

Validation of 3DVH estimated DVH metrics for prostate VMAT plans

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Abstract. The accuracy of 3DVH (Sun Nuclear Corporation, USA) reported DVH metrics for target volumes and Organs at Risk (OARs) for two Prostate Volumetric Modulated Arc Therapy (VMAT) plans was studied. The accuracy of 3DVH estimated DVH metrics in the presence of Multi Leaf Collimator (MLC) systematic errors was also tested with error introduced plans calculated in Pinnacle. The results of the study show that the DVH metrics estimated by 3DVH for error-free plans agree with the TPS calculation within 3%. The D95 to PTV was shown to be sensitive in detecting studied MLC errors. However the accuracy of 3DVH estimated DVH metrics for Target Volumes and OARs in the presence of MLC errors for VMAT prostate plans has limitations with this small data set. Although for most situations values matched within 3% for small MLC errors, there was up to a 9.8% difference between the TPS and 3DVH in the presence of a simulated 5mm MLC positioning error. Further study with more plans including other treatment sites is required to fully assess the performance of 3DVH in detecting potential clinical delivery errors.

1. Introduction

Measurement based three dimensional (3D) dosimetric verification is highly recommended to ensure dose calculation and delivery accuracy of complex modern radiotherapy techniques [1, 2]. Recently many dosimetric systems have been introduced that provide semi 3D or 3D dose information of the delivered treatment plan in a specific phantom geometry. Many metrics have been recommended to evaluate the agreement between measured and calculated dose matrices quantitatively [3]. Among them gamma (γ) index is widely implemented in many dosimetric systems and used in clinics [4]. However due to lack of correlation between these quantitative metrics and clinically relevant dose parameters there is an increasing demand to evaluate delivered dose to the relevant clinical structures in the patient geometry. Different approaches have been adapted by different dosimetric systems to estimate the dose in patient geometry based on the measurement performed by detectors [5, 6]. Sun Nuclear Corporation, USA recently introduced a patient dosimetric QA software system, 3DVH, that estimates the dose to clinical structures in patient geometry using a planned dose perturbation (PDP) algorithm. In this study we evaluate the accuracy of 3DVH software in estimating dose to patient



geometry for Volumetric Modulated Arc Therapy (VMAT) for prostate cancer. To investigate a situation where there may be a delivery error, the accuracy of the software in estimating the dose in the presence of systematic errors in Multi Leaf Collimator (MLC) position has been studied.

2. Materials and Methods

2.1. Planning and delivery system

A 6MV photon beam model for an Elekta –Synergy (Elekta Ltd, Crawley, UK) linac in the Pinnacle (Philips Ltd, USA) treatment planning system (TPS), v9.2, was used to generate all the treatment plans in this study. The Elekta–Synergy linac used has the MLCi head and the VMAT plans were delivered using continuously variable dose rate (CVDR) with Integrity, v1.1, console software.

2.2. Clinical plans and simulated errors

Two prostate VMAT plans were considered to study the accuracy of 3DVH in estimating the delivered dose to patient geometry. Systematic shifts in MLC leaf position, ranging from $\pm 1\text{mm}$ to $\pm 5\text{mm}$ in steps of 1mm, were introduced to the VMAT arc using in-house software [6]. The plans with MLC error were calculated in Pinnacle to study the impact of error on target volume and OAR doses.

2.3. ArcCHECK measurement and verification

The error-free and error-introduced plans were measured using the ArcCHECK dosimetric system. A point dose measurement using a CC13 ion chamber was also performed at the centre of the ArcCHECK phantom for all plans to provide the measured point dose information to the 3DVH, v3.0, software. The PDP algorithm implemented in 3DVH perturbs the planned patient dose voxels based on the ray traced error maps obtained from ArcCHECK measurements and TPS dose matrix calculated in ArcCHECK geometry. More details on the description of the algorithm can be found elsewhere [7].

2.4. Comparison metrics

The TPS and 3DVH estimated DVH parameters including D95 to CTV and PTV and mean dose to PTV, CTV, Rectum and Bladder were compared to verify the dosimetric accuracy of delivered error-free plans. A minimum 3% agreement between the TPS and 3DVH estimated DVH metrics for error free plans are expected to accept the plan. To assess the accuracy of 3DVH reported DVH metrics in the presence of simulated errors, the errors were introduced to the patient plan in the TPS using in-house software and dose calculations were performed. The TPS calculated DVH metrics for the error plans were compared against the 3DVH reported metrics for error introduced plans.

