Analysis of random and systematic errors in three dimensional conformal radiation therapy – a study at National Cancer Institute, Maharagama

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Abstract— *The aim of this study was to assess three dimensional set-up errors for three dimensional conformal radiation therapy (3-DCRT) at National Cancer Institute, Maharagama (NCIM). This study included 50 patients from each head and neck, brain and pelvic cases and 300 Portal images. Set-up errors were obtained by comparing Digitally reconstructed radiographs (DRR) and Electronic portal imaging device (EPID) images. The mean displacements for all images were compared using Kruskal-Wallis test analysis with the threshold α = 0.05 which indicated significant differences within the major three axes. (Brain-p< 0.0001, Head and Neck-p= 0.001, pelvic-p< 0.0001). The values of portal verification for brain, head and neck and pelvic cases are within boundaries which are 88%, 83% and 78% respectively. The set-up margins were within tolerance for all three cases in all directions.*

Keywords— **Three dimensional conformal radiation therapy, Setup errors, Digitally reconstructed radiographs, Electronic portal images.**

I. INTRODUCTION

The goal of Radiation Therapy for cancer is to reliably provide optimal target coverage and dose level to the Gross tumour volume (GTV) and planning target volume (PTV) while minimizing the toxicity to organs at risk (OAR) (Khan, 2000). The coverage of target volume is a direct function of set-up margins, which should be optimized to prevent inadvertent irradiation of adjacent normal tissues. PTV that encompasses the clinical target volume (CTV) with some margins (Gupta et al., 2007).

Set-up errors can be random errors or systematic errors. Random errors blur the dose distribution, whereas systematic errors cause a shift of the cumulative dose distribution relative to the target. The random errors which represent day-to-day variation in the setup of patient, occurs only once and as the name implies is unpredictable. The systematic error is dangerous since it will affect all radiation delivery sessions and may inflict serious damage destroying either healthy tissues or provoking tumour recurrence. Evaluation of set-up errors is based on the comparison between a portal image and a reference image, which may be a digitized simulation film, a Digital Reconstructed Radiograph (DRR), or another portal image. In this study comparisons are done by using portal image and DRR.

II. METHODS

In this study 50 patients were included through randomized cluster sampling from each head and neck, brain and pelvic cases. Adequate immobilization and positioning devices were applied to selected patients and pre-treatment portal images were obtained for first two fractions per patient, using Portal Vision aS1000 which was amorphous silicon based EPID system consisting of a detector screen and optical chain. It was mounted iso-centrically on the Linear Accelerator with a detector size of 30×40 cm. Portal images were acquired at orthogonal gantry angles 0˚ and 90˚ using a typical exposure time 1 Monitor Unit (MU) at a dose rate of 300 MU/min and 6MV energy.

DRR's were used as a reference image for comparison with portal images which were reconstructed from computed tomography (CT) images. Evaluation of set-up errors was done by defining reproducible and easily identifiable bony landmarks of the treatment field each in anterior and lateral images. For the purpose of documentation and analysis, anterior, superior, and right sided shifts were coded as positive shifts and posterior, inferior and left-sided shifts as negative shifts.

Displacements between DRR's and EPID images were estimated and analysed along three major axes by matching rigid bony structures and data was analysed by using nonparametric tests method. A total of 150 patients met the inclusion criteria in which 300 portal images were available for analysis. Rotational errors were not assessed in the study. The dose delivered by portal imaging was not taken into consideration in calculating the final total dose received by any patient.

Mean displacements, population systemic and random errors and three dimensional vectors of displacements were calculated. Set up margins were calculated using published margin recipes in International Commission on Radiation Units and measurements (ICRU) Report 62 (Bethesda, 2000), Stroom (Stroom, Heijmen, 2002; Stroom et al., 1999) and van Herk (van Herk, 2004; van Herk et al., 2000).

III. RESULTS

The values of displacements in the group with brain, head and neck and pelvic cases were measured and assessed in vertical (Antero-posterior), longitudinal (Supero-inferior) and lateral (Medio-lateral) directions. The MINITAB Statistical Package and Microsoft office Excel software were used for the data analysis.

The mean displacements, systematic and random errors in the group of Brain, Head and Neck and Pelvic cancer patients, along the three major axes are given in Table 1,2 and 3 respectively. The overall mean displacements in all three major axes were significantly higher in the pelvic cancer than the other two groups. A comparison of overall means for all groups is given in Table 4.

The mean displacements for all images in the major three axes were compared using Kruskal-Wallis test analysis with the threshold α=0.05 (which corresponds 95% confidence). Comparisons showed significant differences within the major three axes. The patients in all three cases were divided into subgroups with acceptable displacements and where the measurements exceeded the action level is given in Table 5.

Brain Cancer	3-D translations (cm)		
	Vertical	Longitudinal	Lateral
Overall mean	-0.0590	0.0780	-0.0710
Random error	0.2427	0.1985	0.1640
Systematic error	0.1707	0.1623	0.1450

Table 1. Set-up error analysis for brain cancer patients

Head and neck-cancer	3-D translations (cm)		
	Vertical	Longitudinal	Lateral
Overall mean	-0.0570	-0.0680	0.0610
Random error	0.1931	0.1720	0.1382
Systematic error	0.1796	0.2199	0.1721

Table 2. Set-up error analysis of for head and neck cancer patients

Pelvic Cancer	3-D translations (cm)		
	Vertical	Longitudinal	Lateral
Overall mean	0.1030	-0.1770	0.0750
Random error	0.2339	0.1603	0.1628
Systematic error	0.2698	0.3284	0.2568

