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Validation of Measurement Based Dose Volume Metrics for the Quality Assurance of VMAT Plans

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Abstract

Aim: To validate the accuracy of ArcCHECK measurement-based 3DVH dose-volume metrics for the quality assurance of volumetric modulated arc therapy (VMAT).

Methods: Ten each of prostate and head and neck (H&N) VMAT plans were considered for this study. Three types of errors were introduced into the original plans: gantry angle independent and dependent MLC errors, and gantry angle dependent dose error. The percentage difference in PTV-D95 between TPS and 3DVH was compared for no-error and error introduced plans.

Results: For prostate and H&N plans with no error in delivery the PTV D95 calculated by the TPS and 3DVH agreed with a difference of -0.5 (1.7)% and -1.5 (1.9)% respectively For gantry independent MLC errors, a difference (σ) of 4.7 (2.6)% and 1.6 (2.1)% was observed between TPS and 3DVH calculated PTV D95 for prostate and H&N plans. Similarly for gantry dependent MLC errors a difference of 12.8 (5.4)% and -2.6 (4.5)% was observed. No major change in PTV-D95 was observed for gantry dependent dose errors for the TPS or 3DVH.

Conclusion: For no error delivery the 3DVH estimated DVH metrics showed acceptable agreement with the TPS calculation. For error scenarios considered in this study, in H&N plans the 3DVH estimated DVH metrics showed sensitivity to simulated errors, however for prostate plans the 3DVH estimated DVH metrics didn't show sensitivity to errors considered in the study.

Keywords

VMAT, Dose-volume metrics, Delivery error

Introduction

The measurement based dosimetric validation is an integral part of pre-treatment Quality Assurance (QA) checks in advanced radiotherapy techniques [1]. In this approach the dose measurements performed using detector systems in phantoms are used as a surrogate to ensure the plan and delivery accuracy in this approach [1,2]. Whilst the assessment of delivered plan accuracy in terms of clinically relevant dose-volume metrics in patient geometry is desired in clinical practice, the quantitative comparison of planned and measured dose matrices is assessed using gamma analysis [3]. This is mainly due to limited spatial information of measured dose matrix and difficulty in transferring the measured dose information form homogeneous phantom geometry to heterogeneous patient geometry. In treatment techniques such as Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) the estimation of patient dose based on measurements in phantom is even more difficult due to complexity in delivery.

Modern dosimetric systems have the capability to provide semi-3D or 3D information of the measured dose with high spatial resolution. The methods to transfer the dose measured in phantom to patient geometry also have been developed to enable the direct validation of treatment plans based on dose volume metric in patient geometry [4]. One such system used in clinics is the ArcCHECK (Sun Nuclear, Melbourne, USA) dosimeter and 3DVH software [5]. The combined ArcCHECK and 3DVH enables the validation of dosimetric accuracy of clinical treatment plans based on measurement based dose-volume metrics in patient geometry. In the clinical utilisation of these tools it is paramount to understand the limitations of these methods to set appropriate tolerance and action levels to make the decision on acceptability of the treatment plans. In this work we have systematically studied the accuracy of 3DVH reported dose-volume metrics in clinical VMAT plans of different complexity levels. The accuracy of 3DVH reported dose-volume metrics in the presence of given delivery errors was comprehensively studied by introducing three different types of MLC and dose delivery errors and comparing the Treatment Planning System (TPS) reported metrics to the 3DVH reported metrics..

Materials and Methods

Planning and delivery

The VMAT plans were generated using the SmartArc optimisation

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tool available in the Pinnacle v9.8 (Philips Healthcare, Fitchburg, WI, USA) Treatment Planning System (TPS). A 6MV photon beam model for an Elekta-Synergy (Elekta Ltd, Crawley, UK) linear accelerator (LA) was used for planning. The details of the SmartArc optimisation algorithm used in Pinnacle can be found elsewhere [6]. Dose calculations for all plans in the study were performed using the Adaptive convolution dose calculation algorithm available in the Pinnacle TPS with 2.5 mm × 2.5 mm × 2.5 mm voxel size. The Synergy accelerator used in this study was equipped with an MLCi head and Desktop Pro, v7.0, LA control software. Mosaiq, v2.30.0D1, (Impac Medical Systems, Inc. California, USA) record and verification (R&V) system was used for the transfer of VMAT plans from TPS to LA.

VMAT plans

Simple arc: A conformal arc generatedfor a spherical target volume (STV) of 8 cm diameter was considered to study the accuracy of 3DVH-estimated dose-volume metrics (DVMs) in a simple plan scenario. The plan wasgenerated, using 178 control points (CPs) with 2° gantry spacing. The dose volume metrics of the STV and 2 overlaying spherical annular zones around the STV, the first one with a 5 mm added margin (ROI-1) and the second with a 10 mm added margin (ROI-2), were defined to study the accuracy of the Planned Dose Perturbation (PDP) algorithm estimated DVMs in high and low dose regions.

Clinical cases: Ten prostate and ten head and neck (H&N) cases were considered to study the accuracy of the 3DVH estimated DVMs in a real clinical scenario. The arc length used for the VMAT plans ranged between 240° and 360°. To assess the complexity of the plans considered in the study a multiplicative combination of leaf travel and modulation complexity score (LT-MCS) was calculated using in-house software [7]. The mean (σ) LT-MCS value for the simple arc, prostate and H&N plans are 1.0, 0.348 (0.04) and 0.111 (0.06) respectively. The lower LT-MCSv value represents higher complexity in the plan with H&N planshighly complex for the studied plan cohorts.

Studied errors

Three types of errors to the VMAT plans, as described by Arumugam, et al. [8,9], were intentionally introduced to the original plans considered in this study.

