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ORIGINAL ARTICLE

Determination of patient set-up error and optimal treatment margin for intensity modulated radiotherapy using image guidance system

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Summary

Purpose: *The geometrical uncertainties in the patient positioning during intensity modulated radiotherapy (IMRT) are crucial as there is potential to underdose the tumor and overdose the nearby critical structures. Image guided techniques provide a solution to assess the patient set-up uncertainties and help determine the optimal planning target volume (PTV) margin to the clinical tumor volume (CTV).*

Methods: *A retrospective study was conducted to evaluate patient set-up errors along the three translational directions at different treatment sites such as the brain, the head and neck (H&N) and the prostate. A total of 60 patients' set-up error data was analysed to evaluate the systematic and random errors and the optimal CTV-PTV margin.*

Results: *For brain and H&N sites, more than 90, 80 and about 100% of the total image acquisitions were less than 3 mm in lateral, longitudinal and vertical directions respectively. For the prostate cases, the frequency of patient set-up error to be less than 3 mm were 79.7, 75.6 and 80% in lateral, longitudinal and vertical directions respectively. About 0.6% had more than 7 mm error in the lateral and longitudinal directions for the prostate site. CTV-PTV margin of 3.4, 3.4 and 1.9 mm for brain cases, 3.5, 3 and 1.8 mm for H&N cases and 5, 4.6 and 4.5 mm for the prostate cases in the lateral, longitudinal and vertical directions respectively were determined.*

Conclusion: *Image guidance is an effective method to evaluate the accuracy of IMRT treatment delivery. The optimal CTV-PTV margin can be determined to ensure adequate dose to CTV, specific to the site.*

Key words: *image guided radiotherapy, intensity modulated radiotherapy, patient set-up errors*

Introduction

IMRT aims at delivering highly conformal dose distribution around the tumor volume and rapid dose fall-off away from it, hence has a characteristic high dose gradient at the interface between the tumor and the normal tissues. The geometric uncertainties during the treatment delivery are very crucial for this complex treatment. Patient set-up errors can lead to potential underdosing of tumor volumes and overdosing nearby critical structures [1,2]. International Commission of Radiation Measurements and Units (ICRU) 50 and 62 recommends creating a PTV with a margin to the CTV to ensure it adequately receives the tumoricidal radiation dose [3,4]. The PTV margins depend on various factors such as inter-fractional patient set-up errors, intra-fractional tumor motion, patient immobilisation system, uncertainties in contouring the tumor volume etc. It is essential for every radiotherapy centre to assess the patient set-up error for each anatomical site, specific to their quality system, when using complex treatment delivery techniques. Image guidance tech-

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nologies provide a solution to verify the accuracy of patient set-up just prior to or even during the treatment delivery [5]. On-treatment image guided radiotherapy (IGRT) aims at acquiring orthogonal 2D planar images or 3D volumetric cone beam CT (CBCT) images of the patient with respect to the treatment beam and thereby provides the three dimensional positional accuracy of the patient based on the patient bony anatomy and/or soft tissue visualisation which helps to determine the optimal CTV-PTV margins and spare the nearby critical structures [6]. In our radiotherapy centre, IMRT with image guidance is routine for treatment sites such as brain, H & N and prostate where the nearby critical structures and normal tissues need to be spared, without compromising the prescription dose to the target volume.

This study was conducted to assess the set-up errors for patients being treated with IMRT, thereby to determine the optimal CTV-PTV margin specific to our centre.

Methods

Patient cohort

A retrospective study on set-up error measurements was conducted for patients treated with IMRT for sites such as the brain, the H&N and the prostate. The planning and treatment data of a total of 60 patients, 20 patients in each of the site brain, H&N and prostate were used for this study. All the patients were aged between 45 and 70 years.

Treatment simulation and planning

All the brain and the H&N patients were immobilized with the head only and the head, neck and shoulder perforated thermoplastic mask (Type S™, CIVCO medical solutions) respectively in the treatment position while the prostate patients were immobilized with whole body vacuum cushions (Vac-Lok™, CIVCO Medical Solutions, Orange City, IA). The patients were scanned in head first supine position in the CT simulator (SOMATOM EMOTION™ Siemens Medical Solutions, Concord, CA) with 3 mm image slice thickness with anatomical scan limits well enough to extend at least above 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. MRI images were registered and fused with the CT images to aid contouring. For brain and H&N plans, PTV were created with an isotropic margin of 5 mm all around the defined CTV and planning risk volumes (PRVs) were created for critical structures such as the spinal cord, brainstem and optic structures. For prostate patients, PTV margin of 10 mm all around except 8 mm in the posterior were given to the prostate CTV and 5 mm margin were given for the pelvic lymph node CTV. For all patients, treatment plans were created on treatment planning system (Oncentra™, Elekta/Nucletron, Veenendaal, The Netherlands) for their corresponding prescription dose to be delivered with IMRT step and shoot delivery technique on the linear accelerator (Oncor Expression™, Siemens Medical Solutions, Concord, CA) with 6 MV photon beam. The overall treatment course lasted between 5 and 7 weeks for brain and H&N sites and 8 weeks for prostate cases.

