Benchmarking Techniques for Stereotactic Body Radiotherapy to Early-Stage Glottic Laryngeal Cancer: LINAC-Based Non-Coplanar VMAT Vs. Cyberknife Planning

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Introduction and Purpose

SBRT for glottic larynx cancer has recently been proposed as an alternative treatment regimen, with improved patient convenience and cost savings. The hypo-fractionation scheme could also improve local control rates, especially for high-risk primaries at the T2 stage. A recent clinical trial study on larynx SBRT has accumulated encouraging results[1]. However, the study is based on the robotic Cyberknife system, which is not as widely available as the conventional L-shaped LINAC systems. This study is performed to evaluate the feasibility of designing non-coplanar VMAT plans on the LINAC systems to achieve similar dosimetric endpoints as the Cyberknife plans, thus rendering the Larynx SBRT more accessible to the general radiotherapy community.

Materials and Methods

10 patients diagnosed of cTis-T2N0M0 glottic larynx carcinoma were studied. All patients have been planned and treated on the Cyberknife system with a prescribed dose of 42.5Gy/5 fractions to the involved hemilarynx. For Cyberknife, plans were delivered using fixed-cones due to small PTVs. For each patient, a five-arc non-coplanar VMAT plan was retrospectively designed in Eclipse™ to evaluate the feasibility of treatments using conventional LINACs. Dose engine was Monte-Carlo for Cyberknife and AcurosXB for Eclipse to achieve accurate dose calculation of PTVs with air cavity, based on evaluations through an in-house wax phantom study.

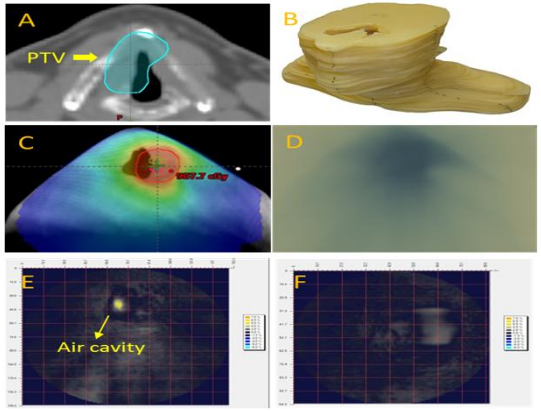

Figure 1. (A). Larynx SBRT PTVs usually involve air cavity, making it challenging for accurate dose calculation. (B). In-house wax larynx phantom used for dose calculation engine verification. (C). Larynx SBRT dose distribution calculated using one dose engine. (D). EBT3 film measurement results. The film was sandwiched in the wax phantom slabs to the slice location of (C). (E). 2D dose analysis using 2%/2 mm criteria for the Eclipse AAA algorithm. (F). 2D dose analysis using 2%/2 mm criteria for the Eclipse AcurosXB algorithm.

It is clear that the AcurosXB algorithm offers higher in-air dose calculation accuracy, and it was selected as the Eclipse dose calculation engine for this study.

To maximize the potential of the PTV coverage and the OAR avoidance, different couch kicks were introduced into the Eclipse arcs to generate non-coplanar VMAT plans. The span of each arc has been optimized to avoid potential collisions during delivery.

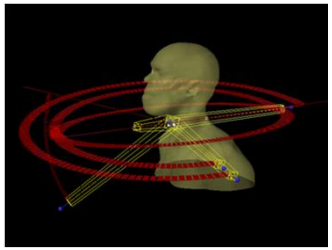

Figure 2. 3D rendering of the non-coplanar VMAT beam configuration. A total of five arcs were used for each patient case with the same beam geometrical setting. The arc number was decided after 'trials-and-errors' to balance both plan quality and delivery time.

Field ID	Technique	Machine/Energy	MLC	Scale	Gantry Rtn [deg]	Coll Rtn [deg]	Couch Rtn [deg]
Arc1	SRS ARC-I	TrueBeam1 - 6X	VMAT	Varian IEC	270.0 CW 179.0	10.0	10.0
Arc2	SRS ARC-I	TrueBeam1 - 6X	VMAT	Varian IEC	90.0 CCW 181.0	350.0	350.0
Arc3	SRS ARC-I	TrueBeam1 - 6X	VMAT	Varian IEC	330.0 CW 20.0	10.0	90.0
Arc4	SRS ARC-I	TrueBeam1 - 6X	VMAT	Varian IEC	330.0 CW 20.0	10.0	90.0
Arc5	SRS ARC-I	TrueBeam1 - 6X	VMAT	Varian IEC	179.0 CCW 181.0	350.0	0.0

Figure 3. Detailed beam configurations for the non-coplanar VMAT plan.