1. Gantry angle independent MLC shift to simulate the systematic offset in the MLC position (ranging from ± 1 mm to ± 5 mm),
2. Gantry angle dependent MLC error (amplitude ranging from ± 1 mm to ± 7 mm), to simulate the sag in MLC position as a function of gantry angle,
3. Gantry angle dependent dose error (amplitude ranging from 1% to 7%) to simulate the output fluctuation as a function of gantry angle. The total monitor units (MU) of the VMAT arcs were maintained with the specified gantry angle dependent errors introduced to the relative weights of the CPs.

In-house developed software was used to introduce the errors [10]. The error introduced plans were recalculated in the TPS and the treatment delivery files of these plans were exported to the LA for delivery.

ArcCHECK and 3DVH

The dose measurements were performed using the ArcCHECK helical diode array detector and SNC software (Sun Nuclear Corporation, Melbourne, Florida, USA). ArcCHECK is a cylindrical phantom of 27 cm diameter and 21 cm length. It consists of 1386 diode detectors arranged in a helical grid pattern with 10 mm detector spacing. The absolute dose calibration procedure recommended by the manufacturer was followed to calibrate the ArcCHECK. The long term reproducibility of the ArcCHECK measurements was studied by analysing the reference 10 × 10 cm^2 field measurement performed during clinical VMAT plans validation for a two year period. The TPS generated dose matrix for a static 10 × 10 cm^2 was compared with the ArcCHECK measurement using gamma analysis with 2% local dose tolerance and 2 mm distance to agreement (DTA). The dose points receiving less than 10% of the maximum dose were not included in the analysis.

All ArcCHECK measurements were performed with a simultaneous CC13 ion chamber (IBA Dosimetry GmbH, Germany), placed at the centre of the ArcCHECK device. The dose measured by the ion chamber was used in the 3DVH analysis as recommended by the manufacturer. The PDP algorithm utilised in 3DVH software (Sun Nuclear Corporation, Melbourne, Florida, USA) uses the ArcCHECK measurement frames and the dose calculated in ArcCHECK geometry to derive the dose error maps [5]. These error maps are ray traced through the TPS dose matrix of the plan and calculated on a CT data set representing ArcCHECK geometry. The ray traced error matrices are used to perturb per beam dose contributions calculated by the TPS in patient geometry to achieve translation of the difference measured in ArcCHECK geometry to the patient geometry. More technical details on the ArcCHECK and PDP can be found elsewhere [11].

Validation methodology

The overall methodology used in the study to validate the PDP estimated dose matrices is shown in figure 1. In arm 1 the 3DVH estimated dose matrices based on error-free and error measurements were compared against the error-free TPS dose matrices to study

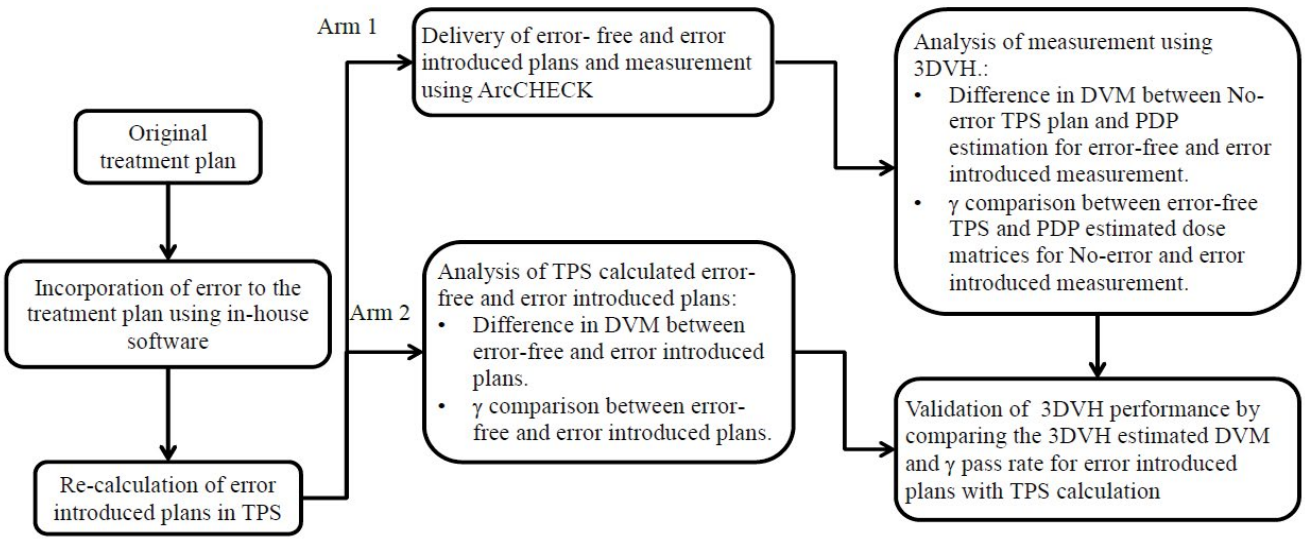

Figure 1: A flow diagram showing the overall methodology used in the study for the validation of PDP estimated dose-volume metrics.

the sensitivity of PDP estimation to delivery errors. In arm 2 the TPS calculated dose matrices for error introduced plans are compared against the error-free TPS calculations. The analysis results of arm1 are compared against the arm 2 results to evaluate the PDP estimations, considering arm 2 (TPS dose matrix comparison) results as the gold standard.

Comparison parameters

The PDP estimated dose received by the 95% volume (D95) to STV, ROI-1 and ROI-2 for error-free and error introduced delivery were compared against the TPS calculations. For clinical prostate plans, D95 to the Planning Target Volume (PTV) and mean dose and Volume receiving 60 Gy (V60) of rectum were compared. Similarly for H&N plans the D95 to PTV and mean dose and dose to 2 cc volume (D2cc) of spinal cord were compared.

