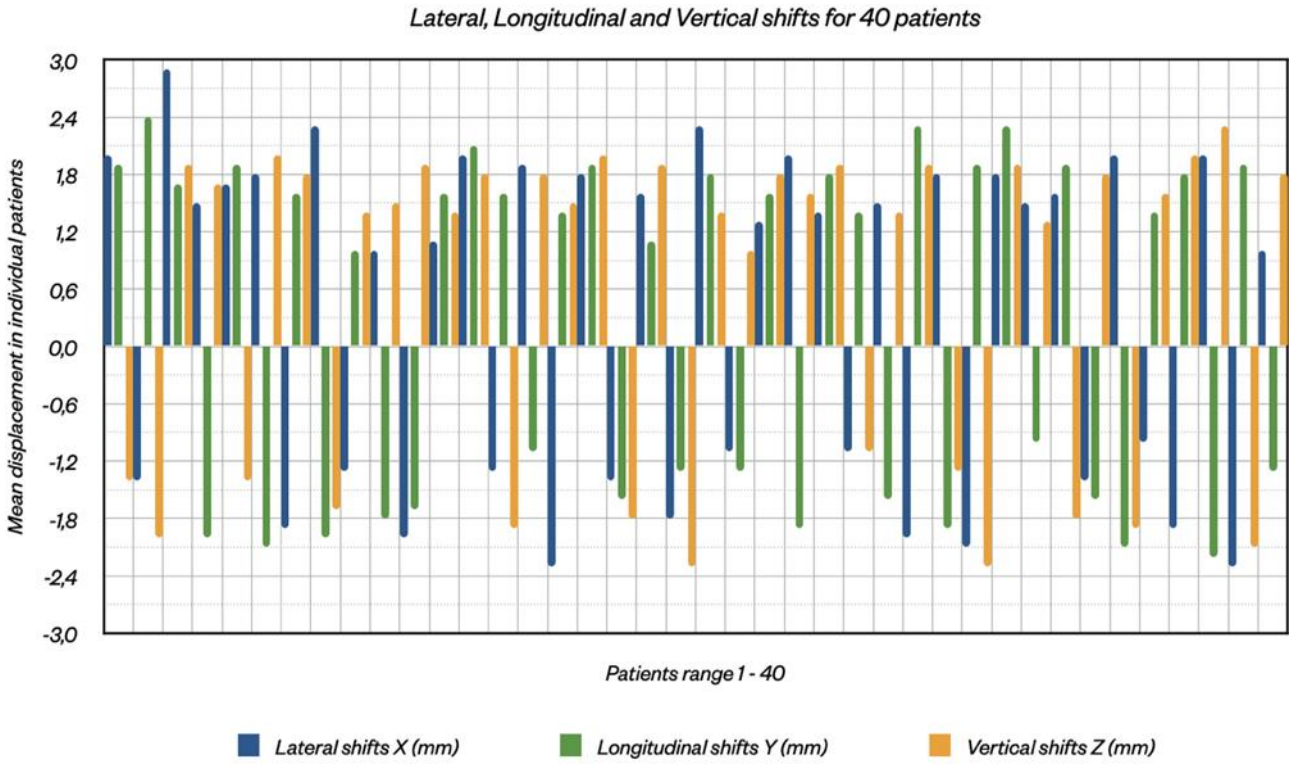

Figure 4. ***Mean variation in Lateral direction (X), Longitudinal direction (Y) and Vertical direction (Z) for 40 patients' setup.***

4. Conclusion

The present study we have found that the 3mm setup margin is the optimal CTV-PTV margin to consider setup errors in HNC patients. These setup errors allow us to have. Better target coverage and ensure the safety of OARS in the neighbor of the treated region and prediction of radiation treatment outcomes and prognostics especially when patients are being treated using IMRT, VMAT, Tomotherapy and SRS to reduce the occurrence of missing the target volume and accidentally giving an overdose to healthy tissue. The determination of CTP-PTV margin is important for radiation treatment with high dose rate and small setup precision treatment all along with other quality insurance making sure that our patients will have the best treatment possible.

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Conflict of Interest

The authors declare no conflict of interests.

Refrences

[1] Ferlay J, Autier P, Boniol M, et al. Estimates of the cancer in- cidence and mortality in Europe in 2006. Ann Oncol 2007; 18: 581–592.

[2] Stroom JC, Heijmen BJ. 2002 Radio Ther Oncol. 64(1) 75-83. Herk VM, Remeijer P, Lebesque JV.

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(2), 26-33 | ISSN:2251-6727

2000 Int J Radiat Oncol Biol Phys. 47(4): 1121-35.

[3] Bel A, Herk M, Lebesque JV. 1996 Med Phys. 23 1537-47. Hurkmans CW, Remeijer P, Lebesque JV, Mijnheer BJ. 2001 Radiother Oncol. 58 105-20.

[4] Gupta T, Chopra S, Kadam A, Agarwal JP, Devi PR, Laskar GS. 2007 Radiat Oncol. 2 44.

[5] Stroom JC, Boer HC, Huizenga H, Visser AG. 1999 Int J Radiat Oncol Biol Phys. 43(4) 905-19.

[6] Landberg T, Chavaudra J, Dobbs J, Gerard JP, Hanks G, Horiot JC. 1999 J Int Comm Radiation Units Measurements. 32(1): 48-51.

[7] Gregoire V, Levendag P, Ang KK, et al. CT-based delinea- tion of lymph node levels and related CTVs in the node- negative neck: DAHANCA, EORTC, GORTEC, NCIC, RTOG consensus guidelines. Radiother Oncol 2003; 69: 227–236.

[8] Hong TS, Tome WA, Chappell RJ, Chinnaiyan P, Mehta MP, Harari PM. 2005 Int J Radiat Oncol Biol Phys. 61(3): 779-88.

[9] Xu F, Wang J, Bai S, Xu QF, Shen YL, Zhong RM.. 2008 Chin J Cancer. 27(10): 1111-6.

[10] Kataria T, Abhishek A, Chadha P, Nandigam J. 2011 J Cancer Res Ther. 7(1): 40- 6.

[11] Herk VM, Remeijer P, Lebesque JV. 2000 Int J Radiat Oncol Biol Phys. 47(4) 1121-35.

[12] Jones D. 1994 Med Physics. 21(6): 833-34. Hadi SM, Farshid A, Mastaneh S, Elham H, Mina T, Rostami A, et al. 2018 Canc Therapy Oncology.

[13] W. P. Segars et al., "4D XCAT phantom for multimodality imaging research," Med.Phys. 37 (9), 4902-4915 (2010).

[14] Chang J. A statistical model for analyzing the rotational error of sin- gle isocenter for multiple targets technique. Med Phys. 2017;44:2115–2123.

[15] Yue NJ, Knisely JH, Nath R. A method to implement full six-degree target shift corrections for rigid body in image-guided radiotherapy. Med Phys. 2006;33:21–31.

[16] Zhang Q, Xiong W, Chan MF, Song Y, Burman C. Rotation effects on the target-volume margin determination. Physica Med. 2015;31:80–84.