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ORIGINAL ARTICLE

Double isocenter optimization with HD-MLC linear accelerator to treat extended fields in patients with head and neck cancers

Yucel Saglam[1], Ugur Selek[1,2], Yasemin Bolukbasi[1,2], Ali Ihsan Atasoy[1], Fatih Karakose[1], Vildan Alpan[1], Eyub Yasar Akdemir[1], Sukran Senyurek[1], Nulifer Kilic Durankus[1], Duygu Sezen[1,2], Ahmet Kucuk[3], Erkan Topkan[4]

[1]Koc University, School of Medicine, Department of Radiation Oncology, Istanbul, Turkey. [2]University of Texas, MD Anderson Cancer Center, Department of Radiation Oncology, Houston, TX, USA. [3]Mersin City Education and Research Hospital, Radiation Oncology Clinics, Mersin, Turkey. [4]Baskent University Medical Faculty, Department of Radiation Oncology, Adana, Turkey.

Summary

Purpose: *For departments with a congested patient burden or with a limited number of eligible LINACs, we investigated whether LINACS dedicated for SRS-SBRT with limited field high-definition (HD) multi-leaf collimator (MLC) could help to carry this load, and utilized a double-isocenter (DI) optimization with a limited field size of HD-MLC to defeat the craniocaudal field size restriction to match treated plans in a wide-field MLC LINAC for head and neck cancer patients.*

Methods: *Fourteen patients with locally advanced head and neck cancers were included, previously treated with simultaneous integrated boost volumetric modulated arc treatment (VMAT) in 33 fractions of clinical target volumes (CTV) of 70Gy, 63Gy, and 57Gy, via single isocenter (SI) plans in Millennium MLC-120 of Varian Trilogy. The DI plans were generated on Pinnacle TPS to be delivered in HD 120 leaves MLC on Varian TrueBeam. The organs at risk (OAR) doses and the prescription volume parameters were compared.*

Results: *DI plans in HD-MLC LINACs were successfully matching the previously treated plans for OAR and CTV constraints. The CI (1.18 versus 1.26; p=0.004) and HI (0.23 versus 0.29; p<0.001) were significantly improved with DI, while the MUs (1321.5 versus 800.3; p<0.001) and the treatment delivery times (6.1 versus 3.7 min; p<0.001) per fraction increased modestly with DI compared to SI, respectively.*

Conclusions: *We revealed that DI optimization plans prepared for HD-MLC could effectively accomplish our goal dosimetrically in locoregionally advanced head and neck cases, despite a modest increase in the MU and treatment delivery times per fraction. This technique may provide an alternative in case of downtimes of standard MLC systems or a standalone treatment machine in case of high volumes requiring extended-field IMRT procedures, or possibly shorten the lengthy waiting times in facilities with limited SRS or SBRT patients.*

Key words: *HD MLC, isocenter, IMRT, VMAT, head and neck*

Introduction

Multi-leaf collimators (MLC) are irreplaceably fundamental parts of all modern linear accelerators (LINACs) which facilitate the beam shaping that fits best to the planning target volume (PTV) and empowers 3-dimensional conformal radiation therapy (RT) [3-DCRT], intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) plans conceivable. Likewise, MLCs are additionally required for both intracranial and extracranial stereotactic radiosurgery (SRS) and stereotactic body radiation therapy (SBRT) applications. Various vendors furnish LINAC frameworks with variable MLC structures in a broadly alterable thickness and width of tungsten leaves and

Corresponding author: Ugur Selek, MD. Koc University, School of Medicine, Department of Radiation Oncology, Koc University Hospital, Davutpaşa Caddesi No: 4, 34010, Topkapi, Istanbul, Turkey.
Tel: +90 537 7243724; Fax: +90 212 537 3112395; Email: ugurselek@yahoo.com
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maximum field sizes fashion [1-3]. Because of the smaller SRS and SBRT target volumes, micro or high-definition MLC (HD-MLC) systems with fine leaf widths are universally fancied to increase the PTV dose conformity by tightening the prescribed dose and related isodose lines to the intended PTVs [4-6]. While the LINAC devices with HD-MLC are assuredly ideal for SRS/SBRT, these LINACs are usually incompetent to enable the treatment of craniocaudally long treatment fields that are past the limits of such LINACs, like the locoregionally advanced head and neck- (HNCs), rectal-, and gynecologic cancers.

Departments with congested patient burden or with limited number of eligible LINACs could frequently require available slots in waiting list for patients with treatment field sizes >20 cm, for sites such as head and neck cancer, and LINACs equipped with small treatment HD MLC fields are expected to help carry this load, as well as to compensate any possible downtime in a workhorse LINAC in these departments, however inability to treat larger fields than their built in maximum field size complicates the situation, and decreases the per day productivity and efficiency of these LINACs. In this background, in order to observe whether these HD MLC limited field LINACS could be dependable, we have evaluated the capability of limited length of 22 cm HD MLC (40 cm x 22 cm) for extended treatment fields of craniocaudally >22 cm treated in standard MLC (40 cm x 40 cm) and have compared double isocenter (DI) optimized treatment plans prepared for HD MLC with previously treated single isocenter (SI) plans dosimetrically in our local regionally advanced head and neck cases.