A gamma (γ) comparison of PDP estimated dose matrices for error-free and error introduced measurement against the error-free TPS calculated dose matrix was performed. These γ pass rates were compared with a similar analysis performed for the error-free TPS dose matrix against the delivery error introduced TPS dose matrices (Figure 1). The γ comparison was performed with local (L) dose tolerance criteria. Two levels of tolerance, 2% and 3%, and two magnitudes of distance-to-agreement (DTA), 2 mm and 3 mm, (2%L/2 mm and 3%L/3 mm) were considered in the γ analysis. The voxels receiving less than 10% of the mean PTV dose were not included in the analysis.

Correlation between TPS calculated PTV D95 and γ pass analysis results of 3DVH

The correlation between the change in gamma pass rate and change in PTV D95, as estimated by the TPS, with errors was studied by calculating the correlation co-efficient (r) between these two parameters for the studied error scenarios. The correlation co-efficient between mean γ pass rates with tolerance criteria of 2%L/2 mm and 3%L/3 mm, and mean decrease in PTV D95 of the studied plans as calculated by 3DVH was also investigated.

Results

Simple arc plan

The mean (σ) percentage difference (%) in D95 between the error free TPS calculation and 3DVH-estimation for error-free and error introduced deliveries for all considered errors is shown in figure 2. The same metric calculated by TPS for error scenarios is also shown in the same figure. In the TPS calculation for both gantry angle independent and dependent MLC error scenarios the D95 to STV decreased as the magnitude of error increased. In comparison the 3DVH estimated change in DVH metric showed only minor changes (maximum of only -1.7%, p = 0.03) in D95 with errors. In gantry angle dependent dose error scenario there is no change in D95 with error both in TPS and 3DVH estimation (Figure 2).

The γ comparison results for 3DVH estimated dose matrices and TPS calculated dose matrices for all considered error scenarios are shown in figure 3. In gantry angle dependent MLC error plans the γ pass rate was reduced to 54.4% and 65.72% with 2%L/2 mm and 3%L/3 mm tolerance criteria for the TPS dose comparison for the 7 mm MLC error (Figure 3). Similarly in the analysis of 3DVH estimated dose matrices the γ pass rate was reduced from 98.6% and 99.7%, for no-error delivery, to 81.8% and 93.2% for 7 mm MLC error (Figure 3). The difference in decrease in γ pass rate between

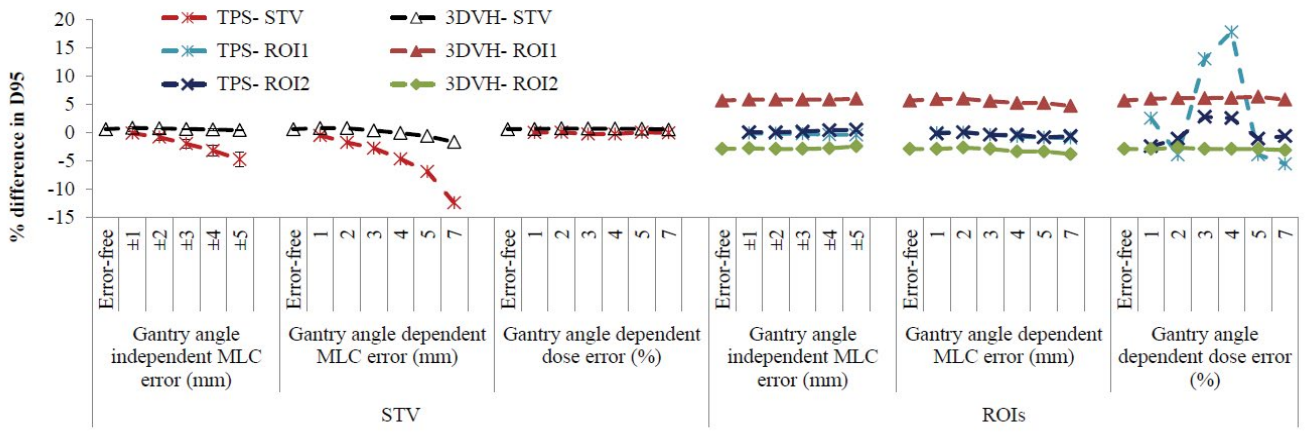

Figure 2: The % change in D95 of STV, ROI-1 and ROI-2 for considered error scenarios as calculated by the TPS and 3DVH for simple conformal arc plan.

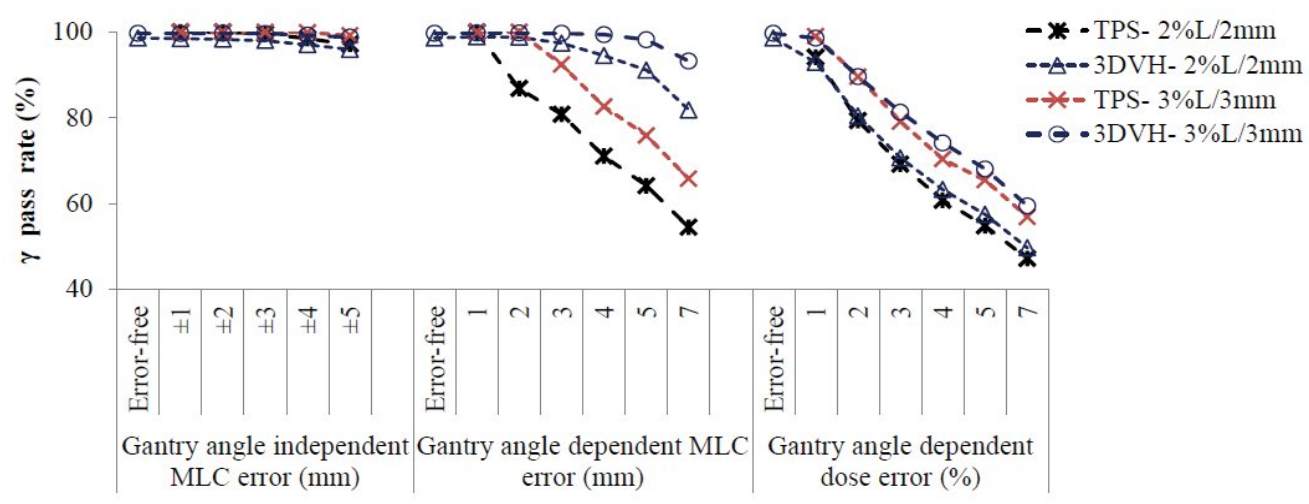

Figure 3: The γ pass rates of TPS calculated and 3DVH estimated dose matrices for error-free and studied error scenarios for the simple conformal arc plan.

