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Estimation of clinical target volumeto planning target volume margin in radiation therapy for different treatment sites

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Abstract
Background and purpose:*During radiotherapy, setup errors in patient positioning play a vital role in tumor control and normal tissue overdosage. This analysis aimed to assess patient setup errors and to suggest maximal planning target volume (PTV) for different treatment sites.*
Material and method:*Using computed tomography (CBCT) and electronic portal imaging device (EPID). In 100 patients, a total of 300 sessions have been assessed for head and neck, thorax, breast, abdomen, and pelvic. Systematic and random population errors and the 3D shift vector is determined. PTV margins were calculated using a formula from van Herk.*
Results:*systematic and random errors were 0.08, 0.16 and 0.11 cm and 0.1, 0.21 and 0.13 cm for head and neck cases whiles values of 0.17, 0.18 and 0.15 cm and 0.17, 0.18 and 0.19 cm for thorax cases. For breast, values of 0.17, 0.18 and 0.19 cm and 0.28, 0.25 and 0.29 cm, whereas 0.18, 0.23 and 0.18 cm and 0.32, 0.29 and 0.2 cm for abdomen cases, and 0.11, 0.16, and 0.11 cm and 0.15, 0.15, and 0.17 for pelvic cases in vertical, longitudinal and lateral directions, respectively. The PTV margins were less than 0.5 cm for head, neck, and pelvic sites and are less than 0.7 cm for thorax, breast, and abdomen cases in three translational directions.*
Conclusion:*The errors in setup depend on the location of the tumor. The use of image guidance techniques is an important way to validate the setup.*
Keywords:*Systematic error; Random error; planning target volume; Patient setup uncertainty.*

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I. Introduction

The concept of radiation therapy (RT) is to extend the portion to the target in a dependable way while reducing the dangerous value to the normal tissues. Pursuant to the International Commission for Radiation Units and Measures (ICRU 50, 62, 71, and 90), the planning target volume (PTV) specifies that a geometric margin should be used around the clinical target volume (CTV) to ensure sufficient cover[1–4]. Thus, the chances of missing the target may be possible during the treatment. In the treatment modalities intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT), we use the high gradient delivery plan to deliver conformal dose to the target and less dose to organs at risk; therefore, considering this adequate margin calculation is necessary[5]. Reducing margins is possible through the appropriate use of image-guided techniques that allow for online or offline protocol for correction. Image guidance systems such as cone beam computed tomography (CBCT) and electronic portal imaging devices (EPIDs)are used to minimize setup errors[6]. Reducing setup error would allow treatment margins to be reduced, leading to improved local control at the tumor site and dose escalation. Setup errors can be classified into two parts: systematic errors and random errors. While the random errors blur the dose distribution, the systemic element of errors leads to a shift in the cumulative dose distribution relative to the PTV[7].Systematic errors are recurring reproducible errors that appear in the same direction and magnitude but random (daily) errors can differ in direction, magnitude and are unexpected[8]. Contrary to random errors, the systemic errors are more severe, since they affect all therapy sessions.Systemic errors can lead to tumor recurrence or serious damage in normal organs.

The goal of this study was to determine target volume (PTV) margin in radiation therapy errors using measured setup errors for pelvic,thorax, head and neck, breast, and abdomen tumors based on clinical evidence produced during pre-treatment verification of tumor by cone-beam computed radiography (CBCT).

II. Materials and Methods

2.1 Image acquisition and matching procedures

Images are taken with computed tomography (Siemens, SOMATOM Definition AS, VA48A) and used for target delineation and dose planning before commencing a course of radiation treatment. During the CT acquisition, tiny tattoos are placed on the patient identifying the location on the scan table, called "user origin.". The isocenter coordinates relatively to the origin of the user are stated during the dose planning stage. Until the first treatment fraction is administered the patient is placed on the couchby aligning the room lasers with the tattoos and the couch is shifted according to the isocenter coordinates. New skin markers that identify the isocenter location are indicated on the patient, and for the remaining sessions, the patient is positioned directly in that location on the couch top. After that, matching strategies with portal images are also used to put the patient in the right location of treatment more precisely.The image series obtained by CT are used to create the reference images used for matching images. These comparison images are generated using Varian Medical Systems' application called "Image browser." There are forms of reference images that are used in digitally reconstructed radiographs (DRR) and CT (3D imaging) planning at Baheya hospital.The DRR is created by the projection of monoenergetic X-ray lines into a 2D image plane via the volumetric data. Due to various anatomical materials, the information from transmission lines describes the attenuation across voxels.The patient verification application (PVA) for TrueBeam and on-board imager (OBI) for Clinac iX systems acquires 1D and 2D kV, and 3D CBCT imaging.