Methods

Patient Selection

The review board of the University approved the design of the present dosimetric study before the acquisition of any patient information. Written informed consent was provided by each participant, either themselves or legally authorized representatives for publication of their outcomes. Our dosimetric comparison research protocol comprised 14 patients meeting the inclusion criteria, presented with T2-4N2M0 locally advanced nasopharyngeal and oropharyngeal cancers (patient characteristics, Table 1) as per The American Joint Committee on Cancer staging (AJCC) (8th edition), who were planned with the same version of treatment planning system (TPS) and selected out of patients treated for a craniocaudal field size of >22 cm between December 2017 to December 2019. To be qualified, all patients needed to be prescribed simultaneous integrated boost radiotherapy with total doses of 70 Gy, 63 Gy, and 57 Gy to the clinical target volumes (CTV_{70Gy}), CTV_{63Gy}, and CTV_{57Gy} in 33 daily fractions (SIB-IMRT) treatment technique, respectively. All patients in this study were treated with concurrent chemotherapy (single agent cisplatin, 100 mg/m^2, every three weeks). The exclusion criteria for patient selection included clinical N3 neck disease at simulation, any nodal disease abutting skin, nasopharyngeal T4 for intracranial extension, involvement of cranial nerves, orbit, hypopharynx, parotid gland, and oropharyngeal T4 disease. Patients with bulky nodes, larger than 6 cm in greatest dimension, or extension below the caudal border of cricoid cartilage, or overt extranodal extension received induction chemotherapy.

Fixation and imaging procedure

The patients were immobilized in supine position with full head and neck five-point reinforced masks (CIVCO, Kalona, Iowa) fixed to the base plate. The treatment

Table 1. Patient characteristics

Patient	*Primary*	*Age*	*T - stage*	*CTV_{70Gy} volume (cc)*	*CTV_{63Gy} volume (cc)*	*CTV_{57Gy} volume (cc)*
1	NPC	72	T2N2M0	203.8	570.5	168.9
2	NPC	48	T3N2M0	171.7	447.1	109.3
3	NPC	49	T4N3M0	125.1	147.8	505.6
4	NPC	60	T2N2M0	149.6	430.2	148.3
5	NPC	43	T2N2M0	207.1	569.3	279.4
6	NPC	58	T2N2M0	134.9	471.2	169.1
7	NPC	62	T2N3M0	133.5	624.2	110.9
8	NPC	60	T3N1M0	165.5	590.8	193.2
9	NPC	47	T4N3M0	193.8	611.7	233.3
10	OPC	52	T3N2M0	93.6	467.3	295.5
11	OPC	53	T3N2M0	171.4	502.5	274.6
12	OPC	58	T3N2M0	199.4	520.6	209.5
13	OPC	83	T2N2M0	95	242.1	275.2
14	OPC	61	T3N2M0	195.6	544.1	155.6

cc: cm^3, CTVxGy: clinical target volume of x Gy, TNM: tumor-node-metastasis, NPC: nasopharyngeal carcinoma; OPC: oropharyngeal cancer

planning simulation CT scans, using intravenous contrast, with a 3 mm slice thickness and an in-plane pixel size of 1×1 mm^2, were acquired on a Philips Brilliance Big Bore 16 slice CT scanner (Philips Medical Systems Inc., Cleveland, OH).

Target and organ at risk volume delineation

All gross target volumes (GTV) and clinical target volumes (CTV) were delineated by an experienced senior radiation oncologist as per the institutional guidelines in use [8,9], and departmentally peer-reviewed. Fusion contrast enhanced MRI to define the primary GTV was standard for all cases on the same day or ± 2 days of simulation CT.GTV for primary (GTV-P) was determined based on simulation CT, fusion MRI, staging PET-CT, clinical information, and consultation endoscopic findings, GTV for nodal disease (GTV-N) included any grossly involved lymph nodes (>1 cm or nodes with a necrotic center or PET positive).Three CTV volumes were created based on risk definitions; CTV_{70Gy}, covering GTV-P and GTV-N with a margin of 8 mm (as low as 1 mm in close proximity to critical structures

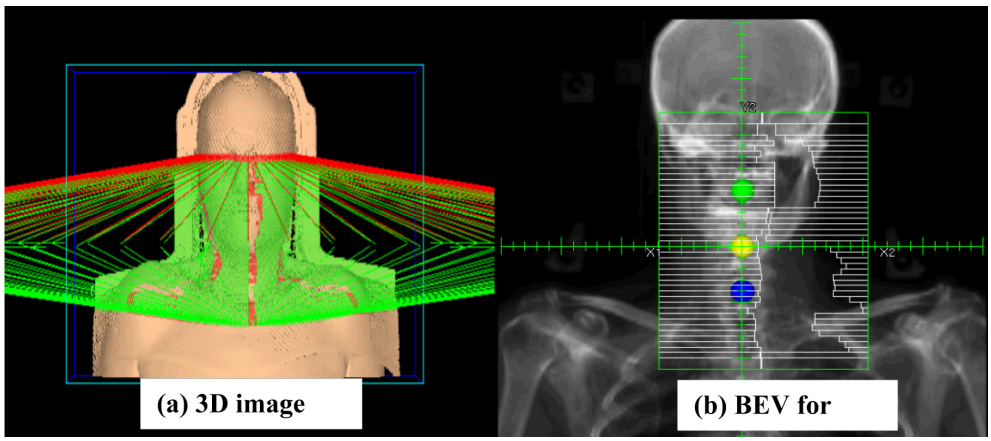

Figure 1. (a) Double full arcs on SI with ML MLC linear accelerator on a body, and **(b)** the concept of SI arcs with BEV of VMAT beams on an example patient (182°-178° and 178°-182° on isocenter) on center-axial slice. The yellow color point is isocenter and junction marker for DI. CTV: clinical target volume, DI: double isocenter, HD: high-definition, ML: millennium, MLC: multi-leaf collimator, SI: single isocenter, VMAT: volumetric modulated arc therapy.