3DVH and TPS dose matrices was not statistically significant (p value 0.06 and 0.14 for γ pass rate with 2%L2 mm and 3%L3 mm tolerance criteria respectively).

Clinical VMAT plans

Prostate plans: Figure 4 shows the mean (σ) percentage change in dose-volume metrics of the PTV and rectum as calculated by the TPS for the studied error scenarios in prostate plans. The same metrics for the studied structures estimated by 3DVH based on the ArcCHECK measurements are also shown in the same figure. Similar to the simple arc plan, the prostate PTV D95 decreased with MLC errors in TPS calculation. The mean (σ) values of mean dose, and D95 to PTV and Rectum V60 calculated by the TPS and 3DVH for no error plans and plans with minimum and maximum values of simulated error values in each errors scenario for prostate plans is shown in table 1. The TPS calculated PTV D95 was reduced by a maximum value of -14.1 (8.5)% with 7 mm gantry angle dependent MLC error compared to the no error plan (Figure 5). The 3DVH estimated PTV D95 showed a small increase in D95 with MLC errors. The mean (σ) difference in PTV D95 increased from -0.5 (2.0), for no error delivery, to 0.6 (4.2) % for the 7 mm MLC error delivery (Figure 4).

The γ pass rates of the TPS dose matrices and 3DVH estimated dose matrices for the considered error scenarios are shown in figure 6. Both in the TPS and 3DVH dose matrix analysis the pass rate decreased as magnitude of error increased in each scenario. The γ pass rate for TPS dose matrices was reduced to 42.7 (5.4)% and 57.4 (5.8)% with 2%L/2 mm and 3%L/3 mm tolerance criteria for the 7 mm gantry angle dependent MLC error (Figure 6). Equivalent values determined from the 3DVH estimated dose matrices were 72.0 (7.5)% and 85.8 (7.2)%. There is no statistically significant different in decrease in γ pass rate between 3DVH and TPS dose matrices (p value 0.06 and 0.14 was observed in γ pass rate with 2%L2 mm and 3%L3 mm tolerance criteria).

Head and Neck plans: The change in PTVD95 as calculated by the TPS and 3DVH for studied error scenarios is shown in figure 5. Similarly the change in D2cc of the spinal cord is shown in the same figure. The mean (σ) values of mean dose, and D95 to PTV and Rectum V60 calculated by the TPS and 3DVH for no error plans and plans with minimum and maximum values of simulated error values in each errors scenario for prostate plans is shown in table 1. The TPS and 3DVH estimated change in DVH metric with error agreed well in all considered scenarios. The decrease in γ pass rate with error in both

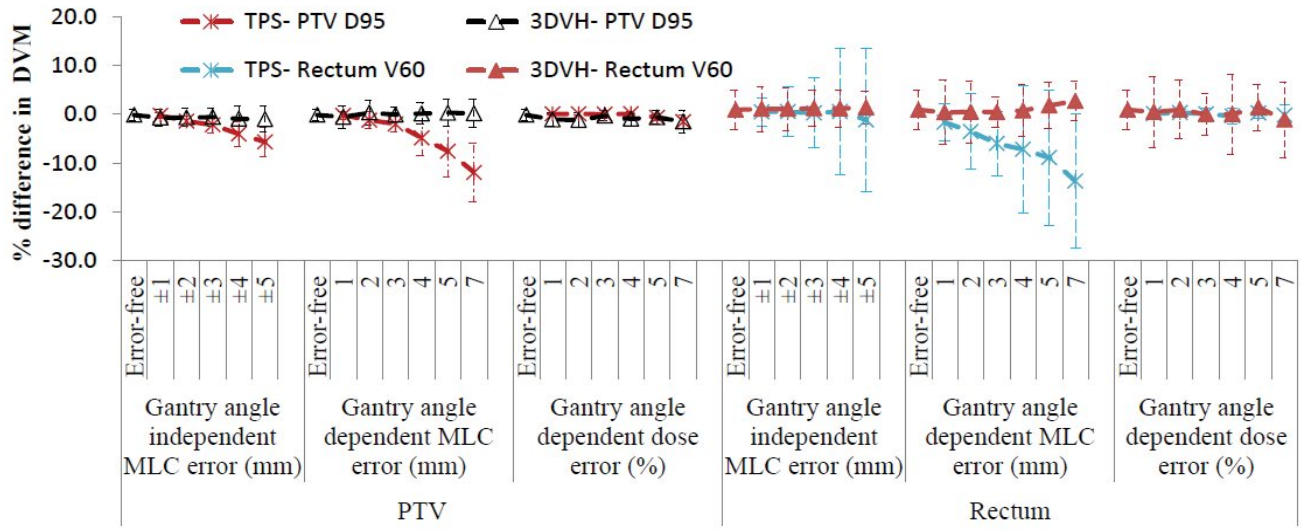

Figure 4: % change in PTV D95 and Rectum V60 for the considered error scenarios as calculated by the TPS and 3DVH for prostate VMAT plans.

Table 1: Mean (σ) values of DVH metrics calculated by TPS and 3DVH for no error and error introduced plans in studied prostate and head and neck VMAT plans.

