Volumetric Modulated Arc Therapy dose delivery evaluation using the Radiological Physics Center head and neck phantom

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Introduction

Volumetric Modulated Arc Therapy (VMAT) is a radiotherapy technique that delivers intensity modulated treatments while simultaneously rotating the gantry. The simultaneous gantry rotation and dynamic MLC movement add an additional level of complexity to both the dose calculation and delivery of VMAT treatments compared to static gantry IMRT.

Because of the large number of variables available for manipulation in VMAT treatments, it has the potential to generate plans of equal or better quality than IMRT. Treatment planning studies are necessary to determine if VMAT techniques can generate plans of comparable quality to IMRT, especially for more complex treatment geometries, such as those encountered in head and neck cancers, where target volumes are in close proximity to normal tissues.

The accurate delivery of a planned treatment is an essential component of quality assurance and must be verified through measurements. Such verifications are especially relevant for complex treatment geometries. The Radiological Physics Center (RPC) has an established protocol to validate the dose delivered by complex treatment techniques, such as IMRT, using an anthropomorphic phantom.

Fig. 1. RPC IMRT head and neck phantom with its insert removed and both halves of the insert separated

Purpose

In this project, we evaluated the plan quality of two VMAT techniques, Elekta VMAT planned with Pinnacle[3] SmartArc and delivered on an Elekta Synergy and Varian RapidArc delivered on a Varian Clinac iX, for a complex head and neck phantom radiotherapy treatment and compared the treatment plans to the current standard of care, IMRT.

Additionally, the delivery accuracy of the calculated doses for the two VMAT treatments, Elekta VMAT and RapidArc, and IMRT treatments were evaluated using the protocol established by the RPC for head and neck IMRT.

Head and Neck Phantom

The RPC head and neck phantom (Figure 1) has an insert (Figure 2) with two simulated planning treatment volumes (PTVs) and a simulated organ at risk (OAR) structure representing the spinal cord. The primary PTV wraps around the spinal cord OAR volume.

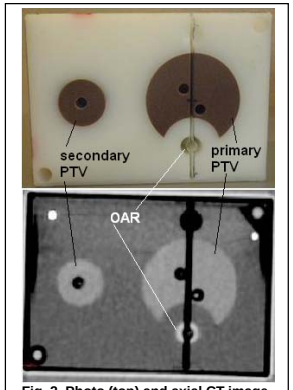

Fig. 2. Photo (top) and axial CT image (bottom) of phantom insert showing the PTVs and OAR

The phantom insert includes TLD (four in the primary PTV, two in the secondary PTV, and two in the OAR) and radiochromic films in the axial and sagittal planes bisecting the primary PTV. The phantom is filled with water.

Methods

Clinically relevant treatment plans were created for the RPC H&N phantom from typical prescription and dose constraints for Elekta VMAT planned with Pinnacle[3] Smart Arc, and RapidArc and IMRT planned with Eclipse. The treatment plans were evaluated to determine if they were clinically comparable using several dosimetric criteria, including ability to meet dose objectives, conformity index (CI) and homogeneity index (HI).

$$CI = \frac{V_{prescrip}}{V_{PTV}} \quad \text{Eq. 1} \qquad HI = \frac{D_{5\%}}{D_{95\%}} \quad \text{Eq. 2}$$

$V_{prescrip}$ is the total volume of tissue receiving the prescription dose and V_{PTV} is the volume of the PTV structure. $D_{5\%}$ is the dose delivered to the hottest 5% of tissue and $D_{95\%}$ is the minimum dose received by 95% of the tissue, both obtained from the plan's DVH.

The dose delivery accuracy of the Elekta VMAT, RapidArc and IMRT treatments were evaluated using RTOG criteria used by the RPC to credential institutions to participate in clinical trials. Absolute doses and relative dose distributions were measured with TLD and radiochromic film, respectively. The treatments were delivered to the phantoms three times.

