Determination of Optimal Clinical Target Volume to Planning Target Volume Margins for Conformal Radiotherapy Planning using Image Guidance System in Rectal Cancer in Prone Position

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Abstract

Context: In advanced radiotherapy techniques such as three-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiotherapy (IMRT), geometrical uncertainties are very crucial as they may lead to under dosing of tumor and over dosing of the nearby critical structures and hence, it is important to determine planning target volume (PTV) margins which are specific for every center. **Aims:** The aim of this study is to determine adequate clinical target volume (CTV) to PTV margins specific to our radiotherapy center. **Settings and Design:** To calculate CTV to PTV margins for rectal cancer patients in prone position using kV cone beam CBCT data sets. **Materials and Methods:** With the Patient immobilized in prone position using thermoplastic mask, a CT simulation was done and a comprehensive 3DCRT plan was generated. Daily kV CBCT was done to check the patient setup error. Daily setup errors were recorded and evaluated retrospectively. **Results:** CTV-PTV margin calculated for pelvis in the prone position was calculated using van Herk Formula and were found to be 0.5, 1.8, 0.7 cm in the lateral, longitudinal, and vertical directions, respectively. **Conclusions:** Image guidance is an effective method to evaluate patient setup errors. Good quality immobilization devices and stringent patient setup policies can help to reduce PTV margins further.

Keywords: Pelvis radiotherapy, planning target volume margins, prone position

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Introduction

In advanced radiotherapy techniques such as three-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiotherapy (IMRT), geometrical uncertainties are very crucial as they may lead to underdosing of tumor and overdosing of the nearby critical structures.[1,2]

The International Commission of Radiation Measurements and Units (ICRU) report 50 and 62 recommends assigning a planning target volume (PTV) created by giving a margin to clinical target volume (CTV) to assure that the CTV receives tumoricidal dose.[3,4] The factors on which the PTV margins depends are: uncertainties in contouring the tumor volume, patient immobilization system, inter-fractional patient setup errors, intra-fractional tumor motion errors, etc., and hence while using complex radiotherapy technique it is important to assess patient setup errors for different anatomical sites and for different systems utilized. On treatment, image-guided radiotherapy (IGRT) aims at acquiring 2D planar images using electronic portal imaging device (EPID) or 3D volumetric cone beam computed tomography (CBCT) images of the patient with respect to the treatment beam and thereby provides the 3D positional accuracy of the patient based on the patient bony anatomy and/or soft-tissue visualization which helps to determine the optimal CTV-PTV margins and spare the nearby

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critical structures.[5] Thondykandy *et al*. and Patni *et al*. have published and validated previously PTV margins specifically to their center for pelvis in the supine position.[6,7] In our radiotherapy center, 3DCRT and IMRT with image guidance is a routine practice. This study was conducted to assess the setup errors for rectal cancer patients being treated with 3DCRT in prone position, to determine the optimal CTV-PTV margin specific to our center.

Materials and Methods

A retrospective study on setup error measurements was conducted for patients treated with 3DCRT for rectal cancer in the prone position. The planning and treatment data of a total of seven patients and a total of 135 CBCT data sets (resolution ≥6 lp/cm) were used in the study.

All patients were immobilized in prone position on four clamp base plate with thermoplastic mold. The patients were scanned in head first prone position in the CT simulator (Philips brilliance big bore simulator) with 3-mm image slice thickness with anatomical scan limits well enough to extend at least >5 cm from the intended treatment region. Fiducial markers were placed using room lasers of the CT simulator to define patient coordinate system. On the CT images, CTV and other critical structures were contoured in accordance with the ICRU reports 50 and 62. PTV was created with an isotropic margin of 10 mm all around the defined CTV and planning risk volumes were created for critical structures such as the small bowel, bladder, femur head, penile bulb in males, labia (minor + major) in females. For all patients, treatment plans were created on CMS Xio (4.80.002 version, Elekta) treatment planning system for their corresponding prescription dose, which was delivered with 3DCRT technique on the linear accelerator (Elekta Synergy) with 6 MV photon beam. The overall treatment course lasted from 1 week to 6 weeks depending on the prescription. Two patients received 25 Gy in 5# over 1 week and five patients received 50.4 Gy in 28# over 6 weeks. IGRT treatment position verification was done for all patients using kV image guidance system attached with the linear accelerator capable of acquiring kV 3D (CBCT). Image guidance was performed daily in which kV CBCT images were acquired on each fraction except for few fractions during which image guidance cannot be done because of mechanical error. Quality assurance of XVI is done monthly in our center. The patients were positioned using treatment room lasers and marks on the immobilization device. Verification images were acquired and were matched using visible bony landmarks with their respective digitally reconstructed radiographs generated using the planning CT images. The kV CBCT images were automatically registered based on mutual information with the planning CT images after selecting the region of interest and visually verified. Rectal protocol was not followed while matching the images. The patient setup error, which is the deviation between the actual and the expected patient position with respect to the treatment beam was recorded along the three translational directions, lateral (left-right), longitudinal (superior-inferior), and vertical (anterior-posterior) along the X, Y, and Z axes, respectively, and corrected accordingly.