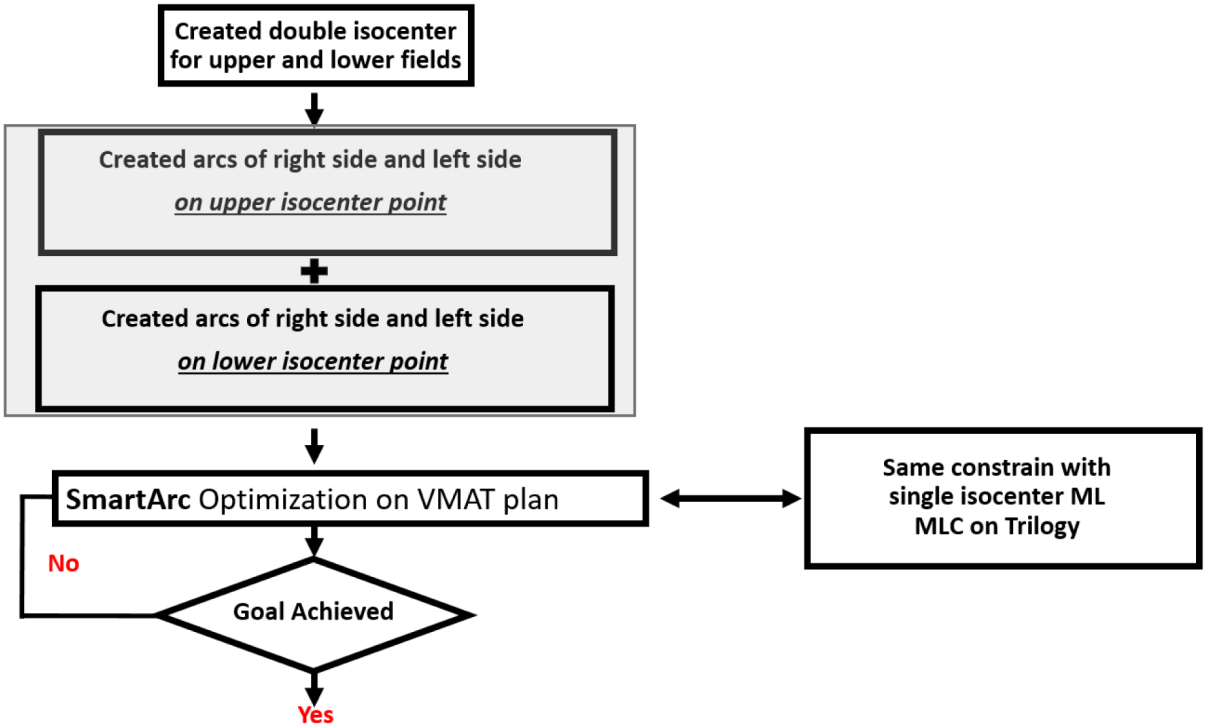

Figure 2. A study strategy of DI optimization. CTV: clinical target volume, DI: double isocenter, ML: millennium, MLC: multi-leaf collimator, SmartArc optimization: to create rotational intensity-modulated radiation therapy, VMAT: volumetric modulated arc therapy.

such as chiasm, brain stem etc.) given circumferentially around the GTV; CTV_{63Gy}, high risk for subclinical disease including microscopic disease and potential routes of spread for primary and nodal tumor; and CTV_{57Gy}, the lower risk subclinical disease such as low anterior neck. Based on our protocol, nodal CTVs are relatively generous including some muscle outside of the nodal fat plane (not trimmed from muscle) to provide much of the setup error to be "built in" to the CTV contour drawn [8,9]. Our institutional standard PTV for VMAT contained automated 0.4cm circumferential expansion of the all CTV surfaces to create PTV_{70Gy}, PTV_{63Gy}, and PTV_{57Gy}, modified at base of the skull if necessary, in order to account for the patient setup errors.

LINAC configuration

The Varian Trilogy LINAC (Varian Medical Systems, Palo Alto, CA) is equipped with the Millennium MLC of 120 leaves with a minimum leaf width of 0.5 cm and a maximum field size of 40 cm x 40 cm. Completed treatments were delivered by using VMAT technique of 2 full arcs (182-178 and 178-182) in ML MLC of Varian Trilogy (Maximum fields size is 40x40). The TrueBeam LINAC (Varian Medical Systems, Palo Alto, CA) is equipped with a 'high definition' 120-leaf HD-MLC which typically features two banks of 60 tungsten leaves; the central 8 cm is comprised of 32×0.25 cm wide leaves being projected at the isocenter, and the outer 14 cm is comprised of 28×0.50 cm wide leaves, revealing a maximum of 22.0 cm MLC defined field length perpendicular to leaf motion at 100 cm from the X-ray source [7].

VMAT treatment planning

The VMAT plans were carefully designed for each patient on the Philips Pinnacle Treatment Planning System 9.10 (Philips Medical Systems Inc., Cleveland, OH) via a collapsed cone convolution (CCC) algorithm. Two full arcs on single isocenter (SI)-VMAT treatment plans were delivered on Varian Trilogy (Varian Medical Systems, Palo Alto, CA) with a maximum dose rate of 600 MU/min. We constructed four quatro full arcs on double isocenter (DI)-VMAT treatment plans to be theoretically delivered on Varian TrueBeam (Varian Medical Systems, Palo Alto, CA) with a maximum dose rate of 600 MU/min. A grid size of 0.3×0.3×0.3 cm^3 was employed for all required calculations. All DI plans were generated by an experienced senior medical radiation physicist (YS) and departmentally peer-reviewed according to the institutional guidelines [8,9].