The measured and calculated doses for each treatment plan were compared to determine if they were clinically acceptable based upon dose differences and distance-to-agreement. The TLD point dose measurements in the PTVs were compared with the dose calculated at each point by the treatment planning systems. The ratio of the measured dose to the calculated dose must be within ±7%. Dose profiles were taken in the posterior-to-anterior direction from the axial film and compared with the calculated dose distribution along that line. The measured penumbra of the dose falloff on the posterior of the primary PTV must be within 4 mm of the calculated penumbra.

A gamma analysis was also performed using acceptability criteria of ±7%/4 mm. The percent of points passing this analysis was compared with the average of 452 institutions evaluated by the RPC for credentialing using the head and neck phantom.

Results

The DVH resulting from each plan is shown in Figure 3. All plans were able to meet the objectives set by the RPC (data not shown).

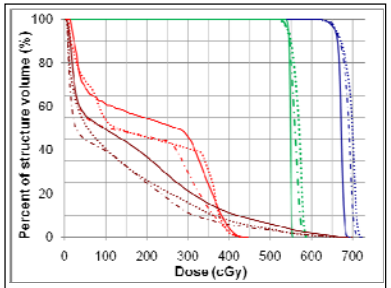

Fig. 3. DVHs of the primary PTV (blue), secondary PTV (green), OAR (red), and normal tissue (brown) for the Elekta VMAT (solid), RapidArc (dotted), and IMRT (dashed) treatment plans

The CI for the primary PTV and the HI for both PTVs are shown in Table 1 for all three treatment plans. Lower values of CI and HI indicate more conformal or more homogenous dose distributions.

Table 1. Conformity index (CI) and homogeneity index (HI) for all three treatment techniques

	Elekta VMAT	RapidArc	IMRT
CI (primary PTV)	1.08	1.02	1.01
HI (primary PTV)	1.04	1.08	1.07
HI (secondary PTV)	1.02	1.07	1.06

When comparing the measured and calculated doses, all three treatment plans met the RPC ±7%/4 mm criteria for credentialing.

The point dose measurements of the six TLD in the PTVs were all within 5.2% of the dose calculated by the treatment planning systems for all treatment deliveries.

The average of the ratios at the six TLD locations evaluated per treatment delivery are shown below in Table 2 for both treatment types. The single greatest deviation of the measured dose from calculation is also reported for each treatment delivery.

The measured penumbra for all three treatment deliveries of all treatment plans were within 3.5 mm of the calculated penumbra.

Table 2. Average and greatest deviation of the ratios (measured/calculated dose) of the six TLD positions

Treatment	Ratio	Delivery 1	Delivery 2	Delivery 3
Elekta VMAT	Average	0.96	0.97	0.97
	Greatest deviation	0.95	0.95	0.97
RapidArc	Average	1.03	1.04	1.04
	Greatest deviation	1.05	1.05	1.05
IMRT	Average	1.02	1.01	1.01
	Greatest deviation	1.03	1.03	1.03

The percent of points passing the gamma analysis for each treatment delivery and their average is shown below in Table 3. The percent of points passing was on average better for all three treatments in comparison with the average percent passing of all institutions evaluated, 87%[7].

Table 3. Percent of points passing a gamma analysis for all three treatment deliveries of each plan and the overall average

Treatment	Delivery 1	Delivery 2	Delivery 3	Average
Elekta VMAT	84%	89%	92%	88%
RapidArc	92%	91%	87%	90%
IMRT	94%	97%	98%	96%

Conclusions

Treatment plan quality of the Elekta VMAT, RapidArc and IMRT treatments were comparable for consistent dose prescriptions and constraints. The Elekta VMAT plan, planned with Pinnacle[3] SmartArc, was more homogenous but less conformal than RapidArc and IMRT, which were planned with Eclipse. Additionally, the dosimetric accuracy of the Elekta VMAT and RapidArc treatments was verified to be within acceptable tolerances.

References

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