In addition to the beam settings, the same planning objectives and constraints were used for VMAT and Cyberknife planning. Detailed criteria is in Table 1.

Organ	Evaluation	Goal	Unit
PTV	VRx	> 95%	V%
Left/Right Carotid Artery	Dmax*	< 26.9	GY
Spinal Cord	V22	< 0.35	CC
	Dmax*	< 28.0	GY
Skin	Dmax*	< 42.5	GY
Contralateral Arytenoid	V18.3	< 0.1	CC
	Dmax*	< 21.4	GY
Rx to Isodose	RX to isodose	85%~ 95%	%

Table 1. Planning objectives and constraints for both Cyberknife plans and Eclipse plans with a prescription dose of 42.5 Gy/5 fractions.

The dosimetric and clinical efficiency comparisons were performed between the retrospective VMAT plans and the original Cyberknife plans, using metrics including PTV coverage, maximum doses to various OARs (carotid arteries, spinal cord, skin and contralateral arytenoid), R50 (ratio of the 50% isodose volume to the PTV volume), R20 (ratio of the 20% isodose volume to the PTV volume), homogeneity index, conformity index and treatment time estimation. Statistical significance was assessed using the Wilcoxon signed-rank test.

Results

Figure 4. Isodose map comparison between an original Cyberknife plan (designed in MultiPlan™) and the retrospective non-coplanar VMAT LINAC plan (designed in Eclipse).

It is evident in Fig. 4 that non-coplanar VMAT can achieve similar, if not superior, dosimetric endpoints as the Cyberknife plan. The isodose lines of the VMAT plan fit more compactly to the PTV target.

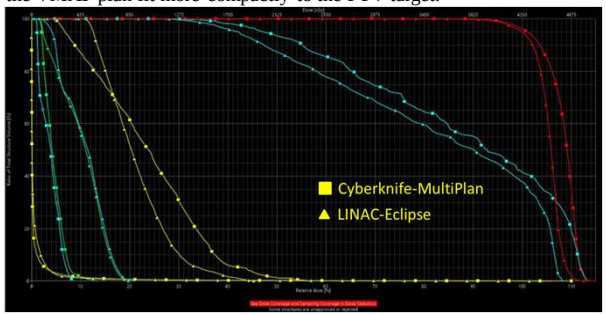

Figure 5. DVH comparison between an original Cyberknife plan and the retrospective non-coplanar VMAT LINAC plan. Similarly, the LINAC plan achieves similar, if not superior, PTV coverage and OAR sparing as compared to the original Cyberknife plan.

Metrics	Cyberknife-MultiPlan	LINAC-Eclipse	P value
D_{max} of Carotid Arteries	13.94	12.58	> 0.4
D_{max} of Spinal Cord	5.79	8.64	< 0.001
D_{max} of Skin	41.47	41.87	> 0.7
D_{max} of Contralateral Arytenoid	18.13	16.16	< 0.01
R_{50}	5.04	5.91	< 0.004
R_{20}	17.48	19.94	< 0.04
Homogeneity Index	1.15	1.08	< 0.01
Conformity Index	1.19	1.17	> 0.35

Table 2. Dosimetric endpoints comparison between LINAC and Cyberknife plans. All the dosimetric values presented here are the average of the 10 patient cases studied.

Quantitatively (Table 2), non-coplanar VMAT achieved comparable dosimetric endpoints to Cyberknife. The average PTV coverages are 95% and 96% for VMAT and Cyberknife, respectively. As shown in Table 2, Cyberknife has better dose sparing on spinal cord; however, both are well below the tolerance of 28Gy (Table 1). VMAT plan has better dose sparing on contralateral arytenoid. In general, the dosimetric results are comparable between the two types of plans, demonstrating the feasibility of treating larynx SBRT patients using conventional L-shaped LINACs.

VMAT uses less than 1/3 of the total MUs of Cyberknife plans and halves average treatment time (~20min vs. 40min, excluding pretreatment setup).

Conclusion

Larynx SBRT can be conducted on either Cyberknife machines or conventional LINACs with dosimetrically equivalent target coverage and similar OAR sparing. Further end-to-end tests including the full-course of setup and intra-fractional imaging are warranted before applying the non-coplanar VMAT techniques into treating larynx patients.

1. D.L. Schwartz, A. Sosa, S.G. Chun, C. Ding, X.J. Xie, L.A. Nedzi, R.D. Timmerman, B.D. Sumer, "SBRT for early-stage glottic larynx cancer-Initial clinical outcomes from a phase I clinical trial," PloS one 12, e0172055 (2017).