Single isocenter (SI) with ML MLC on Trilogy

The treated VMAT plans were generated according to our institutional clinical practice standards which dictate two full arcs with a single isocenter rotating clockwise and counter-clockwise starting from the respective 182° and 178° gantry angles. Multiple control points for 178 segments in two full arcs were created using the Smart Arc optimization algorithm in the Pinnacle treatment planning framework, specified as the gantry speed, dose rate, total delivery time, and the leaf travel speed. The same dose objectives and weightings were utilized for the DI optimization technique with four quatro arcs. 3D image reconstruction and schematic diagram of the concept of two full arcs VMAT with 182°-178° beam eye view (BEV) on the axial slice of an exemplified patient are as portrayed in Figure 1.

Double isocenter (DI) with HD MLC on TrueBeam

The DI optimization technique typically relies upon the four quatro full arc foundation, which necessitates the simultaneous optimization of the four arcs in use. Four quatro arcs created on DI were used in our present dosimetric research without sum by including them in the treatment planning flow under the optimization procedure. The treatment planning flow-chart utilized herein for the DI optimization technique was as displayed in Figure 2. The DI optimization strategy incorporated two steps: First, the definition of the two separate PTVs with their own isocenters for 2 arcs to a total of 4 arcs, and second, the optimization of four VMAT arcs with the DI technique quatro, respectively.

For each plan, the original single isocenter was carefully placed to precisely divide the original PTV into two separate PTV fields: PTV superior (PTVs) and PTV inferior (PTVi), respectively. Then the new isocenters for the DI plan were set in the craniocaudal direction just in the middle of PTVs and PTVi. After creating the DI, clockwise and counterclockwise arcs for each of the PTVs and PTVi were generated for the operational plan to a grand total of 4 arcs.

The SmartArc optimizations for quatro arcs were succeeded simultaneously using the identical OAR constraints and normalization volumes to achieve the same PTV coverage used in the SI technique in the original Pinnacle plan. Then the final dose calculation was performed by employing the CCC algorithm in Pinnacle TPS just following the fulfillment of the predetermined endpoint. The typical 3D image reconstruction and BEVs of the concept of DI optimization with the respective arc beams of 182°-178° and 178°-180° on digitally reconstructed radiography (DRR) of a representative patient were as displayed in Figure 3.

Dosimetric comparisons

All plans were normalized to at least 95% of the volume of PTV_{70Gy} to be covered by the 70 Gy isodose surface and 99% of PTV_{70Gy} needs to be at or above 65.1 Gy. Plan evaluation was due to expected coverage of PTV_{70Gy}, but allow slight underdosing of PTV_{63Gy} and PTV_{57Gy} due to much of the setup error to be "built in" to the CTV contour drawn, receiving at least >93% of prescribed dose, while CTV_{63Gy} and CTV_{57Gy} are expected to receive at least 98% of the prescribed dose.

The primary goal during planning and comparison was defined as similar CTV coverage for all approaches as defined above, while, the secondary goal constituted the mean dose to the total parotid glands (left + right) <26 Gy; and the dose maximum (D_{max}) to the spinal cord <45 Gy, brainstem <54 Gy, optic chiasma <54 Gy, mandible <70 Gy, larynx $V_{2/3}$<50 Gy (2/3 volume of larynx receiving 50 Gy), each optic nerves <54 Gy, each eye ball, each lens <5 Gy, and each cochlea <35 Gy, separately.

The competing DI and SI treatment plans were comparatively analyzed concerning the initial treatment planning OAR constraints for each patient, including the D_{max} for the spinal cord, brainstem, optic chiasm, left and right optic nerves, left and right globes (or eyeballs), left and right lens, left and right cochlea, bony mandible; the D_{mean} for the total parotids; and V50 Gy for the 2/3 of the larynx. The coverage of all target volumes (CTV_{70Gy} - CTV_{63Gy} - CTV_{57Gy}) including $D_{98\%}$ Gy as minimum dose, $D_{2\%}$ Gy as $_{max}$imum dose, D_{mean} Gy as mean dose, the conformity index (CI) as recommended by RTOG, and the homogeneity index (HI) as recommended by ICRU 83 were compared. The CI 95 was calculated as the ratio between the volume enclosed by the 95% isodose (V_{95}) line and the target volume (TV) receiving >95% (CI = V95% / TV 95%). The 95% isodose was chosen according to the ICRU62, to provide 95% TV coverage. The HI was calculated as [HI = ($D_{2\%}$–$D_{98\%}$) / D 50%], according to the ICRU 83 definition. Monitor units (MU) and delivery time per fraction (seconds) of the two techniques were also compared.