Table 3. Set-up error analysis for pelvic cancer patients

Group	Brain	Head and neck	Pelvis
Vertical	-0.0590	-0.0570	0.1030
Longitudinal	0.0780	-0.680	-0.1770
Lateral	-0.0710	0.0610	0.0750
P(α□0.05)*	□0.0001	0.0010	□0.0001

Table 4. Comparison of mean displacements for all groups

Group	Number of images	Within boundaries	Outside boundaries
Brain	100(100%)	88%	12%
Head and neck	100(100%)	83%	17%
Pelvis	100(100%)	78%	22%

Table 5. Summary of portal verification of all three groups

Direction	ICRU 62	Stroom	Van Herk
Vertical	0.297	0.511	0.597
Longitudinal	0.256	0.464	0.545
Lateral	0.219	0.405	0.477

Table 6. CTV-PTV margins for brain cancer patients

Direction	ICRU 62	Stroom	Van Herk
Vertical	0.264	0.494	0.584
Longitudinal	0.279	0.560	0.670
Lateral	0.221	0.441	0.527

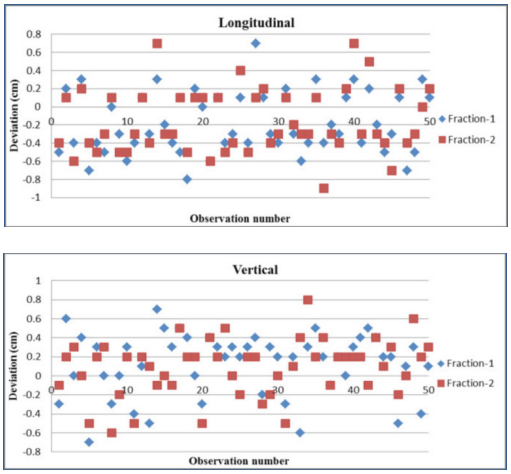
Table 7. CTV-PTV margins for head and neck cancer patients

Direction	ICRU 62	Stroom	Van Herk
Vertical	0.357	0.703	0.838
Longitudinal	0.365	0.769	0.933
Lateral	0.304	0.627	0.756

Table 8. CTV-PTV margins for pelvic cancer patients

Calculated CTV to PTV margins for Brain, Head and Neck and Pelvic cases are given in Table 6, 7, and 8 respectively. Margins were calculated from population systematic and random errors according to ICRU Report 62, Stroom and van Herk's formulae.

Scatterplot of displacements for all observations in all three directions for head and pelvic cancer are shown in Figure 1. Pelvic group had more displacements than the other two groups.



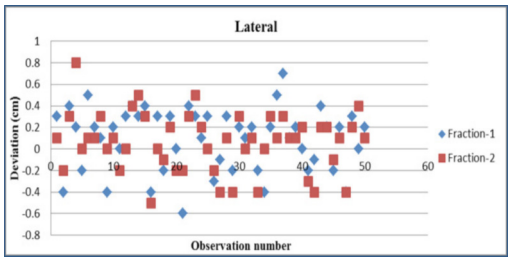


Fig.1 Scatter plot of displacements in all three directions for all pelvic cancer cases studied

IV. DISCUSSION

The comparisons showed significant differences of displacements within the major three axes of the three case groups studied. The patients with pelvic cancer gave higher displacements than the patients with brain and head and neck cancers. Therefore, this group of patients required a special care and should be monitored more often using EPID. The good setup accuracy can be achieved for pelvic cancer patients by using thermoplastic immobilisation device with ankle rest or foot rest which will help to prevent pelvic and leg rotation within the immobilisation device.

The highest value of the vector length was observed in the pelvic cancer, 10.9045 cm and the lowest value of vector length was observed in the head and neck cancer, 5.3838 cm. In this study we did consider obesity. This issue is important in patients which pelvic cancer.

About eighty three percentage of the set-up deviations were within tolerance in all three directions. (Brain < 3 mm, Head and neck < 3 mm, and Pelvis < 5 mm). The CTV-PTV margins were within 3mm for brain, 3mm for head and neck, 5mm for pelvic cancers in all directions. Population systematic (Σ) and random errors (σ) also correlated well with the published literature.

Several mathematical formulae have been recommended for generating CTV-PTV margins. The ICRU 62 ($sqrt\Sigma^2 + \sigma^2$) states that systematic and random uncertainties should in an ideal approach which should then be used for margin calculation. However, this approach assumes that random and systematic errors have an equal effect on dose distribution, which may not necessarily be the case.

Using coverage probability matrices and dose-population histograms, Stroom et al ($2\Sigma + 0.7\sigma$) and Van Herk et al ($2.5\Sigma + 0.7\sigma$) have suggested formulae incorporating this differential effect.

Image-guided radiation therapy (IGRT) is an innovative and exciting approach for set-up verification that can be potentially useful for high-precision techniques with inherently conformal dose distributions and sharp dose gradients. Contemporary IGRT systems allow accurate internal target positioning and even real-time tumour tracking with potential to substantially reduce set up margins.

V. CONCLUSION

The study suggests that there is a significant difference within the three major axes. Approximately 83% of all patients had tolerance uncertainties. EPID is a useful tool for a fast and reliable assessment and correction of various geometrical errors during the whole process of radiotherapy. The monitoring and verification of radiotherapy using EPID should be applied in radiation departments where the 3-DCRT is introduced.

The increased number of portal images is the way to manage random and systematic errors effectively. Considering appropriate, stable structures in relation to major three axes and inserting fiducial markers are better to assess field position.

Offline correction is very effective in managing the systematic component of set-up error but has little effect on the random component and complete removal of both systematic and random set-up error can be achieved by on-line position verification since its logical and feasible extension of all EPI protocols give significant advantages that far outweigh the disadvantages.

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