There are two types of similar procedures used, comparing online and offline. Online matching is conducted by the oncologists at the treatment unit before a given fraction is provided and whereas post-treatment offline matching is done using stored image data.Online matching is achieved through the image application supported by Varian Medical Systems at iX and TrueBeam. On the reference image, the acquired image is immediately overlaid with the isocenter of the acquired image positioned above the DRR isocenter. The image data used for online matching is stored and can be used in the "Offline Review" framework developed by ARIA by Varian Medical Systems for offline matching and verification.

2.2 Matching protocols

To some extent, most protocols allow correction of the inter-fractional systematic error, i.e., the divergence between treatment fractions, and a daily image protocol will seek to correct the random error. Because of the tremendous workload the system demands, a daily matching protocol cannot always be used.Therefore, the Baheya Hospital also uses an offline matching procedure of the bony anatomy or PTV site where portal images (Figure 1) or CBCT (Figure 2) are obtained within the first three days of service. Online matching is done during these three fractions to prevent massive, inter-fractional systematic errors.

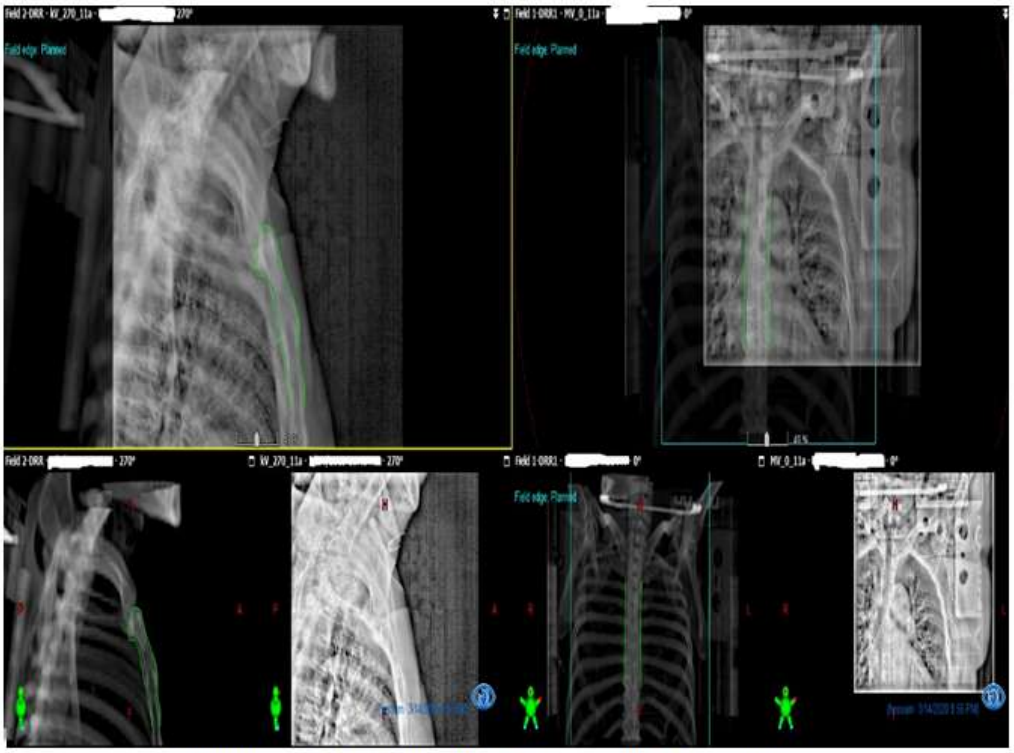

Figure 1 Typical matching DRR for Breast treatment by portal images

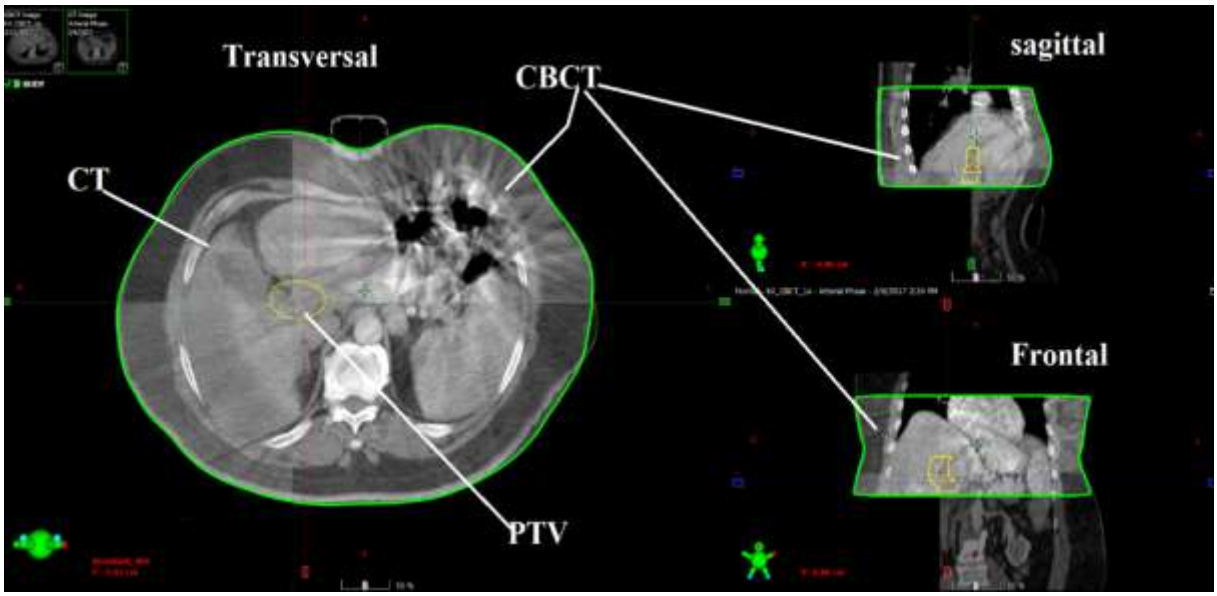

Figure2 Typical matching CT for Liver treatment by CBCT

2.3 Evaluating systematic (Σ) and random (σ) errors

Systematic errors are treatment prep errors and all sessions are affected by such errors. Faulty instruments, defects in initial system set-up, or design or mistake in the improper use of the instruments may be the source of these defects. Systematic errors may cause a dose delivery change away from the planned clinical target volume (CTV), or cause the PTV amount to be overdose or underdose.The systematic error is generally defined and measured in patient population ways, and is considered to be composed and summarized according to equation (1)[9].

$$\Sigma^2 = \Sigma^2_{motion} + \Sigma^2_{setup} + \Sigma^2_{delineation} + \Sigma^2_{transfer} \qquad \text{Eq. (1)}$$