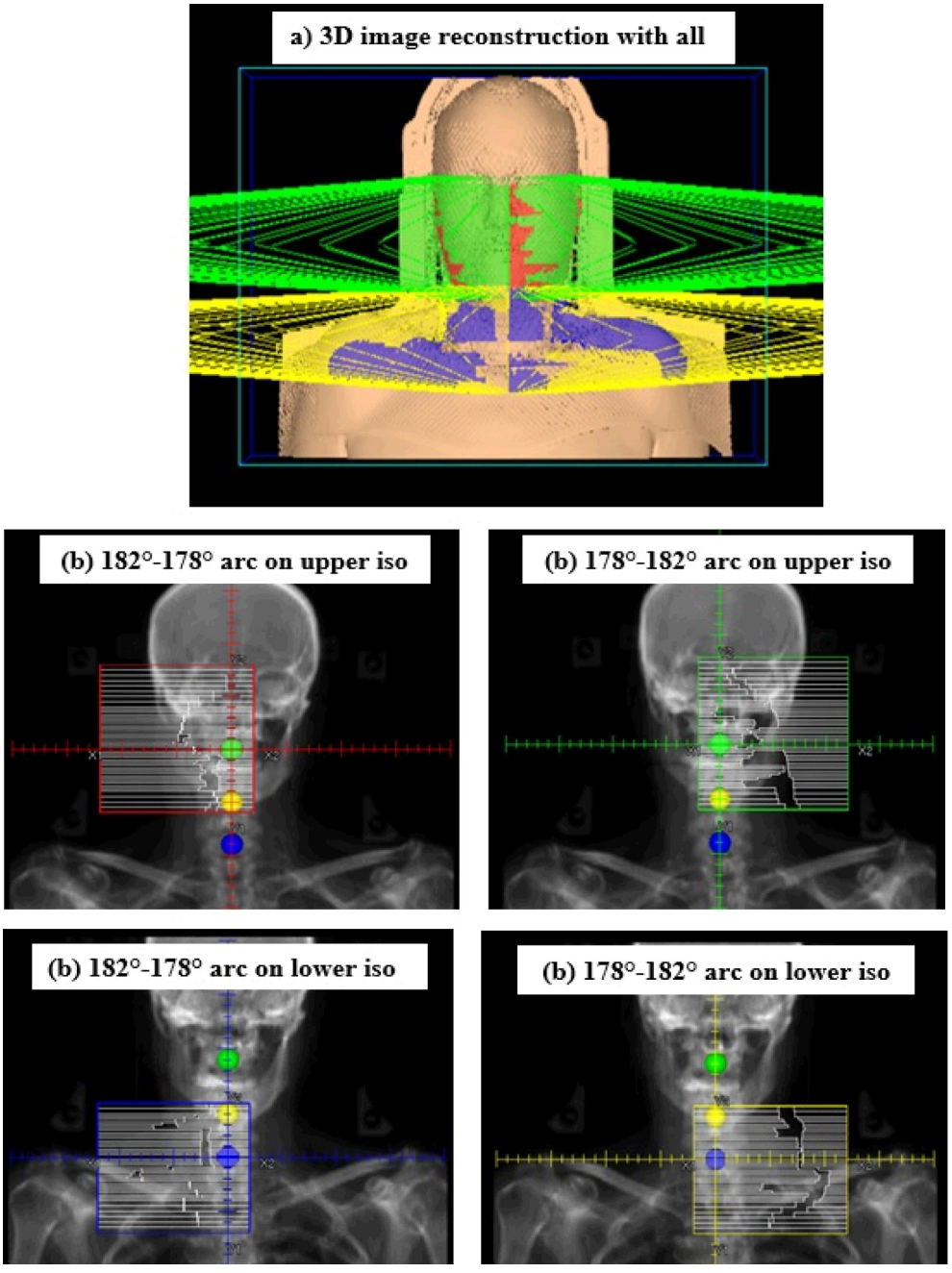

Figure 3. (a) DI arcs with HD MLC linear accelerator on a body, and **(b)** the concept of DI arcs with BEV of VMAT beams on an example patient (182°-178° and 178°-182° on upper isocenter, 182°-178° and 178°-182° on lower isocenter) on DRR. The green color point is upper isocenter, the blue color point is lower isocenter, the yellow color point is junction marker. DI: double isocenter, DRR: digitally reconstructed radiograph, HD: high-definition, MLC: multi-leaf collimator, VMAT: volumetric modulated arc therapy.

Statistics

Mann Whitney-U statistics were preferred for the comparisons among the results of the DI-Truebeam-HD MLC and SI-Trilogy-ML MLC. A value of $p<0.05$ was considered to indicate a statistically significant difference.

Results

The CTV coverage, CI, HI, per fraction treatment time and MUs are detailed in Table 2. Per plan-based analyses revealed that all plans were clinically acceptable in terms given criteria. Comparative analyses between the SI and DI techniques exhibited statistically no significant difference between the CTV minimum dose ($D_{98\%}$), CTV maximum dose ($D_{2\%}$), and D_{mean} parameters; while both the CI (1.18 versus 1.26; p=0.004) and HI (0.23 versus 0.29; p= 0.021). The MU per fraction (1321.5 versus 800.3 MU for SI; p<0.001) and the resultant per fraction treatment delivery time (6.1 versus 3.7 min; p<0.001) were increased significantly with the DI technique, as expected.

Table 2. Plan quality parameters SI and DI plans (mean ± std. dev.)

Factor	*Single isocenter*	*Double isocenter*	*p value*
CTV_{70Gy}			
D_{mean}	74.0 ± 1.3	73.5 ± 0.8	0.270
$D_{98\%}$	69.2 ± 1.0	69.1 ± 0.8	0.963
$D_{2\%}$	74.4 ± 0.7	73.7 ± 1.0	0.063
CTV_{63Gy}			
D_{mean}	64.9 ± 1.5	64.3 ± 1.3	0.105
$D_{98\%}$	62.1 ± 1.0	62.2 ± 0.9	0.730
$D_{2\%}$	65.4 ± 1.7	64.8 ± 1.5	0.051
CTV_{57Gy}			
D_{mean}	58.0 ± 1.5	57.6 ± 1.5	0.141
$D_{98\%}$	56.0 ± 0.8	56.2 ± 0.7	0.290
$D_{2\%}$	60.6 ± 1.9	60.5 ± 1.9	0.565
Treatment time (min/fx)	3.7 ± 0.2	6.1 ± 0.2	<0.001
Monitor units	800.3 ± 67.1	1321.5 ± 80.0	<0.001
CI	12.6 ± 0.1	1.18 ± 0.1	0.004
HI	0.29 ± 0.1	0.23 ± 0.1	0.021

CTV: clinical target volume, Gy: Gray, D_{mean}: mean dose, Dx%: dose on X%, min/fx: minute of per fraction, CI: conformity index, HI: homogeneity index

Table 3. Dosimetric results for organs at risk according to SI and DI techniques (mean ± std. dev.)