		Prostate plans					
		PTV					
Error scenario	Magnitude of error	Mean dose (Gy)		D95 (Gy)		Rectum V60 (%)	
		3DVH	TPS	3DVH	TPS	3DVH	TPS
	No error	77.8 (2.1)	78.4 (1.7)	74.9 (2.9)	75.4 (2.7)	21.3 (9.0)	20.5 (7.8)
Gantry angle independent MLC error	± 1 mm	78.1 (1.9)	78.4 (1.7)	75.2 (2.7)	75.2 (2.8)	21.3 (8.3)	20.5 (7.8)
	± 5 mm	77.3 (2.8)	77.0 (2.5)	74.2 (3.3)	69.8 (5.4)	21.6 (8.0)	18.6 (7.7)
Gantry angle dependent MLC error	1 mm	78.0 (1.8)	78.2 (1.7)	74.8 (2.5)	75.3 (2.8)	19.0 (5.9)	20.6 (7.0)
	7 mm	79.2 (1.7)	77.7 (2.1)	75.7 (2.2)	64.0 (7.5)	22.3 (7.6)	13.4 (18.3)
Gantry angle dependent dose error	1 %	76.7 (1.0)	78.1 (1.6)	73.5 (1.6)	74.6 (2.5)	22.5 (3.5)	26.2 (16.5)
	7 %	76.8 (1.1)	78.1 (1.4)	73.2 (1.7)	74.6 (2.6)	22.4 (3.2)	25.7 (15.2)
Head and neck plans							
		PTV					
		Mean dose (Gy)		D95 (Gy)		Spinal cord D2cc (Gy)	
	No error	59.7 (4.4)	60.4 (4.4)	51.2 (3.8)	52.3 (3.9)	36.0 (5.0)	36.2 (4.4)
Gantry angle independent MLC error	± 1 mm	59.7 (4.1)	60.4 (4.3)	51.2 (3.9)	52.3 (3.8)	35.9 (5.0)	36.3 (4.4)
	± 5 mm	59.5 (4.8)	60.4 (4.7)	51.1 (4.5)	55.3 (8.2)	35.8 (5.3)	36.2 (4.7)
Gantry angle dependent MLC error	1 mm	59.2 (5.6)	60.5 (4.6)	50.7 (5.5)	55.4 (8.0)	35.6 (5.4)	35.9 (4.9)
	7 mm	57.9 (7.6)	60.3 (4.3)	49.7 (6.8)	53.2 (6.7)	34.5 (6.2)	34.4 (6.1)
Gantry angle dependent dose error	1 %	57.5 (2.8)	60.4 (4.7)	49.6 (2.8)	52.3 (4.1)	36.0 (6.1)	36.2 (4.7)
	7 %	63.7 (7.3)	61.4 (5.0)	57.5 (9.3)	52.1 (4.8)	37.7 (7.1)	37.9 (6.2)

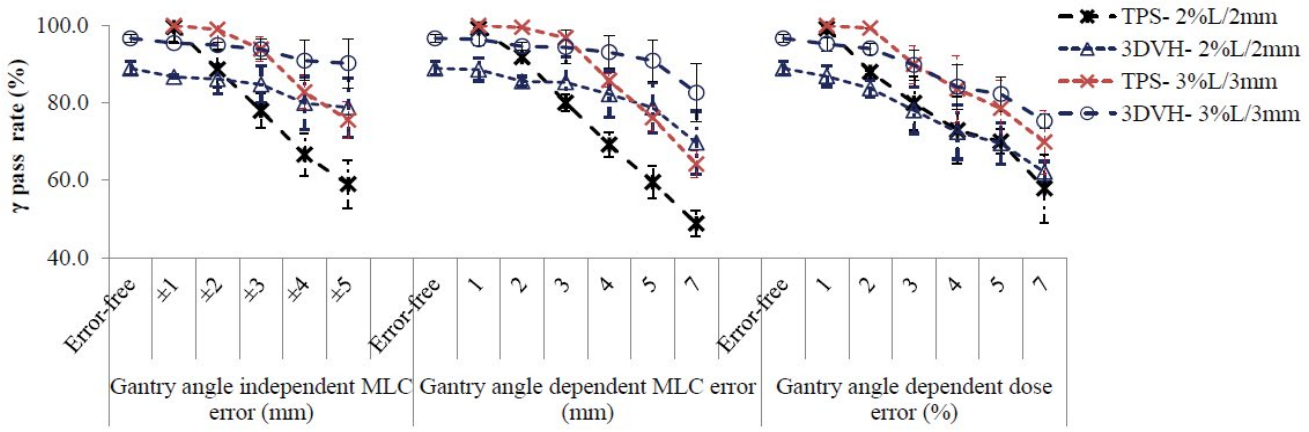

Figure 5: % PTV D95 and spinal cord D2cc for the considered error scenarios as calculated by the TPS and 3DVH for head and neck VMAT plans.

