Quantified VMAT plan complexity in relation to measurement-based quality assurance results

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INTRODUCTION

Volumetric modulated arc therapy (VMAT) can be used to deliver highly conformal doses via dynamic multileaf collimator (MLC) movement, as well as variable dose rate and gantry speeds. However, these sources of modulation can contribute to uncertainties in dose delivery.[1]

Measurement-based dose verification is generally regarded as the most accurate method of assessing delivery accuracy,[1] though quantifying plan complexity via complexity metrics has been shown to indicate the degree of dose agreement. For this study, MLC movement was believed to be a significant contribution to dose uncertainty. As such, aperture-based complexity metrics were investigated.

MOTIVATION

Complexity metrics have generally been shown to be capable of predicting quality assurance results. However, variations in treatment planning systems, delivery systems, and measurement tools between institutions require that investigations of complexity metrics are done by each individual institution. While exact results cannot be directly adopted, the methodology can be replicated to yield pre-treatment quality assurance tools specific to a given institution.

METHOD

VMAT Plans

- 93 VMAT plans redelivered on Varian TrueBeam linac
- 91 VMAT plans redelivered on 2 beam-matched Varian TrueBeam STx linacs
- Generated using Pinnacle3 (v9.10)
- Delivered at 600 MU/min, 6 MV

Quality Assurance (QA)

- Measurements collected using a 2D planar ion chamber array (MatriXX Evolution)
- Gamma analysis performed at 3%/2mm and 2%/2mm to compare measured and planned dose distributions
- 10% dose threshold was used
- Tolerance level was set to 95%

Analysis Methods

- Correlation analysis performed using Spearman's rho
- ROC analysis used to identify threshold values for complexity metrics to predict QA results

RESULTS

Results found on the TrueBeam linac were similar to those found on the TrueBeam STx linacs. Extensive results can be found in Nguyen and Chan.[2]

Gamma Passing Rate (GPR)

When using the 2%/2mm criterion, 78 of 93 plans delivered on the TrueBeam and 86 of 91 plans delivered on TrueBeam STx linacs yielded GPRs greater than the tolerance limit. Figures 1(a) and 1(d) depict the distribution of GPRs for the TrueBeam and TrueBeam STx linacs respectively.

Correlation Analysis

Complexity metrics generally yielded weak to moderate correlations to the GPR at 2%/2mm, with corresponding correlation coefficients of $0.3 \leq |r| \leq 0.6$. Figures 1(b-c), and 1(e-f) show example correlations using the TrueBeam and TrueBeam STx linacs respectively.

ROC Analysis

Table 1 summarizes capability of complexity metrics to predict QA results on the TrueBeam and TrueBeam STx linacs. Threshold values were taken to guarantee a false positive rate less than 10%. The corresponding ROC curves for the TrueBeam and TrueBeam STx are depicted in Figures 2 and 3 respectively.

Complexity Metric	TrueBeam			TrueBeam STx		
	Threshold	TPR[a] (%)	FPR[b] (%)	Threshold	TPR (%)	FPR (%)
MU Factor (MU/cGy)[3]	3.62	27	6	4.23	20	0
Aperture Irregularity[4]	11.07	53	9	9.82	20	9
Modulation Complexity Score[5]	0.30	33	4	0.32	40	3
Average Field Width (cm)[6]	2.46	27	8	1.88	60	8
Small Aperture Score (10 mm)[3]	0.32	47	5	0.34	60	9

Table 1: Summary of classification performance of complexity metrics to identify highly modulated. Higher true positive rate indicates better performance.
a. TPR – True Positive Rate
b. FPR – False Positive Rate