Organ at risk	*Single isocenter*	*Double isocenter*	*p value*
Spinal cord D_{max} (Gy)	41.6 ± 2.5	41.8±3.3	0.783
Brainstem D_{max} (Gy)	47.6 ± 6.4	46.0±5.9	0.260
Optic chiasma D_{max} (Gy)	33.1±17.9	32.1±17.7	0.613
Right optic nerve D_{max} (Gy)	32.6 ± 15.3	30.8 ± 16.1	0.476
Left optic nerve D_{max} (Gy)	32.3 ± 15.6	31.0 ± 16.0	0.646
Right eye ball D_{max} (Gy)	19.3 ± 10.8	18.4 ± 10.4	0.730
Left eye ball D_{max} (Gy)	21.5±13.9	20.4±13.0	0.748
Right lens D_{max} (Gy)	5.6 ± 3.0	5.6 ± 3.2	0.854
Left lens D_{max} (Gy)	5.5±2.8	5.4±2.7	0.963
Right parotid D_{mean}(Gy)	24.4 ± 1.3	23.0 ± 2.2	0.046
Left parotid D_{mean}(Gy)	24.3 ± 1.5	23.0 ± 1.8	0.056
Total parotid D_{mean}(Gy)	24.4± 1.9	23.0± 2	0.052
Right cochlea D_{max} (Gy)	25.9 ± 10.0	24.2 ± 9.3	0.435
Left cochlea D_{max} (Gy)	24.0±8.4	22.0±7.9	0.232
Mandible D_{max} (Gy)	68.2 ± 2.0	67.6 ± 2.0	0.505
Larynx $D_{V2/3}$ (Gy)	47.4 ± 3.1	44.7 ± 2.9	0.013

D_{max}: maximum dose, D_{mean}: mean dose, Gy: Gray, $D_{V2/3}$: dose on 2/3 of volume

Likewise, the dosimetric outcomes of the target volume, the comparisons between the OAR doses of two techniques revealed that both plans were overall in satisfying the predetermined OAR dose constraints (Table 3). Of note, although the DI plans appeared to serve better right parotid D_{mean} (23.0 versus 24.4 Gy for SI; p=0.04) and laryngeal $D_{V2/3}$ (44.7 versus 47.4 Gy; p=0.013). However, despite these values were statistically meaningful, yet, their clinical relevance is questionable as both techniques were successful in reaching the predetermined OAR dose constraints. The sagittal and coronal views reflecting the typical dose distributions and related DVHs of DI and SI techniques on the sample case are shown in Figure 4. and 5.

Discussion

As departments with congested patient burden or with limited number of eligible LINACs try to struggle efficiently using their treatment slots, we investigated whether LINACS dedicated for SRS-SBRT with limited field HD-MLC could help carry this load, as well as to be an alternative at downtimes in workhorse LINACs in any department. We have evaluated the capability of limited length of 22 cm HD MLC for extended treatment fields of craniocaudally >22 cm treated in a standard MLC LINAC and have revealed that double isocenter (DI) optimization plans prepared for HD MLC could effectively accomplish our goal dosimetrically in our local regionally advanced head and neck cases, despite modest increase in the MU and treatment delivery times per fraction.

The strategy of expanding the treatment portals beyond the treatment device capacity for required dose prescription was successfully practiced in years: initially in 2-dimensional RT & 3D-CRT with the dosimetric intersection of lateral opposed fields above the hyoid bone and oppositional fields