Image guided radiotherapy

Treatment position verification was done for all patients using MV image guidance system attached with the linear accelerator capable of acquiring MV planar and 3D cone beam CT (CBCT). Image guidance was performed for the first 3 consecutive treatment fractions and twice weekly thereafter, in which MV CBCT images were acquired on the first treatment fraction and once weekly thereafter and orthogonal planar images were acquired on the second and third fraction and once weekly thereafter. The entire imaging doses were accounted and included in the prescription dose of the patients. The patients were positioned with respect to the treatment beam using treatment room lasers and marks on the skin and/or on the immobilization device. In this position, verification images were acquired. The orthogonal MV planar images were matched using visible bony landmarks with their respective DRRs (Digitally reconstructed radiographs) generated using the planning CT images. The MV CBCT images were automatically registered, based on mutual information with the planning CT images and visually verified. The patient set-up error, which is the deviation between

Table 1. Image acquisition and reconstruction parameters for different sites

Site	*Imaging MUs*	*Reconstruction slice thickness (mm)*	*Reconstruction image size (pixels)*
Brain, Head & Neck -CBCT imaging	6	3	512 x 512
Prostate - CBCT imaging	15	3	512 x 512
Brain, Head & Neck -orthogonal planar imaging	2	-	512 x 512
Prostate - orthogonal planar imaging	4	-	512 x 512

CBCT: cone beam computed tomography, MUs: monitor units

Table 2. Patient set-up error frequency distribution along the lateral (X), longitudinal (Y) and vertical (Z) directions for the brain, the head and neck and the prostate sites. The data within the parenthesis show the percentage values

Set-up error (mm)	*Brain*			*Head and neck*			*Prostate*		
	X	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*
>1	185 (76.4)	170 (70.2)	153 (63.2)	210 (72.4)	204 (70.3)	179 (61.7)	271 (79.7)	265 (77.9)	251 (73.8)
>2	86 (35.5)	97 (40.1)	11 (4.5)	102 (35.2)	112 (38.6)	14 (4.8)	159 (46.8)	157 (46.2)	127 (37.4)
>3	15 (6.2)	46 (19.0)	0 (0)	17 (5.9)	47 (16.2)	0 (0)	69 (20.3)	83 (24.4)	68 (20.0)
>4	3 (1.2)	0 (0)	0 (0)	2 (0.7)	0 (0)	0 (0)	43 (12.6)	37 (10.9)	28 (8.2)
>5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	19 (5.6)	17 (5.0)	5 (1.5)
>7	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.6)	2 (0.6)	0 (0)

Table 3. Calculated systematic error (Σ), random error (σ) and CTV-PTV margin using van Herk's formula

Function	*Brain*			*Head & neck*			*Prostate*		
	X	*Y*	*Z*	*X*	*Y*	*Z*	*X*	*Y*	*Z*
Σ, mm	1.13	1.09	0.54	1.14	0.93	0.50	1.61	1.48	1.47
σ, mm	0.85	0.93	0.74	0.86	0.92	0.73	1.41	1.21	1.19
Margin, mm	3.42	3.36	1.86	3.45	2.98	1.75	5.02	4.56	4.52

actual and expected patient position with respect to the treatment beam was registered along the 3 translational directions such as lateral (left-right), longitudinal (superior-inferior) and vertical (anterior-posterior) along the X, Y and Z axes respectively and corrected according to the department protocol. The acquisition and reconstruction parameters for the planar and CBCT imaging for each site are detailed in Table 1.

Statistics

The set-up error along the 3 translational directions was used to calculate the systematic and random set-up errors for each individual patient and the patient group. The individual patient systematic set-up error (mi) was calculated by taking the mean of the measured set-up error for each imaged fraction in each direction. The individual patient random error (σ_i) was calculated by taking the standard deviation (SD) of the set-up errors around the corresponding mean individual value mi. The group mean set-up error (M) was calculated by taking the mean of entire group set-up error. The group systematic set-up error (Σ) was derived by taking the SD of the individual mean set-up error about the group mean set-up error M. The group random error (σ) was calculated by taking the mean of all the individual patient random error σ_i.