The elements relate to the standard deviation (SD) of the human target motion and deformation defects, patient setup, target delineation, and transfer of images. The PTV motion involves changes that can be caused by weight loss and tumor relapse in the location and type during therapy. The setup error involves any mistakes that are implemented during the treatment preparation preparatory stages. PTV delineation refers to errors introduced by little information on the actual extent of the CTV margin required to account for microscopic dispersion. Image transfer error describes deviations that may occur when transporting images between various systems, such as the treatment planning system and the linear accelerator. They are known to be distributed properly and independent of each other, such that they can be described in quadrature [10].The systematic error can be calculated for a patient group according to equation (2).

$$\sum^2_{pop} = \frac{\sum_n (\bar{x}_n)^2}{P-1} \qquad \text{Eq. (2)}$$

In equation (2), $\bar{x}_n$ is the mean displacement value for the patient in the given direction relative to the original location in the reference images obtained before the start of the course of treatment and P is the number of patients in the population. The systematic error in population is the standard deviation of all means.

The random errors explain the disparity between dosage sessions that can appear in any direction during therapy and result in a blurred in the distribution of the dosage[10].The random error is defined by equation (3).

$$\sigma^2 = \sigma^2_{motion} + \sigma^2_{Setup} \qquad \text{Eq. (3)}$$

In the equation theσ^2_{motion} is the SD of the random target motion and shape and σ^2_{Setup} is the SD of the random set-up error. For a patient population, the root means square of all standard deviations is known as the random error [11].Random errors occur during the treatment, which is why they are considered errors in execution. Offline protocols can not correct for random errors, and that must be taken into account in the margin used[12].The random error for a patient population can be determined as per equation (4) and (5).

$$\sigma_p^2 = \frac{\sum_n (\Delta_n)^2}{N-1} \qquad \text{Eq. (4)}$$

$$\sigma_{pop} = \sqrt{\frac{\sum_p \sigma_p^2}{P-1}} \qquad \text{Eq. (5)}$$

In equation (4), Δ is the displacement of each session in a direction and the number of sessions for each patient is N and so σ_p is the individual SD of each patient in a direction.The calculations should be used on the assumption that the number of sessions evaluated is roughly the same for all patients.

Correcting these errors helps keep the PTV as small as possible and minimizestherisk associated with normal tissues. In radiation therapy, the margins are used to cover for the errors.