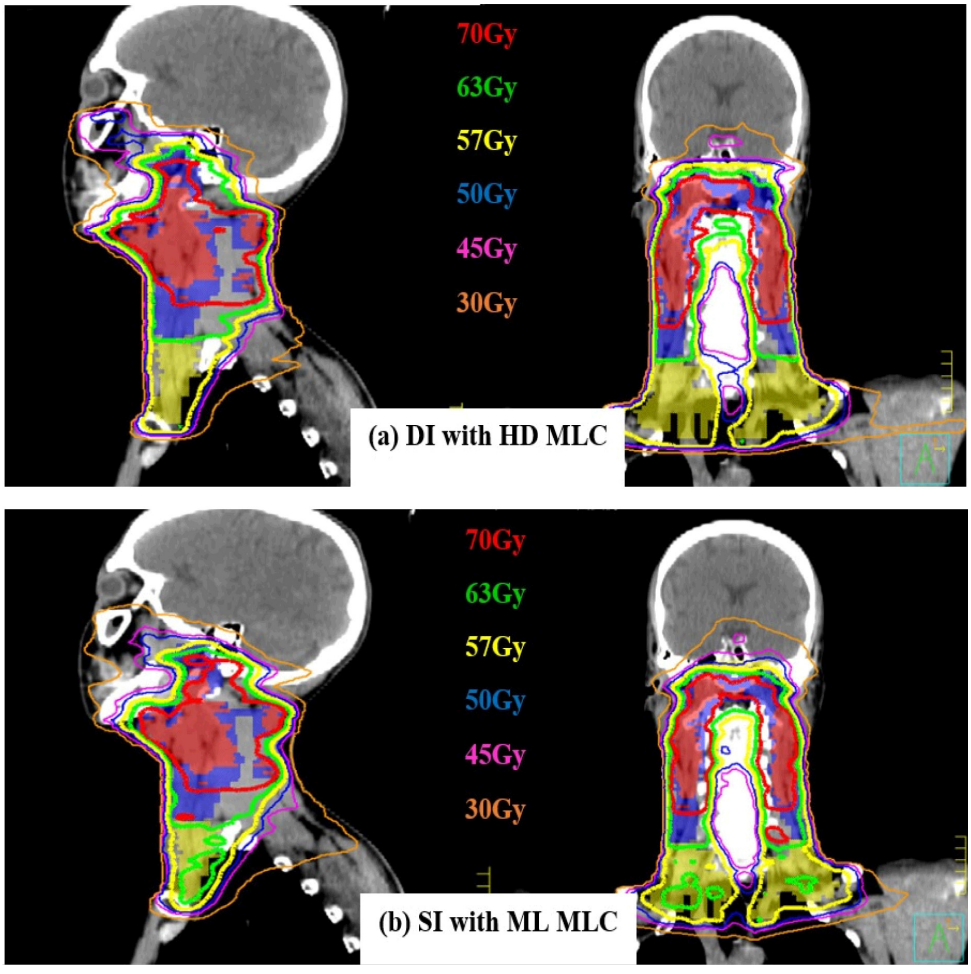

Figure 4. Sagittal and coronal views of isodose distribution of **(a)** VMAT with four quart arcs on DI, **(b)** VMAT with double full arcs on SI for a given example patient. The CTV_{70Gy}, CTV_{63Gy} and CTV_{57Gy} are defined by the red, blue and yellow areas, respectively. CTV: clinical target volume, DI: double isocenter, Gy: Gray, HD: high-definition, IMRT: intensity-modulated radiation therapy, ML: millennium, MLC: multi-leaf collimator, SI: single isocenter, VMAT: volumetric modulated arc therapy.

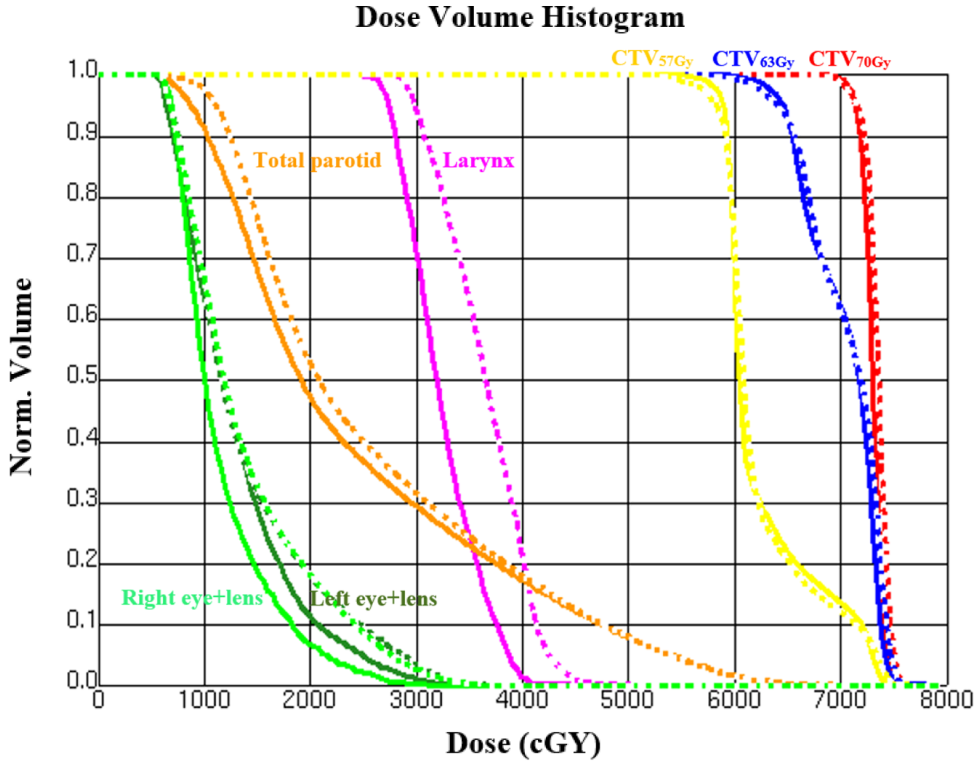

Figure 5. DVH of the sample case for DI (solid line) and SI (dashed line). cGy: centigray, CTV: clinical target volume, DVH: dose volume histogram.

below the same reference structure, as well as in the early days of IMRT by blending a respective IMRT field above and a 3D-CRT below the hyoid bone for pharyngeal cancers [27]. As far as we can tell, the capability to treat the head and neck tumors, specifically pharyngeal cancers, with craniocaudal lengths past the confinements of the HD-MLC equipped LINACs has not been addressed before. Yet, the major difference between the present study and its precede is the synchronous optimization of two diverse VMAT plans to accomplish an ultimately treatable single plan herein, and the generation of a dosimetrically a composite treatment plan via an alliance of two separate plans.