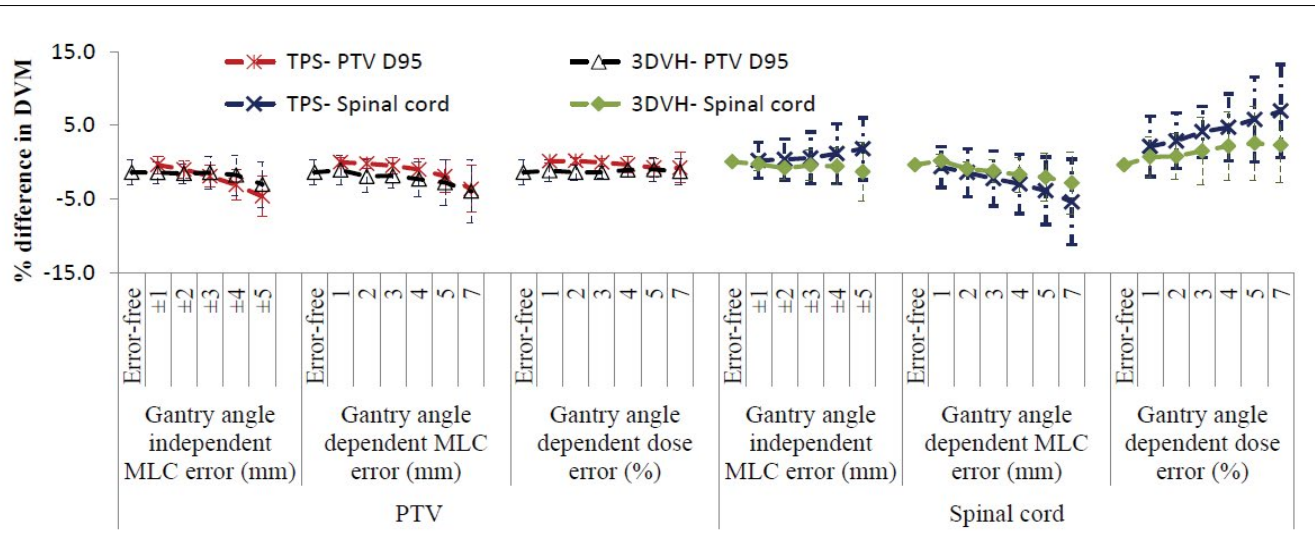

Figure 6: The γ pass rates of TPS calculated and 3DVH estimated dose matrices for error-free and studied error scenarios in prostate VMAT plans.

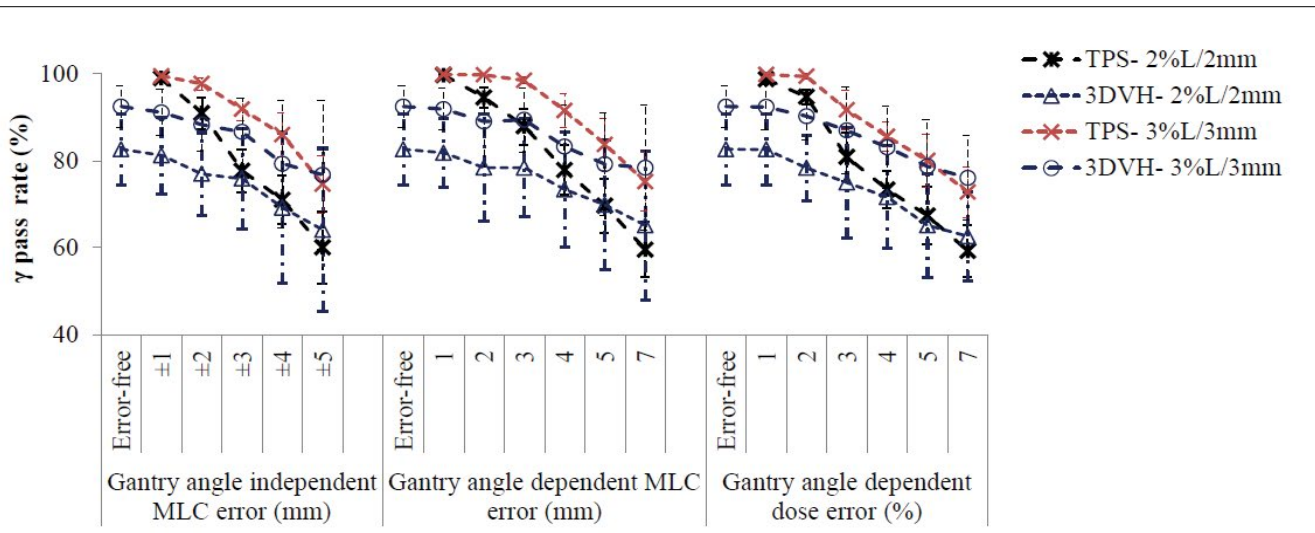

Figure 7: The γ pass rates of TPS calculated and 3DVH estimated dose matrices for error-free and studied error scenarios in head and neck VMAT plans.

TPS calculated and PDP estimated dose matrix analysis agreed within 5% (Figure 7).

Correlation between 3DVH γ pass rate and TPS PTV D95 for error plans

The correlation co-efficient (r) between change in PTV D95, as calculated by the TPS for studied error scenarios and γ pass rate as calculated by 3DVH for the considered error plans, is shown in figure 8. A strong positive correlation ($r > 0.93$) between change in PTV D95 and decrease in γ pass rate was observed for gantry angle dependent and independent error scenarios in the simple arc, prostate and H&N VMAT plans (Figure 8). For gantry angle dependent dose error scenarios no correlation ($r < 0.1$) was observed between γ pass rate and PTV D95. The γ pass rate with both 2%L/2 mm and 3%L/3

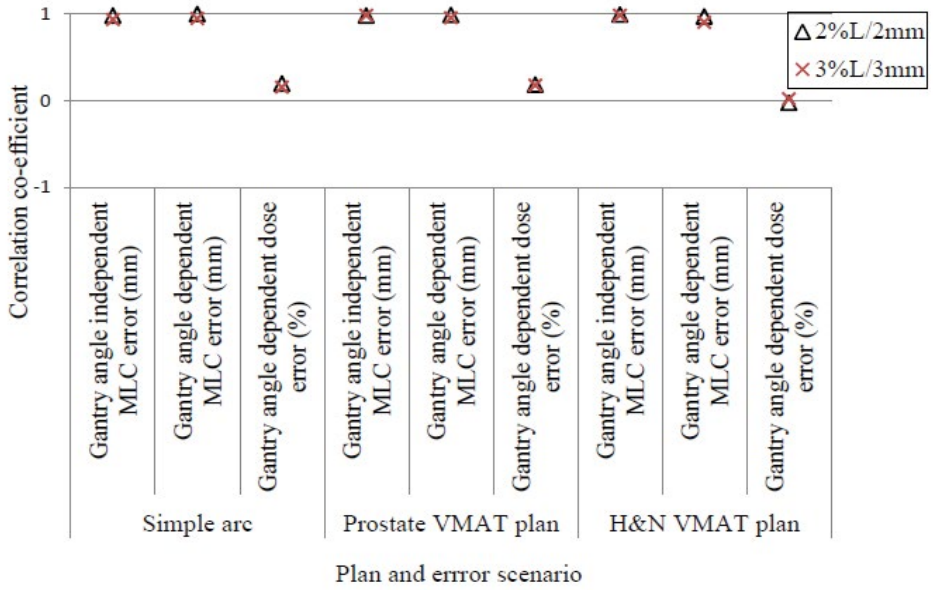

Figure 8: The calculated correlation coefficient between the TPS calculated PTV D95 and 3DVH calculated γ pass rate for error scenarios studied in simple arc, prostate and H&N VMAT plans.

