

Impact of patient rotational errors on target and critical structure dose in IMRT: A 3D simulation study

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Abstract. The impact of 3D rotational errors in patient positioning on dose delivered target volumes and critical structures in IMRT was studied. Patient rotational errors ranging from -3° to $+3^\circ$ was introduced to IMRT treatment plans of pelvis, head and neck and brain treatment sites and the impact of rotational error on DVH metrics was assessed. The magnitude of impact of rotational error on the error in dose delivered to the target volume and critical structures depends on the location of the structures from plan isocentre. In studied plans, a maximum percentage difference of up to $-9.8(1s=13.4) \%$ in D95 to PTV was observed for head and neck treatments. Similarly, in Brain treatments a maximum difference of up to $24.0(1s=33.0) \%$ in maximum dose of Optic chiasm was observed. The results suggest that failure to correct patient's rotational error results in under-dosage to target volumes and over-dosage to the critical structures in some specific treatment scenarios.

1. Introduction

During the past two decades radiotherapy planning, delivery and verification methods have evolved rapidly[1]. While a wide variety of treatment planning, delivery, and image guidance methods including Intensity Modulated Radiation Therapy (IMRT) have been implemented in modern radiotherapy, all these techniques are aiming to achieve a common goal of delivering highly conformal dose to tumor volumes whilst sparing normal critical structures[2].

Highly conformal dose distributions require accurate positioning of patients. Of utmost importance is the agreement between the patient anatomy at the time of treatment to the planning CT. Inaccurate patient set-up may result in geographical miss of target volumes (TVs) and possible overdose to critical structures[3]. Modern linear accelerators (LAs) come equipped with image guidance systems that help to ensure the accuracy of patient position at the time of treatment[4]. While the majority of image guidance systems can determine the positional offsets in three translational directions (left-right, anterior-posterior and superior-inferior) only, some systems also calculate the offsets in rotational directions (pitch, roll and yaw). Conventional patient support systems (PSS) that come with LAs allow positional corrections of patients along three translational and one rotational (yaw) direction. Recently robotic couch systems have been introduced for patient positioning in all six



degrees of freedom with sub mm/degree accuracy[5]. While the accuracy of these robotic couch systems has been reported, there is little evidence of the clinical significance of rotational corrections. The procurement and implementation of new technologies such as robotic couch systems should be justified by assessing clinical benefit versus cost as well as the impact on clinical processes and patient safety. In this work we investigate the impact of rigid body rotational errors in patient position on IMRT TV and critical structure dosimetric endpoints for various treatment sites.

2. Materials and Methods

A set of IMRT treatment plans that include three different treatment sites and various levels of complexity was considered for this study. The Pinnacle treatment planning system, V9.0, (Philips, WI, USA) was used to generate step and shoot IMRT plans for Elekta Synergy (Elekta Ltd, Crawly, UK) and Siemens Oncor (Siemens Ltd, Germany) LAs. Table 1 shows the details of treatment sites and number of patient plans considered in each treatment site.

Table1: Details of treatment sites investigated to study the impact of rotational errors on planned dose.

Treatment site	Treatment case	Target volume dose levels	CTV to PTV margin (mm)	Number of patient plans studied
Pelvis	Intact prostate	Single	7	3
	Prostate Bed	Two	10	3
	Prostate with pelvic nodes	Two	7	3
Head and Neck	Base of tongue with bilateral neck nodes	Three	6	2
	SCC lower lip with bilateral neck nodes	Three	6	1
Brain	Brain stem Glioma	Single	5	1
	Left temporal	Single	5	1
	Glioblastoma			

In all studied IMRT plans the isocentre was placed at the geometric centre of the total target volume. The rotational errors in patient position were simulated by rotating the RT structures about the plan isocentre. The planning CT was imported into Pinnacle as primary and secondary data sets. The structures were rotated by copying the structures from the primary data to rotated secondary data. The secondary data was then reset to achieve structures with rotation. Symmetrical rotational errors ranging from -3° to $+3^{\circ}$, in steps of 1° , along each axis were introduced to all structures of the studied plans. The Clinical Target Volume (CTV) to Planning Target Volume (PTV) margins were fixed at those used clinically in our department for each site (see table 1). The impact of rotational errors on dose to PTVs was studied by comparing D95, V95, and mean dose to PTV. Similarly, D98, V98 and mean dose to CTV were compared. For plans where multiple dose levels existed, the DVH metric of target volumes with their respective high dose volumes subtracted were analysed. Mean and maximum dose to critical structures was also assessed.