The indications for SRS and SBRT have grown notably in the past two decades [10-25]. Therefore, considering the need for high precision during the planning and delivery of such sophisticated treatments, the MLC thickness has been defined as an essential parameter in achieving sub-milimetric accuracy level [4,6,26]. Several researchers compared the influence of various MLC widths on the dosimetric outcomes of head and cancers treated with IMRT [28-30].In such an investigation, Lafond et al explored the impact of the MLC width (4mm versus 10mm) on VMAT plans and have convincingly demonstrated an impressive dosimetric advantage for a narrower MLC width in the more proficient reduction of the dosages got by the OARs, while a 10mm leaf width was superior in terms of MUs and the number of required arcs; specifically the delivery efficiency [28]. Moreover, Kantz and colleagues have indicated that narrower MLC thickness was capable of the provision of superior plans with regards to the PTV coverage with no increments in either of the OAR doses or overall treatment delivery times with VMAT procedure [30]. Target coverage was noted to be comparable or improved with better conformity and homogeneity by HD MLC [30,35,36]. In this context, there might be an increasing interest to prefer HD-MLC systems with limited treatment fields, which would be bringing a handicap to treat craniocaudally larger fields due to smaller field sizes. This leads to a situation in many departments equipped with HD-MLC LINAC to lose the productivity if these machines are only used for SRS / SBRT and treatment slots cannot be filled with enough number of patients, leading to empty slots. Besides, busy departments running workhorse SD-LINACs capable of treating any disease site cannot share the patient burden to decrease the wait lists or crowded long treatment hours if HD-MLC LINAC in the same department cannot treat large fields due to limited field size. If the HD-MLC LINAC would be capable of treating the same

field size as a SD-MLC LINAC, additional financial investments would probably be not necessary to compensate this growing overcharge. Therefore, we aimed to solve the dilemma of having HD-MLC LINACs for more precise treatments but inability to treat larger fields due to limited field size, and have decided to investigate to use double isocenter optimization VMAT treatments in HD-MLC to mirror large field treatments of a routine SD-MLC treatment to overcome this barrier. Our goal was to achieve dosimetrically comparable plans without an extra effort to outperform the previously delivered plan in standard MLC LINAC, we unveiled no clinically significant difference between CTV coverage or OAR sparing in this study, except clinically irrelevant mean dose changes such as CTV_{63Gy}, though documented significantly better HI and CI values with DI technique, possibly due to thin leaf thickness, MLC speed change on partial collimator during optimization and sequencing, and the partial collimator position depending on the individual target volume shape and complexity. Expectedly, total quatro arcs and the use of partial arcs increased the MU and treatment delivery time per fraction in our model.

The VMAT and IMRT techniques have been comparatively studied by various researchers before in terms of dosimetric outcomes of head and neck cancer RT planning [30-32]. Verbakel et al reported that VMAT was a fast, safe, and accurate technique that uses lower MUs than conventional IMRT besides double arc plans provided at least similar sparing of OAR and better PTV dose homogeneity than a single arc or IMRT [32]. Additionally, in a study from the Oncology Institute of Southern Switzerland, Vanetti et al reported that the VMAT was more efficient in improvements in OARs at risk and healthy tissue sparing than the IMRT with regards to the treatment delivery efficiency [31]. The plan qualities of VMAT and IMRT are for the most part reliant on the notable differences between the number of beam angles and the level of modulation from each angle used [29,33,34]. Results of the joint studies have revealed that larger beam angle numbers with fewer modulations were significantly more capable of the provision of accomplishing superior plan qualities than the philosophy which lean towards many modulations with smaller beam angle numbers. Tol et al have reported that using the clinical scenario of complex head and neck radiotherapy, increases plan quality when more than two arcs are used and the four arc plans provide a good trade-off between increased delivery time and improved plan quality [33].

In our dosimetric study, we utilized a double arc technique for each isocenter to accomplish the cumulative quatro arcs for the total DI plan, where double arc VMAT represented our institutional standard approach for the IMRT of head and neck cancers. This was chiefly based on the well-recognized results of the past head and neck cancer studies convincingly demonstrating that the double arc VMAT plans were superior to the single arc VMAT plans with regards to more thorough PTV coverage and OAR sparing capabilities [31-34]. Asserting our current outcomes, in a seminal work by Guckenberger et al, the multiple arc VMAT plans were shown to meaningfully improve the overall plan quality compared to the single arc VMAT plans at the reasonable expense of modestly increased delivery times, dose MUs, and larger low-dose spread volume [34], which was later confirmed by Tol et al quantitatively [33].

The present investigation is restricted by at least two certain factors: First, our consonant findings represent only the results of a dosimetric comparison in a limited number of patients with head and neck cancers. Second, as all plans were generated in the Pinnacle treatment planning system, the practicability of the same technique in other commercial treatment planning systems needs to be addressed in further dosimetric studies utilizing these systems. However, our study has some strength compared to the preceding dosimetric studies, as well. For example, concerning the significant importance of the uniformity of the target volume(s) and OARs delineation and the treatment planning procedures, all plans were generated with the cooperation of an experienced senior radiation oncologist and a radiation physicist during the entire delineation and treatment planning processes in our study, which were peer-reviewed institutionally. Moreover, the utilization of the same treatment planning system and the dose algorithm with the same pre-specified constraints expanded our capacity to accomplish significant levels of reliability and homogeneity during the plan optimization process by evasion of the unavoidable contrasts, which could be brought by the utilization of different optimization and sequencing algorithms.

Conclusion

The results of current dosimetric research seemed to legitimize the clinical utilization of DI technique with the HD-MLC system introduced here as a trustworthy and safe treatment choice for the nasopharyngeal and oropharyngeal cancers with craniocaudal radiation portal lengths past the machine capacity in a manner like its SI counterpart, which remains to be the current standard technique for the IMRT of such patients. This

methodology may be deciphered as a solid reinforcement technique for clinically fitting patients in case of downtimes of standard MLC systems, or even as a solid contender standalone treatment machine if the department has high volumes of patients requiring extended-field IMRT procedures. Additionally, the present DI technique may prevent or shorten the lengthy waiting times in obviously stacked radiation oncology facilities with limited SRS or SBRT patients' volumes.

Ethics approval and consent to participate and publication

The study design was approved by the institutional review board before collection and analysis of any patient data.

Conflict of interests

The authors declare no conflict of interests.

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