mm tolerance criteria showed the same level of correlation with PTV D95 (Figure 8).

Discussion

The direct validation of dose-volume metrics as would occur within a patient geometry could potentially provide a clinically useful method to understand the relevant dosimetric accuracy of a given treatment delivery. The major limitation in the conventional γ analysis of plan and measured dose matrices, as pointed out by others [2,12,13], is that there is no direct correlation between the stated pass rate with specific dose and DTA tolerance criteria and dose to the clinically relevant structures in the patient geometry. Measurement based dose-volume metric estimation in the patient geometry may overcome this limitation and allow validation of plans based on estimated dose to relevant clinical structures.

Modern dosimetric systems provide dose-volume information in patient geometry based on measurements performed in phantoms. Different approaches have been reported in the literature and are in use to estimate the dose to the patient based on measurements performed in phantoms. In this work we systematically studied the accuracy of dose-volume metrics estimated by the PDP algorithm in patient geometry based on ArcCHECK measurements of VMAT plans.

For a simple conformal arc plan the 3DVH estimated D95 for the spherical target volume (STV) agreed with the TPS calculation within 0.5%. However the 3DVH estimated D95 to ROI1 was 5.6% high and for ROI2 this was reduced by 3.0% in comparison to the TPS calculations. Further the 3DVH estimated STV D95 did not show noticeable difference both in gantry angle independent and dependent MLC error scenarios, whereas the TPS calculation showed a maximum decrease in D95 of 4.8 (1.2)% and 12.5% with 5 mm gantry angle independent and 7 mm gantry angle dependent error scenarios (Figure 2). The % difference in D95 for ROI1 and ROI2 remained unchanged in both the TPS calculation and 3DVH estimation. The under and over estimation of D95 of the concentric overlaid volumes might be due to coarse resolution of the measured dose matrix. During the TPS dose perturbation process the PDP algorithm interpolates the ArcCHECK measured dose frames to a finer resolution. The limitation in this interpolation due to coarse detector resolution might be the reason for the discrepancy in 3DVH calculated D95 for these overlaid concentric volumes.

For clinical prostate and H&N plans, the 3DVH estimated PTV D95 for error-free delivery showed good agreement with the TPS estimation. However in prostate plans 3DVH estimated PTV D95 and rectum V60 did not change to indicate the error in the delivery both in gantry angle independent and dependent MLC error scenarios (Figure 4). In H&N plans the PDP estimated dose-volume metrics were in relatively good agreement with the TPS estimation for all studied error scenarios. The 3D gamma analysis showed that in prostate plans the change gamma pass rate in 3DVH estimated dose matrices showed less gradient compared to TPS dose matrices particularly in MLC error scenarios (Figure 6). In H&N plans qualitatively both the TPS and 3DVH dose matrix analysis agreed, but the decrease in pass rate with PDP analysis was relatively less with changes in magnitude of error compared to the TPS dose matrix analysis (Figure 7).

The correlation analysis between change in PTV D95, as calculated by TPS, and γ pass rate of 3DVH estimated dose matrices for error delivery showed a strong positive correlation between these two parameters for gantry angle independent and gantry angle dependent MLC error scenarios (Figure 8). The correlation level was shown to be similar at both 2%L/2 mm and 3%L/3 mm tolerance criteria for simple arc, prostate and H&N VMAT plans. For the gantry angle dependent dose error scenario no correlation between change in PTV D95 and γ pass rate was observed as the PTV D95 was not affected by this error (Figure 4 and Figure 5), however the γ pass rate of 3DVH estimated dose matrices decreased with increasing magnitude of errors. In the gantry angle dependent dose errors, the errors were introduced to the relative weights of the CPs by maintaining overall MUs of the arc same as the original plan. The errors introduced to weight of the CPs didn't affect the dose to PTV due to the accumulation of higher dose in PTV region. However due to differential distribution of dose in peripheral region the γ analysis showed a significant difference between TPS and 3DVH dose matrices. In the studied prostate plans the 3DVH estimation showed no significant change in PTV D95 for error scenarios but the TPS calculation showed a clinically significant decrease in D95 for similar errors (Figure 4). The γ pass rate of 3DVH estimated dose matrices did show a decrease in pass rate compared to error-free delivery. This indicates that the decrease in gamma pass rate can provide an indication of the error in delivery whereas a clinical decision based on the 3DVH estimated dose-volume metric may lead to an inappropriate decision in the presence of an error in treatment delivery.