Calculation of CTV-PTV margin

The patient set-up error measurements were used to calculate the 3 dimensional CTV-to-PTV margins using van Herk's formula, where the PTV margin is given by $2.5\Sigma+0.7\sigma$. The equation assumes that the minimum dose to CTV is 95% to 90% of patients [7].

Results

A total of 242, 290 and 340 image datasets were analysed for brain, H&N and prostate sites, respectively. The patient set-up error frequencies are given in Table 2, which shows that for brain site, 93.8, 81 and 100% of the total image acquisitions were less than 3 mm in lateral, longitudinal and vertical directions, respectively. Similarly the H&N site was 94.1, 83.8 and 100% in lateral, longitudinal and vertical directions, respectively. Also, there was no patient set-up error more than 5 mm in any direction for both of these sites. For prostate cases, the frequency of patient set-up error to be less than 3 mm were 79.7, 75.6 and 80% in lateral, longitudinal and vertical directions, respectively. About 0.6% had more than 7 mm error in the lateral and longitudinal directions for the prostate site.

The mean with one SD in set-up error for each patient in the three translational directions are shown in Figures 1, 2 and 3 for brain, H&N and prostate, respectively. These figures show that the set-up error was lesser in vertical direction compared to the lateral and longitudinal directions. The mean set-up error for the patient group and its SD in the lateral, longitudinal and vertical directions were 0.57±1.13, -0.95±1.09 and -0.01±0.54 mm for the brain site, 0.4±1.14, -0.99±0.93 and 0.08±0.5 mm for the H&N site and 0.6±1.61 mm, -1.06±1.48 mm and -0.04±1.47 mm for prostate site, respectively.

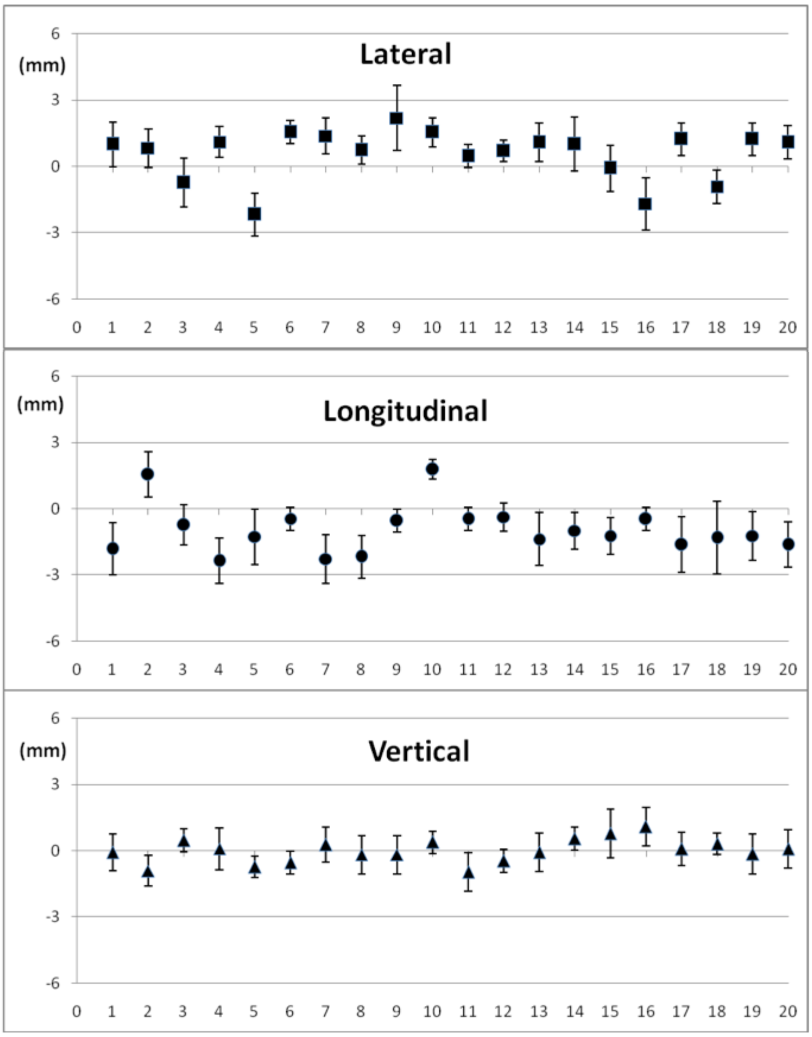

Figure 1. Mean with error bars showing one standard deviation of individual patient set-up error along lateral (left-right), longitudinal (superior-inferior) and vertical (anterior-posterior) directions for 20 patients of the brain site.