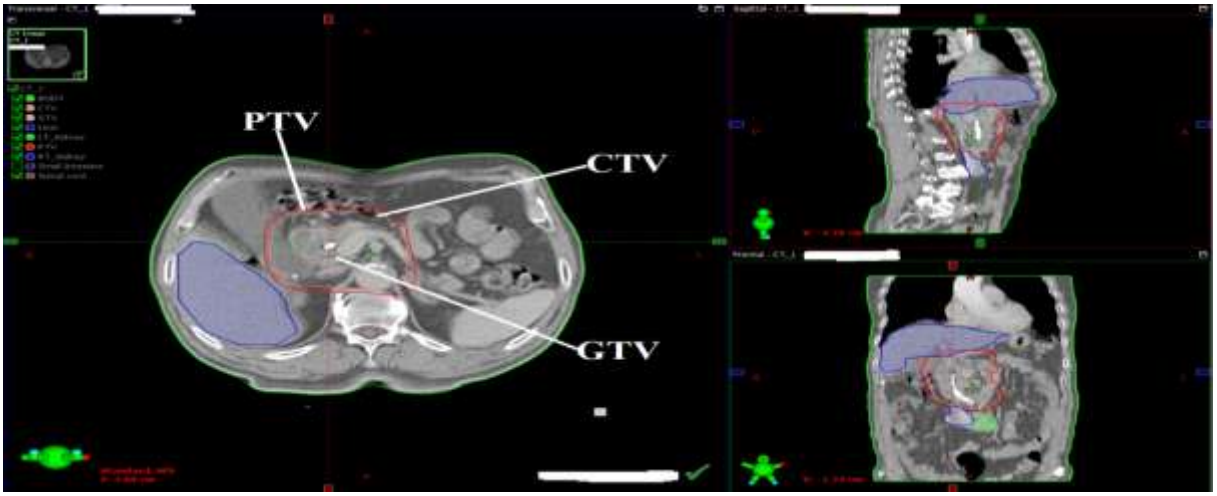

Figure3GTV, CTV, and PTV on Planning CT

2.4 Calculation of the PTV

Depending on the systemic and random errors, the PTV margin is calculated according to institutional measurement.The van Herk Formula [11]is the easiest method for estimating PTV margins in a population dependent on systemic and random errors. The idea behind the van Herk Method is to protect 90% of patients with an isodose line of 95% with the CTV. To this formula, an analytical solution is:(Equation 6)

$$PTV = 2.5\Sigma_{pop} + 0.7\sigma_{pop} \qquad \text{Eq. (6)}$$

III. Results

3.1 PTV margins

In this work, a total of 300 sessions were assessed for head and neck, thorax, breast, abdomen, and pelvic. Table1summarizes the SD of systemic and random errors for the various treatment sites.

Table no1:PTV margins for the different treatment sites

Head and Neck	Direction	Σ (cm)	σ (cm)	PTV (cm)
	Vertical (AP)	0.08	0.10	0.27
	Longitudinal (SI)	0.16	0.21	0.55
	Lateral (RL)	0.11	0.13	0.36
Thorax	Direction	Σ (cm)	σ (cm)	PTV (cm)
	Vertical (AP)	0.17	0.17	0.49
	Longitudinal (SI)	0.18	0.18	0.58
	Lateral (RL)	0.15	0.19	0.49
Breast	Direction	Σ (cm)	σ (cm)	PTV (cm)
	Vertical (AP)	0.17	0.28	0.61

	Longitudinal (SI)	0.18	0.25	0.64
	Lateral (RL)	0.19	0.29	0.67
Abdomen	Direction	Σ (cm)	σ (cm)	PTV (cm)
	Vertical (AP)	0.18	0.32	0.67
	Longitudinal (SI)	0.23	0.29	0.78
	Lateral (RL)	0.18	0.20	0.59
Pelvic	Direction	Σ (cm)	σ (cm)	PTV (cm)
	Vertical (AP)	0.11	0.15	0.37
	Longitudinal (SI)	0.16	0.15	0.51
	Lateral (RL)	0.11	0.17	0.40