The dose matrices calculated by the TPS and estimated by 3DVH were compared using γ analysis and Dose Volume Histogram (DVH) metrics of the clinical structures. The γ analysis was performed using 2%/2mm and 3%/3mm criteria using global (G) and local (L) dose tolerances. The dose elements within the ArcCHECK-PDP (ACPD) calculation volume and high dose threshold of 10% of the maximum dose were used in the γ analysis. The change in γ pass rate with increased magnitude of errors was studied to assess the sensitivity of the 3DVH estimated dose matrix in identifying delivery errors.

3. Results

3.1. Gamma comparison

Figure1 shows the γ pass rate results of the 3DVH predicted dose matrix and TPS calculated dose matrix for error-free and error introduced plans with various tolerance criteria. In general Case 1 showed less variation in γ pass rate at all tolerance levels for introduced errors. The pass rate for Case 2 varied as a function of introduced error. 3%/3mm global criteria (3%G/3mm) was observed to be less sensitive in predicting errors. 2%G/2mm and 3%L/3mm tolerance criteria showed similar pass

rate variations for all plans. 2%L/2mm criteria showed high sensitivity to error for Case 2, the pass rate was reduced from 96.3%, for the error-free plan, to 83.2% for the plan with 5mm error (figure1).

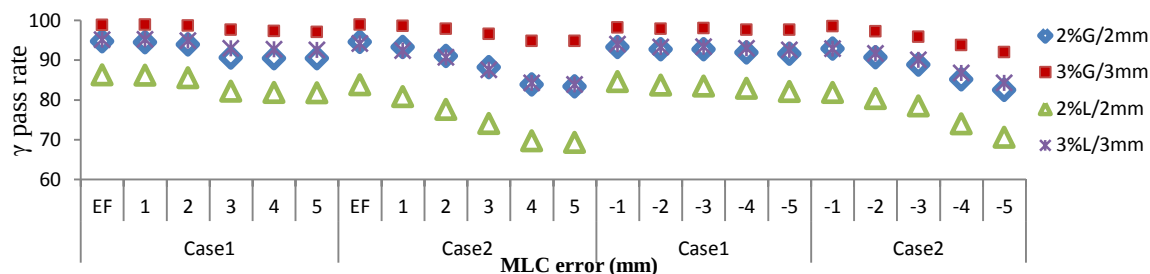


Figure 1. γ pass rate values for γ comparison between error free and +ve and -ve MLC error introduced plans for the studied cases with different γ tolerance criteria.

3.2. Change in DVH metrics calculated by TPS

Figure 2 shows the percentage change in DVH metrics between error-free and +ve MLC error introduced plans calculated by the TPS. Figure 3 shows similar data for -ve MLC shift plans. As expected, the D95 of PTV decreased as the MLC error value increases. A maximum change of -9.8% was observed for the PTV of case2 for the plan with -5mm MLC error. For CTV the D95 decreased for both +ve and -ve errors for case1. For case 2 the D95 improved with +ve errors and decreased with -ve errors. A maximum change of -4.6% decrease in D95 was observed for the CTV with -5mm error. The mean dose to PTV was decreased by a maximum -3.7% with -5mm error. The mean dose to Bladder was increased with +ve MLC error and decreased with -ve MLC errors for both cases. A maximum change of -6.9% was observed for case 1 with -5mm error. The mean rectum dose showed minimum change for both cases with +ve MLC errors whereas with -ve errors the mean dose increased in both cases and case 2 showed an increase of 6.2% with -5mm MLC error.

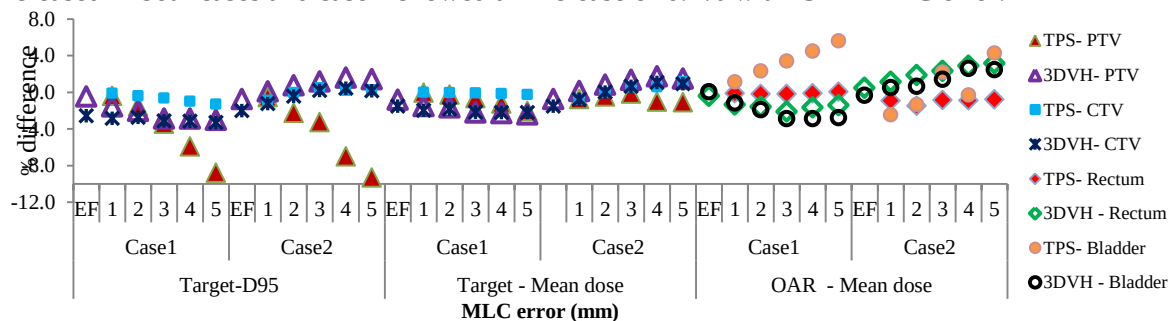


Figure 2. Percentage (%) difference in considered DVH metrics for target volumes and OARs for error-free (EF) and +ve MLC error introduced plans by TPS and 3DVH.