Table 3 shows the systematic error (Σ) and the random error (σ) for the patient group calculated using the set-up errors. The CTV-PTV margin was calculated using van Herk's formula to ensure 95% minimum prescription dose to CTV for 90% of the patients. CTV-PTV margin of 3.4, 3.4 and 1.9 mm for brain cases, 3.5, 3 and 1.8 mm for H&N cases and 5, 4.6 and 4.5 mm for the prostate cases in the lateral, longitudinal and vertical directions, respectively, were determined from the patient set-up error data.

Discussion

Image guidance system has been used to assess the patient treatment set-up errors in IMRT delivery. The set-up errors in the brain, the H&N and the prostate are important as there are nearby critical structures that need to be spared to reduce the normal tissue complication probability.

In this study, it was found that the frequency of set-up error >3 mm was only <6.2 % in the lateral, <19% in the longitudinal and 0% in the vertical directions for the brain and the H&N sites. For prostate, the set-up error >3 mm was between 20 and 24.4% in the three directions. The set-up error in the vertical direction was found to be less than that on the other two directions. Several other researchers have studied the patient set-up errors on different anatomical sites with different treatment techniques and immobilisation devices [8-10]. The results could be largely associated with the immobilization device used, patient set-up procedures and the geometrical accuracy of the treatment machine, room lasers, simulators and the imaging guidance system. Routine quality assurance tests are required to ensure their safety

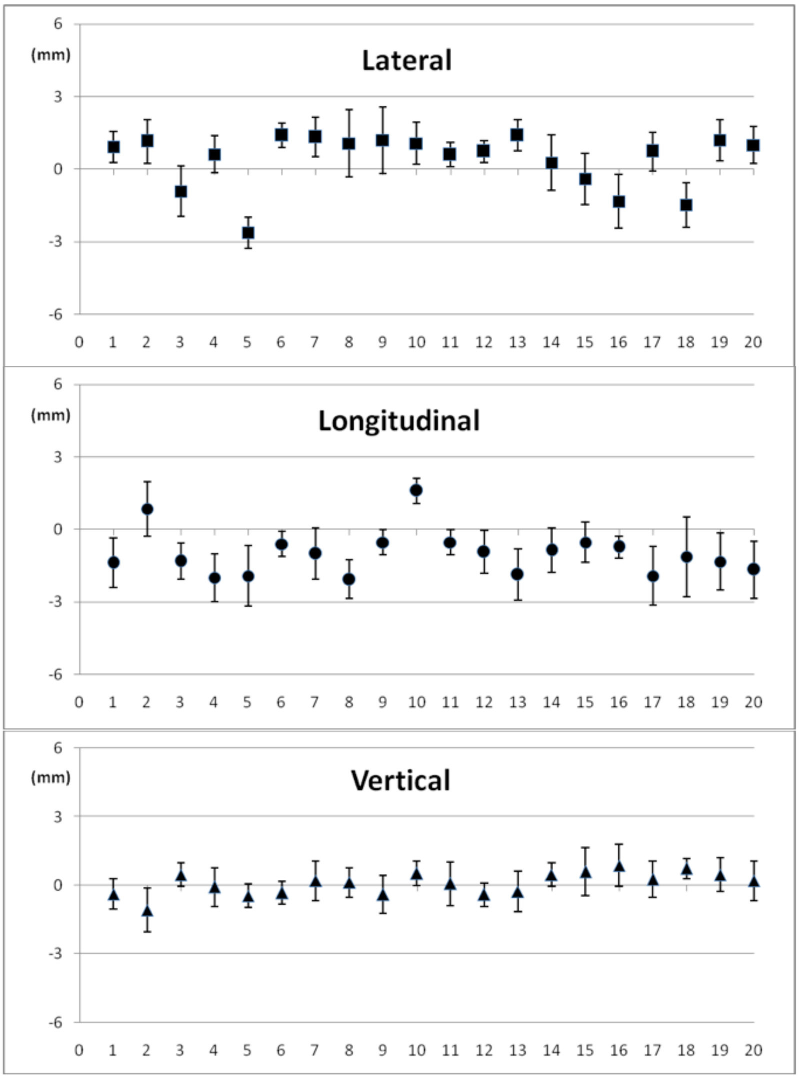

Figure 2. Mean with error bars showing one standard deviation of individual patient set-up error along lateral (left-right), longitudinal (superior-inferior) and vertical (anterior-posterior) directions for 20 patients of the head and neck site.

and accuracy for clinical use [11-13].