These patient setup error measurements were used to calculate the 3D CTV-to-PTV margins using van Herk's formula, where the PTV margin is given by 2.5Σ +0.7σ is the systematic error and σ is the random error for the group of patients. The equation assumes that the minimum dose to CTV is 95% in 90% of patients.[8]

The setup error along the three translational directions was used to calculate the systematic and random setup errors for each individual patient and the patient group. The individual patient systematic setup error (mi) was calculated by taking the mean of the measured setup error for each imaged fraction in each direction. The individual patient random error (σi) was calculated by taking the standard deviation (SD) of the setup errors around the corresponding mean individual value mi. The group mean setup error (M) was calculated by taking the mean of each individual patient's systematic error. The group systematic setup error (Σ) was derived by taking the SD of the individual mean setup error about the group mean setup error M. The group random error (σ) was calculated by taking the mean of all the individual patient random error σi.

$$\Sigma^2_{(\mathrm{Set-up})} = \frac{\left(m_1 - M_{pop}\right)^2 + \left(m_2 - M_{pop}\right)^2 + \left(m_3 - M_{pop}\right)^2 + \ldots + \left(m_n - M_{pop}\right)^2}{(P-1)}$$

$$\sigma^2_{\mathrm{Individual}} = \frac{(\Delta_1 - m)^2 + (\Delta_2 - m)^2 + (\Delta_3 - m)^2 + \ldots + (\Delta_n - m)^2}{(n-1)}$$

$$\sigma_{\mathrm{set-up}} = \frac{\sigma_1 + \sigma_2 + \sigma_3 + \ldots + \sigma_n}{(n-1)}$$

Results

A total of 136 datasets have been evaluated for the pelvis region, while the patient was in prone position. The mean setup error

Table 1: Mean setup error and standard deviation in lateral, longitudinal, and vertical directions

Serial number	Mean setup error and SD in lateral, longitudinal, and vertical directions					
	X (cm)		Y (cm)		Z (cm)	
	Mean	SD	Mean	SD	Mean	SD
Patient 1	−0.15	0.12	0.66	0.59	−0.33	0.18
Patient 2	−0.11	0.2	−0.54	0.85	0.08	0.13
Patient 3	−0.07	0.23	0.29	0.95	0.07	0.31
Patient 4	−0.01	0.23	0.19	0.98	−0.19	0.16
Patient 5	0.02	0.23	0.08	0.85	0.15	0.10
Patient 6	0.14	0.24	−0.59	0.70	0.35	0.20
Patient 7	0.17	0.32	0.43	0.86	0.09	0.30

SD: Standard deviation

Table 2: Calculated systematic error (Σ), random error (σ) and clinical target volume-planning target volume margin using Van Herk's formula (2.5Σ + 0.7σ)

Setup error (cm)	Pelvis		
	X	Y	Z
Σ	0.12	0.47	0.21
σ	0.23	0.96	0.20
Margin	0.5	1.8	0.7

for the patient group and its SD in the lateral, longitudinal and vertical directions is elaborated in Table 1. The CTV-PTV margin was calculated using Van Herk's formula to ensure 95% minimum prescription dose to CTV for 90% of the patients. The unique feature of this formulism is the separation of systemic and random error in the formula, as they impact dose distribution differently and the main limitation is that it assumes, the planned dose distributions contribute exactly to the CTV, representing a perfectly conformal dose distribution in a homogenous medium.

CTV-PTV margin calculated for pelvis in the prone position was, therefore, found to be 0.5, 1.8, 0.7 cm in the lateral, longitudinal and vertical directions respectively as shown in Table 2.

Discussion

Various uncertainties can arise during the treatment planning of rectal cancer in the prone position, which can be due to internal organ motion, the filing status of the bladder or rectum itself and due to setup variations. Uncertainties occurring daily in target volume motion should be accounted. Uncertainties arising due to setup variation can be caused by both interfraction and intrafraction motion which can be minimized using modern image guidance systems, but for the correct implication of these techniques, an optimal margin around the target has to be provided.

The image guidance system is required to assess the patient treatment setup errors in conformal radiotherapy delivery systems. The setup errors in the brain, the Head and Neck and the pelvis are important as there are nearby critical structures that need to be spared and to assure that the CTV receives tumouricidal dose. In our study we found that the CTV-PTV margin in rectal cancer patients being treated in prone position was 0.5, 1.8, 0.7 cm in the lateral, longitudinal, and vertical directions, respectively. Not much of literature is present specifically for PTV margins in the pelvis in prone position. Thondykandy *et al*. demonstrated that with a margin of 10 mm applied in both vertical and longitudinal direction, and a margin of 7 mm along the lateral direction has adequate target volume coverage in pelvic malignancies in the supine position.[6] Patni *et al*. also demonstrated a CTV-PTV margins expansion of 0.584, 1.036, and 0.566 cm in AP, SI, and ML directions, respectively, in pelvic malignancies in supine position.[7] In comparison with these studies margins applied in our center in superior-inferior direction is approximately twice of reported in above studies, but it is well within limits in the mediolateral and the vertical directions. The possible reason behind increase in margin in the SI direction may be, improper immobilization in the SI direction when we use thermoplastic mold, loosening of mold with increasing number of fractions, reduction in abdominal fat due to weight loss during radiotherapy.

Conclusion

Image guidance technology is an effective method to evaluate the accuracy of conformal radiotherapy delivery. With the knowledge of patient setup errors, the optimal CTV-PTV margin can be determined to ensure adequate dose to CTV, specific to the radiotherapy center, more stringent patient setup policy and good quality immobilization device can help reducing margins further.

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Conflicts of interest

There are no conflicts of interest.

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