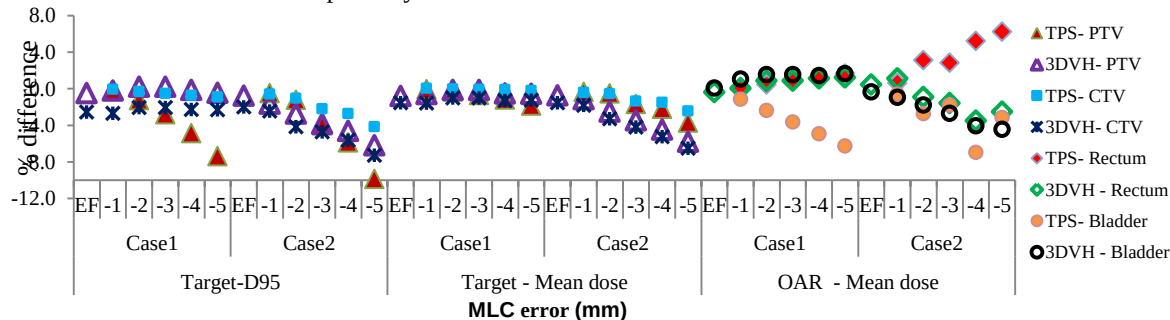


Figure 3. Percentage (%) difference in considered DVH metrics for target volumes and OARs for error-free (EF) and -ve MLC error introduced plans by TPS and 3DVH.

3.3. Accuracy of 3DVH estimated DVH metrics

The DVH metrics estimated by 3DVH for error-free and +ve and -ve MLC error introduced plans are shown in figures 2 and 3. The D95 and mean dose of error-free plans estimated by 3DVH for clinical structures agreed with the TPS within 3%. For MLC error introduced plans the % difference of PTV D95 estimated by 3DVH was consistently less compared to the TPS. A maximum difference of -9.4% was observed between the 3DVH estimated and TPS calculated D95 values for PTV for a plan with 5mm MLC error (figure2). The TPS calculated D95 to CTV showed only small magnitude variation for MLC errors for both cases. The 3DVH estimated D95 values followed the same trend as TPS calculated values (figures2 and 3). The mean dose to target volumes showed only small changes due to +ve MLC errors for studied cases. 3DVH estimation also followed the same trend. In the case of -ve MLC errors for case 2 the 3DVH estimated mean dose change was consistently higher compared to TPS calculated changes. A maximum difference of 4.5% was observed between TPS and 3DVH mean dose values at -5 mm MLC error. The % difference in mean dose to OARs, estimated by 3DVH, showed inconsistent results compared to TPS calculation. The % difference in bladder dose calculated by TPS for Case 1 and the dose to rectum and bladder estimated by 3DVH showed contrary results compared to TPS calculations. For +ve MLC errors the TPS calculated mean dose to Rectum showed minor changes (maximum -1.4% for 5mm error for case 1). The 3DVH estimated % differences for Case 2 were observed to have consistently higher values compared to TPS calculations. In the case of -ve MLC errors the 3DVH estimated % difference was consistently low compared to TPS calculation for Case 2. The % difference in mean dose to bladder for Case 1 estimated by 3DVH showed an inverse trend to that with TPS calculation. The 3DVH and TPS calculated mean dose for Rectum in Case 2 showed relatively close agreement, with a maximum difference of 3% observed between TPS calculated and 3DVH estimated mean dose for the plan with -4 mm error.

4. Discussion

The DVH metrics estimated by 3DVH for error-free plans agreed with the TPS calculation within a generally accepted tolerance of 3%. Clinically significant changes (>5%) in D95 to PTV and mean dose to OARs were observed with the simulated MLC errors. 3DVH estimated D95% difference for error simulated plans agreed with TPS calculation only for -ve MLC error plan scenario of Case 2 (figures 2 and 3). The mean dose to Rectum estimated by 3DVH in the presence of MLC error did not agree with the TPS calculation for Case2. Similarly the mean dose to Bladder estimated by 3DVH in the presence of MLC error did not agree with the TPS calculation for Case 1. The ACPDP has been shown to have limitations in predicting changes in DVH metrics due to the studied MLC shifts. However the γ pass rate with 2%L/2mm tolerance criteria showed a consistent decrease in pass rates with MLC error for at least one of the studied cases (Case 2 results in figure 1).

5. Conclusion

The accuracy of 3DVH estimated DVH metrics for target volumes and OARs in MLC error introduced VMAT prostate plans has been shown to have limitations in this small data set with up to a 9.8% difference between the TPS and 3DVH in the presence of a simulated 5mm MLC positioning error. Further study with more plans, including other treatment sites, is required to fully assess the performance of 3DVH in detecting potential clinical delivery errors.

6. References

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