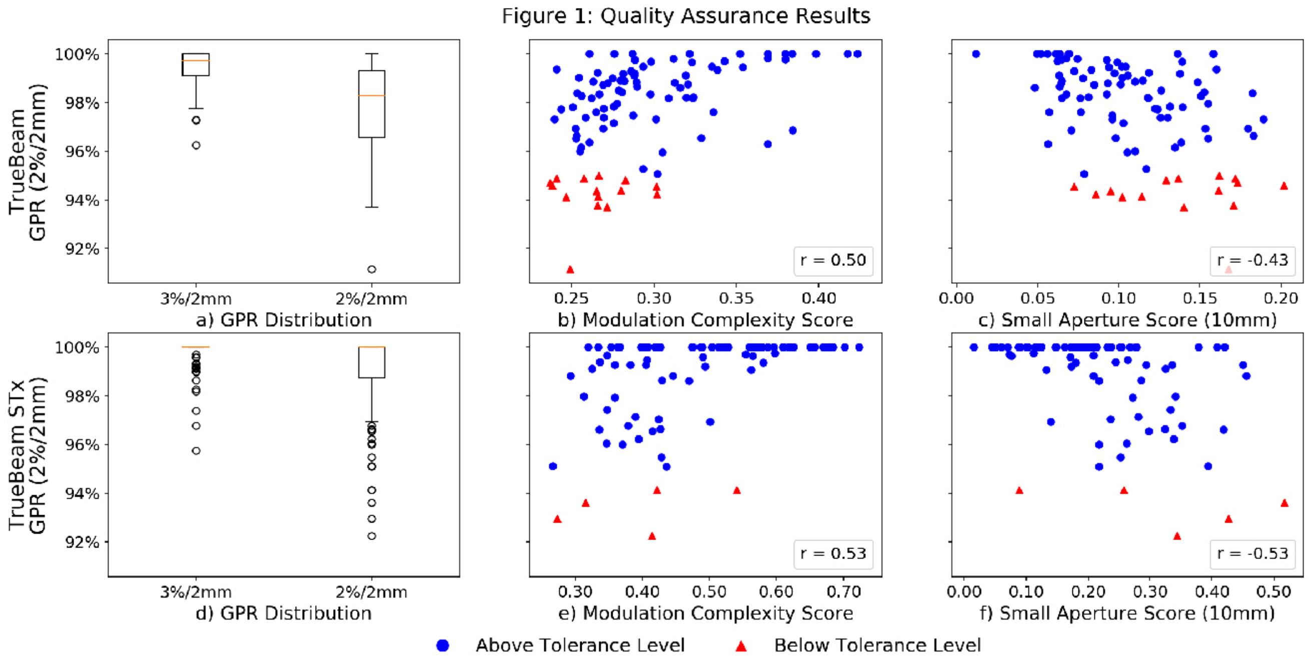

Figure 1: Distributions of Gamma Passing Rate (GPR) on TrueBeam linac (a) and TrueBeam STx linacs (d) shown as boxplots. Example correlations of complexity metrics to GPR on TrueBeam linac (b-c) and TrueBeam STx linacs (e-f) with Spearman's correlation coefficient shown.

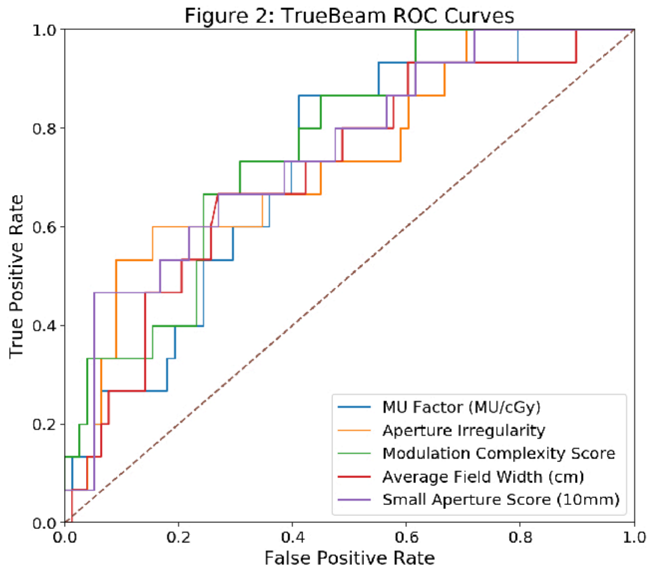

Figure 2: Example ROC curves for VMAT plans delivered on TrueBeam linac. Diagonal line represents random classification performance.

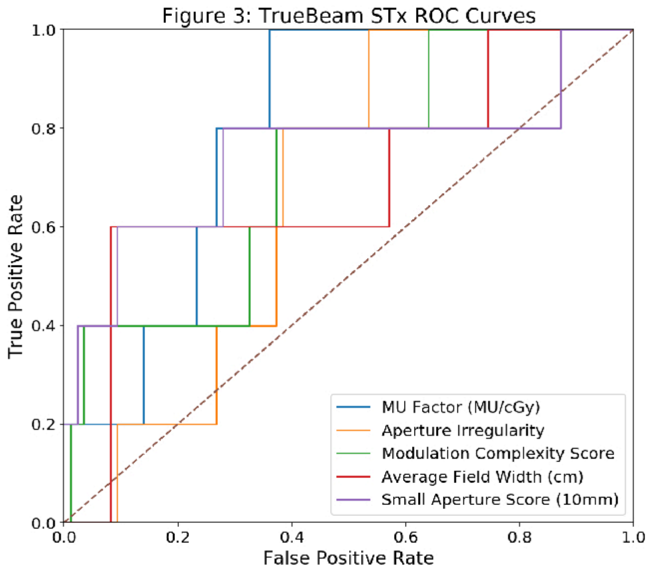

Figure 3: Example ROC curves for VMAT plans delivered on TrueBeam STx linacs. Diagonal line represents random classification performance.

CONCLUSIONS

Complexity metrics have been found to be able to predict QA results. As such, complexity metrics can see potential use as pre-treatment quality assurance tools to compliment measurement-based quality assurance practices. The ability to identify highly modulated plans allows for plan evaluations prior to physics check, and reduces the need for dose verification measurements.

Most complexity metrics showed weak to moderate correlations to the GPR, where extreme values may indicate a larger disagreement between the planned and delivered dose distributions. In addition, ROC analysis found that complexity metrics are able to predict QA results to varying extents.

This work investigated treatment plans that had been deemed suitable for delivery. As such, future works should incorporate treatment plans considered unsuitable for clinical use, as well as plans with artificial constraints on modulation.

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