3. Results and Discussion

Figure 1 shows the mean percentage difference (standard deviation) in DVH metrics for TVs in pelvis, head and neck and brain IMRT plans with rotational errors. In general, the percentage difference in DVH metrics for PTVs increases as the rotational error increases. In pelvic treatments, the mean dose to TVs differed by a maximum of $-0.4(0.3)$ % for low dose PTV with -3° rotational error. A maximum difference of $-2.0(1.0)$ % and $-3.6(2.3)$ % in D95 and V95 was observed for the high dose PTV with -3° error (figure 1a). For CTVs a maximum difference of $-0.9(0.7)$ % in D98 was observed for the low dose CTV.

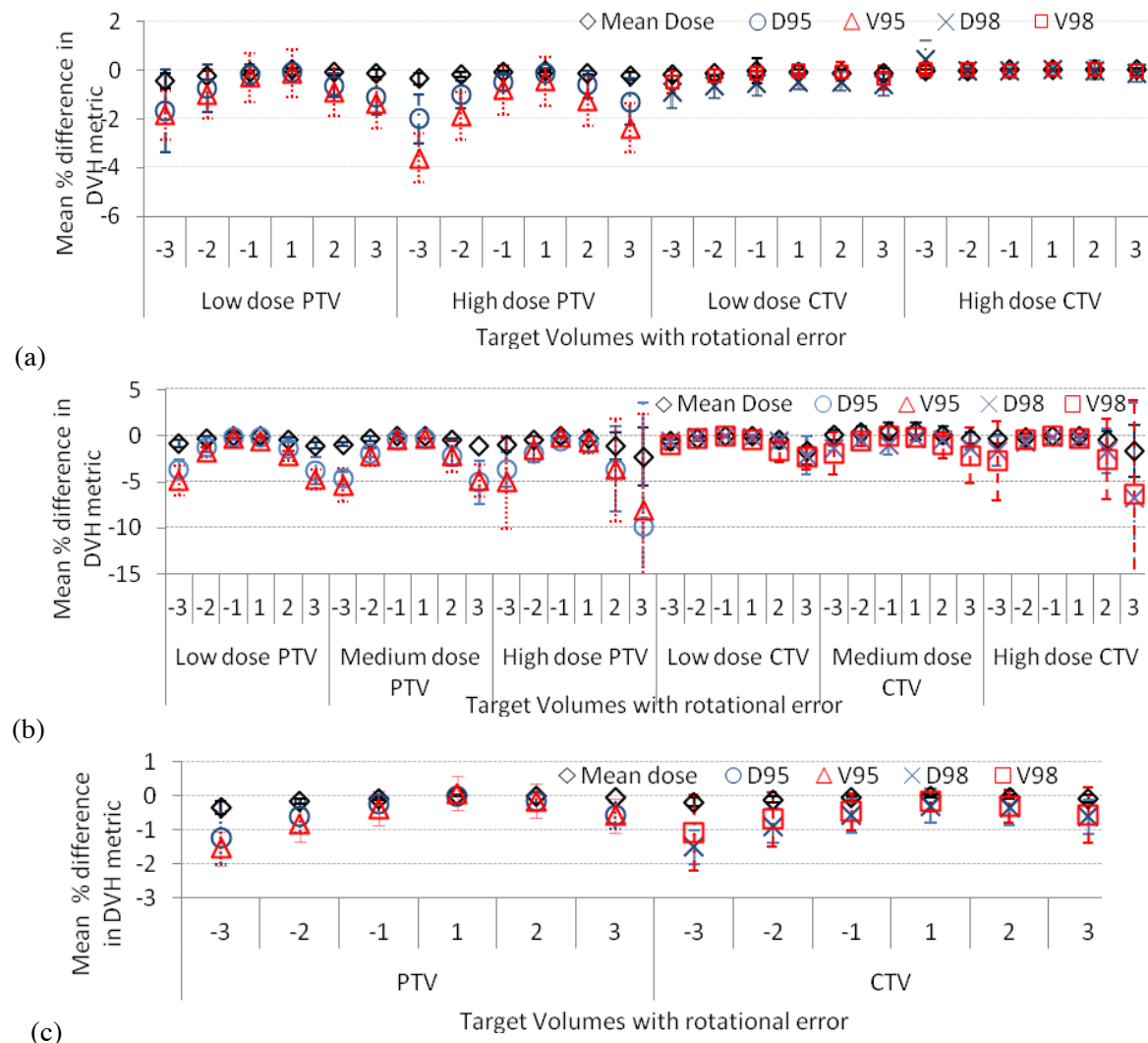


Figure 1: Mean percentage difference in DVH metrics (with 1σ) for rotational error introduced target volumes for (a) Pelvis, (b) Head and Neck and (c) Brain IMRT treatments.