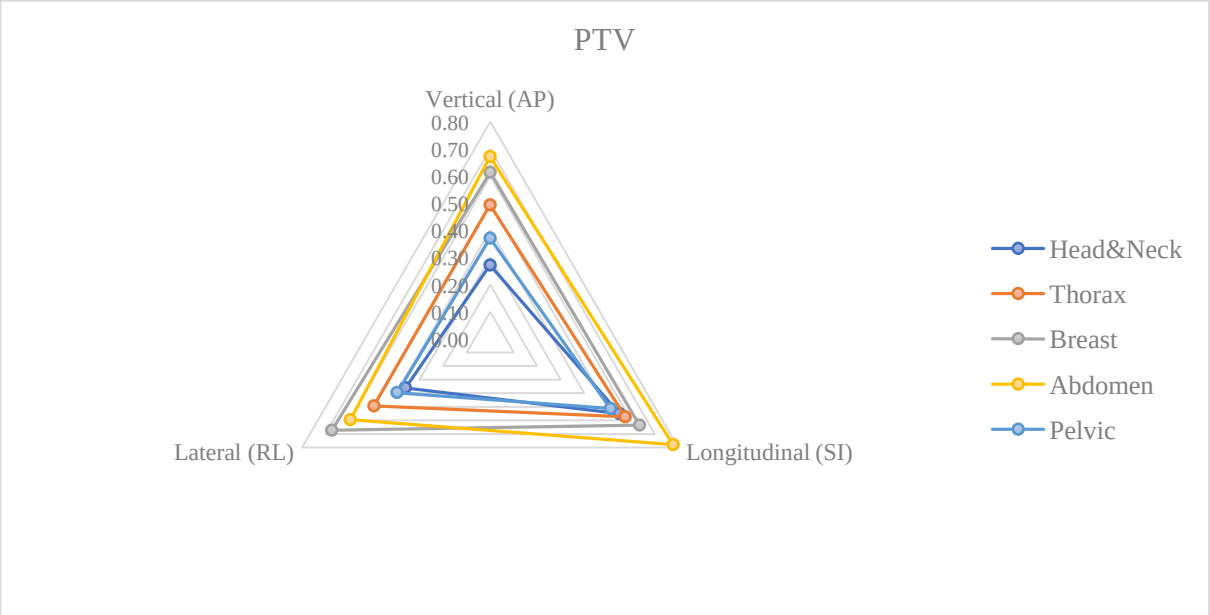

Figure4 Calculated planning target volume (PTV) margins at different Treatment sites.
(AP, antero-posterior; RL, right-left; SI, superior-inferior.)

From figure 4the measured PTV margin was the largest in both directions at the abdomen, with the largest in the longitudinal direction (0.78 cm) followed by the vertical direction (0.67 cm). The measured margin in the head and neck was the lowest in the vertical direction (0.27 cm).

IV. Discussion

Patient positioning verification can be achieved by EPID and CBCT. Therefore, all improvements in the isocenter procedure will be reversed. In this analysis, we used EPID and CBCT to test the inter-fractional setup errors for different treatment sites of 100 patients. Furthermore, the PTV margins were determined with the formulation of van Herk as seen in equation (6). In our hospital, the scale of motion for any direction is 0.5 cm in head and neck, thorax, and pelvic cases and 0.7 cm in breast and abdomen cases. Our analysis results found the systematic and random error distances in three directions were less than 0.32 cm for the abdomen site and less than 0.19 cm for the thorax site (Table 1). In the vertical, longitudinal, and lateral directions, respectively, were less than 0.27 cm, 0.55 cm, and 0.36 cm for the head and neck cases. Overall, in comparison to breast, thorax, abdomen, and pelvic regions, the systematic and random errors in head and neck are minor because these treatment sites are static, and the regular differences in set-up geometry are limited.According to vertical, longitudinal, and lateral measurements, the PTV margins available ranged from 0.27 cm to 0.67 cm, 0.55 cm to 0.78 cm, and 0.36 cm to 0.67 cm respectively. The findings of the previous study in the vertical, longitudinal, and lateral directions varied from 0.43 cm to 0.63 cm, from 1.89 cm to 2.02 cm, and from 0.75 cm to 0.86 cm [12].Our analysis indicates a slightly higher margin value in the vertical direction compared with the previous analysis. Yet the previous study indicates a marginally higher value in both the longitudinal and lateral directions than in our research. These variations are due to the wider utilization of the CBCT and expanded the number of patients with different treatment sites.

V. Conclusions

The systematic and random errors were based on the results of other studies carried out in other radiotherapy departments in the analysis of the final PTV margin. Thus, to evaluate the margins needed for local institution we analyzed systemic and random errors because both margins rely on the fixation and methods used at the clinic in hand. The observed PTV margins would be used for multiple treatment sites in our clinical routine. In this analysis, the setup errors and PTV differences were calculated for different treatment sites for the first time in our department. The errors in setup depend on the location of a tumor. The PTV margin can be obtained from our analysis. Minimizing the PTV margins is an efficient means of reducing risks associated with radiation in normal tissues.

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