The set-up errors and the corrections applied were reviewed offline by a different operator other than the one who performed the online assessment to rule-out the inter-observer variability.

All the patients were corrected for any gross set-up errors prior to the first fraction and these errors, if any, were not included in this study.

Because of the limitations of the imaging system and the treatment unit to assess and correct errors only in the three translational directions, rotational errors were not included in this study. However, the rotational set-up errors may have an impact on the determination of the translational errors [14,15].

The optimal CTV-PTV margins were determined for different sites using the systematic and random set-up errors. With the use of image guidance for patient set-up, we were confident to reduce the margin by 1 mm for brain and H&N sites from 5 to 4 mm and for prostate from 10 to 9 mm all around and 8 to 7 mm posteriorly. For the pelvic nodes the margin of 5 mm on all planes was increased to 6 mm. For prostate we did not reduce the margin to 5 mm as calculated from our set-up errors, as we have not yet evaluated the intra-fractional motion of the prostate and the nearby organs relative to the bony anatomy. Several researchers had studied the effect of reduction in the CTV-PTV margin on the tumor recurrence rate and reduction of normal tissue complication probability. Their studies show that the margin can be safely reduced with the use of image guided treatment delivery [16-19].

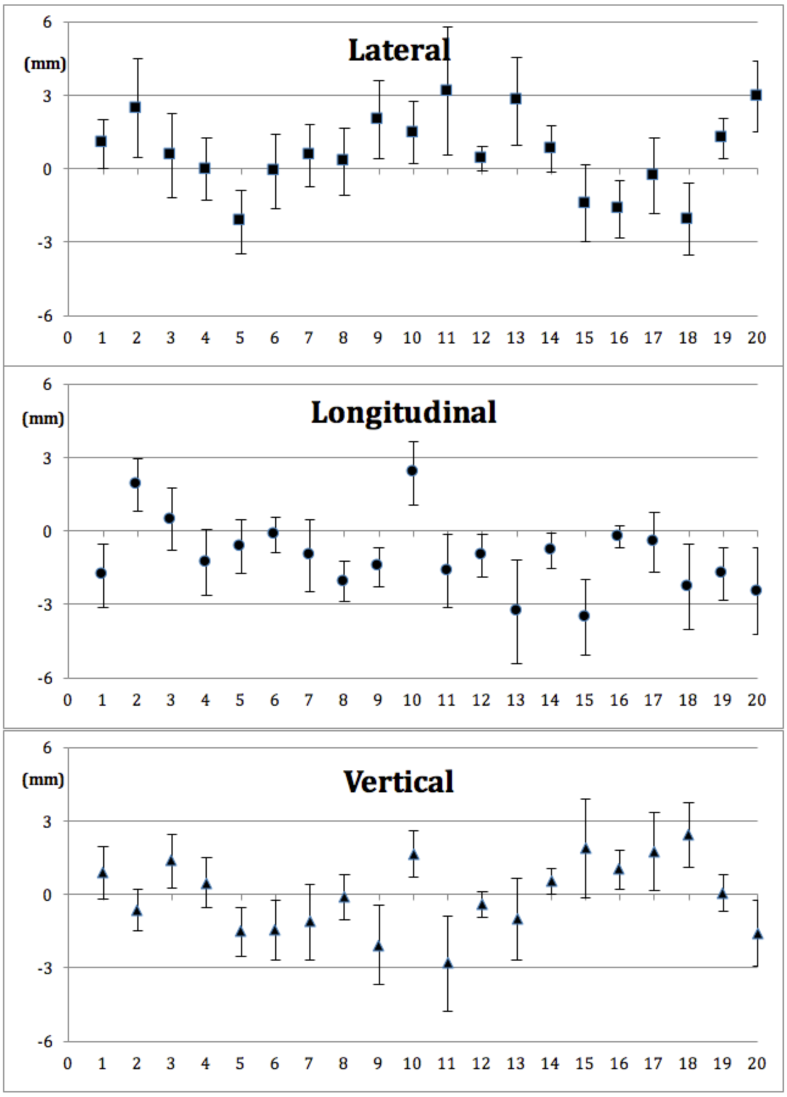

Figure 3. Mean with error bars showing one standard deviation of individual patient set-up error along lateral (Left-Right), longitudinal (Superior-Inferior) and vertical (Anterior-Posterior) directions for 20 patients of the prostate site

In conclusion, image guidance technology is an effective method to evaluate the accuracy of IMRT delivery. With the knowledge of patient set-up errors, the optimal CTV-PTV margin can be determined to ensure adequate dose to CTV, specific to the radiotherapy centre.

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