Evaluation of the dosimetric accuracy in clinical treatment plans based on the measurement guided dose-volume metrics in patient geometry opens the possibility of making a QA decision about the plan based on reported dose-volume metrics. In this study we systematically studied the reliability of dose-volume metrics reported

by 3DVH software and based on ArcCHECK measurements. Nelms, et al. reported the usability of this system in identifying the TPS model related errors and limitations [12]. In this study we evaluated the performance of 3DVH and the ArcCHECK system by simulating three types of MLC and dose related errors in VMAT plans with different levels of complexity in plan and delivery. The study by Song et al showed that for plans with target volumes < 1 cm diameters the 3DVH estimated dose showed the difference of 1, 5% compared to TPS calculated dose [14]. Our study shows that the PDP estimation used in 3DVH in combination with ArcCHECK measurements appears to have a limitation in detecting MLC and dose errors for relatively simple VMAT plans. For the conformal arc plan of simple spherical volume the gantry angle independent MLC errors were not detected based on D95 estimated by 3DVH. For gantry angle dependent MLC errors the 3DVH estimation showed very minimal change in D95 with 7 mm MLC error. In the case of clinical prostate plans the 3DVH estimated PTV D95 showed no change in gantry angle independent and dependent MLC error scenario whereas TPS estimation showed clinically significant change in the D95 for errors above 3 mm (Figure 4). In general H&N VMAT plans are more complex both in plan and delivery. The LT-MCSv of the studied plans suggests that the H&N plans considered in this study is far more complex than simple conformal arc and prostate VMAT plans. The 3DVH and ArcCHECK combination seems to detect the delivery errors reasonably well compared to simple plans. For H&N plans the 3DVH estimated D95 agreed well with the TPS estimation in both gantry angle independent and dependent MLC error scenarios (Figure 5). Even in H&N plans the spinal cord D2cc estimated by PDP showed negative correlation with TPS and for gantry angle dependent MLC and dose errors the change in D2cc with errors were relatively less compared to TPS (Figure 5). This study shows the inherent limitation in the accuracy of 3DVH estimated DVH metrics for clinical plans with different complexity levels.

For the VMAT plans, even though the 3DVH calculated DVMs did not effectively identify the presence of errors, the 3D gamma comparison analysis of the TPS and 3DVH calculated dose matrices showed a decrease in gamma pass rate with errors (Figure 3, Figure 6 and Figure 7). In the clinical utilisation of 3DVH it is important to consider the gamma analysis results of the 3D dose matrices and compliance of the gamma pass rate with clinical site specific minimum pass rate. Our study indicates that making decisions on clinical acceptance of the treatment delivery purely based on the 3DVH calculated DVM might result in missing the presence of clinically significant errors in treatment delivery. In our study all the treatment plans were generated using Pinnacle TPS. The complexity level of the VMAT plans generated by the commercial TPSs for the same clinical sites might vary due to variations in the implementation of VMAT plan optimisation techniques in TPS. Future work will consider the performance of 3DVH in identifying delivery errors in treatment plans generated by different commercial TPS and for other treatment sites.

Conclusion

In complex H&N VMAT plans the 3DVH estimated D95 of PTVs showed relatively good correlation with the TPS estimation for the error scenarios considered in this study. Estimations of dose volume metrics for clinically relevant structures for relatively simple prostate VMAT plans as determined by 3DVH based on ArcCHECK measurements displayed limitations. The 3DVH estimated dose-volume metrics did not show clinically significant changes in D95 for the prostate PTV with user introduced errors in delivery whereas the TPS estimation showed a noticeable change in D95 for these errors.

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References

1. Ezzell GA, Galvin JM, Low D, Palta JR, Rosen I, et al. (2003) Guidance document on delivery, treatment planning, and clinical implementation of IMRT: report of the IMRT Subcommittee of the AAPM Radiation Therapy Committee. Med Phys 30: 2089-2115.
2. Stasi M, Bresciani S, Miranti A, Maggio A, Sapino V, et al. (2012) Pretreatment patient-specific IMRT quality assurance: a correlation study between gamma index and patient clinical dose volume histogram. Med Phys 39: 7626-7634.
3. Low DA, Dempsey JF (2003) Evaluation of the gamma dose distribution comparison method. Med Phys 30: 2455-2464.
4. Carrasco P, Jornet N, Latorre A, Eudaldo T, Ruiz A, et al. (2012) 3D DVH-based metric analysis versus per-beam planar analysis in IMRT pretreatment verification. Med Phys 39: 5040-5049.
5. Nelms BE and Simon WE (2011) Radiation therapy plan dose perturbation system and method. Google Patents.
6. Feygelman V, Zhang GG, and Stevens CW (2010) Initial dosimetric evaluation of SmartArc-a novel VMAT treatment planning module implemented in a multi-vendor delivery chain. J Appl Clin Med Phys 11: 3169.
7. Masi L, Doro R, Favuzza V, Cipressi S, Livi L (2013) Impact of plan parameters on the dosimetric accuracy of volumetric modulated arc therapy. Med Phys 40: 071718.
8. Arumugam S, Xing A, Young T, and Holloway L (2015) Sensitivity of a helical diode array dosimeter to Volumetric Modulated Arc Therapy delivery errors. Phys Med 31: 1043-1054.
9. Arumugam S, Xing A, Young T, Thwaites D, Holloway L (2016) Comparison of three commercial dosimetric systems in detecting clinically significant VMAT delivery errors. Phys Med.
10. Arumugam S, Xing A, Goozee G, and Holloway L, (2013) Detecting VMAT delivery errors: A study on the sensitivity of the ArcCHECK-3D electronic dosimeter. Journal of Physics: Conference Series 444: 012019.
11. Feygelman V, Zhang G, Stevens C, Nelms BE (2011) Evaluation of a new VMAT QA device, or the "X" and "O" array geometries. J Appl Clin Med Phys 12: 3346.
12. Nelms BE, Chan MF, Jarry G, Lemire M, Lowden J, et al. (2013) Evaluating IMRT and VMAT dose accuracy: practical examples of failure to detect systematic errors when applying a commonly used metric and action levels. Med Phys 40: 111722.
13. Nelms BE, Zhen H, Tomé WA (2011) Per-beam, planar IMRT QA passing rates do not predict clinically relevant patient dose errors. Med Phys 38: 1037-1044.
14. Song JH, Shin HJ, Kay CS, Son SH (2015) Dosimetric verification by using the ArcCHECK system and 3DVH software for various target sizes. PLoS One 10: e0119937.