Figure 1b shows the difference in DVH metrics for TVs in head and neck treatments. The percentage difference in mean dose to PTVs and CTVs varied from 0.0(0.2) % to -2.3(3.2) % and from 0.5(0.9) % to -1.6(2.8) % respectively. Increased mean doses were observed in the medium dose CTVs, suggesting overlapping in high dose regions with rotational errors. The difference in D95 and V95 for PTVs ranged from -0.3(0.0) % to -9.8(13.4) % and -0.3(0.1) to -8.1(10.5) % respectively. Larger differences in D95 and V95 for high dose PTVs was observed. This large difference was mainly contributed from the SCC lower lip head and neck case (table 1), due to the fact that the geometric centre of high dose PTV was at 90 mm superior and 52 mm anterior from the plan isocentre. The introduction of rotational errors to this structure about isocentre resulted in relatively high 3D dislocation of PTV from its original position and larger differences in DVH metrics. For the same reason the DVH metrics of the high dose CTV also showed major differences (figure 1b).

Figure 1c shows the mean percentage difference in DVH metrics for brain IMRT treatments. Mean dose showed very small change due to rotational error in all target volumes. A maximum difference of -1.5(1.3) % and -1.1(1.1) % in D98 and V98 was observed for CTVs.

The mean percentage difference in maximum and mean dose to some of the important critical structures in the studied treatment sites is shown in figure 2. In general, the maximum and mean dose

to critical structures varied from planned dose based on the direction of rotational error introduced to the structures. Particularly larger differences, up to 24.3(33.0) %, in maximum dose were observed for optic chiasm in Brain treatments (figure 2).

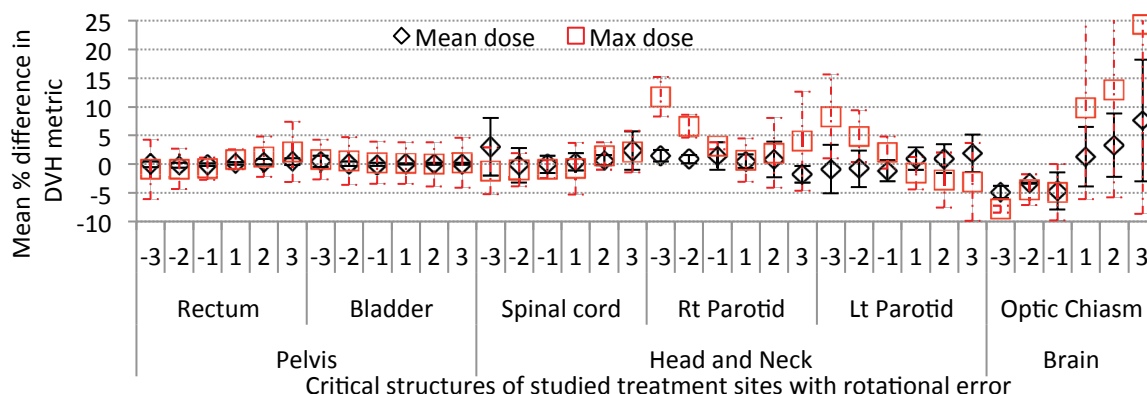


Figure2: Mean percentage difference in DVH metrics (with 1σ) for critical structures due to introduced rotational error for Pelvis, Head and Neck and Brain IMRT treatments.

The introduction of rotational errors resulted in under-dosage to PTVs in all treatment sites. In general the magnitude of dose difference depends on factors such as the dose conformity offered by particular IMRT delivery technique, the deformation in patient anatomy, the magnitude of residual translational error and complexity in target shape etc. In this work we studied the impact of rigid body rotational errors on the dose delivered to structures with the assumption that the residual translational error in patient set-up is zero. The magnitude of impact also depends on the position of geometric centre of the structure with respect to the plan isocentre. PTV margins sufficiently covered the prescription dose to CTVs whose centre was within the vicinity of plan isocentre. However plans with CTVs not centred at the plan isocentre were more sensitive to rotation errors. The dose received by critical structures with respect to rotation errors was also very sensitive to its location (figure 2). In pelvis treatments, rotational errors less than 2° resulted in clinically less important differences in DVH metrics for target volumes and critical structures (figure 1 a and 2). However in brain treatments rotational error as little as 1° had a significant clinical impact on the DVH metrics for critical structures (figure 2). These results suggest the importance of rotational corrections in patient positioning for these special scenarios.

4. Conclusion

The impact of rotational error on the dose delivered to TVs and critical structures depends on the location of the structures from plan isocentre. This study demonstrates that failure to correct patient's rotational error may result in clinically unacceptable underdosage to target volumes and overdosage to the critical structures in some specific treatment scenarios. These findings will inform the implementation of robotic couch corrections in our clinic.

5. References

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