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Original paper

Sparing dysphagia/aspiration related structures using novel hybrid volumetric modulated arc therapy

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ABSTRACT

Purpose: Studies using split field IMRT to spare dysphagia/aspiration related structures (DARS) have raised concern regarding dose uncertainty at matchline. This study explores the utility of hybrid VMAT in sparing the DARS and assesses matchline dose uncertainty in postoperative oral cavity cancer patients and compares it with VMAT.

Methods & materials: Ten postoperative oral cavity cancer patients were planned with h-VMAT and VMAT using the same planning CT dataset. PTV and DARS were contoured using standard delineation guidelines. In h-VMAT 80% of the neck dose was planned using AP/PA technique and then VMAT optimization was done for the total PTV by keeping the corresponding AP/PA plan as the base dose. Planning goal for PTV was $V_{95\%} \geq 95\%$ and for DARS, adequate sparing. Plans and dose volume histograms were analyzed using dosimetric indices. Absolute point and portal dose measurements were done for h-VMAT plans to verify dose at the matchline.

Results: Coverage in both the techniques was comparable. Significant differences were observed in mean doses to DARS (Larynx: 24.36 ± 2.51 versus 16.88 ± 2.41 Gy; $p < 0.0006$, Pharyngeal constrictors: 25.16 ± 2.41 versus 21.2 ± 2.1 Gy; $p < 0.005$, Esophageal inlet: 18.71 ± 2 versus 12.06 ± 0.79 Gy; $p < 0.0002$) favoring h-VMAT. Total MU in both the techniques was comparable. Average percentage variations in point dose measurements in h-VMAT done at +3.5 and −3.5 positions were (1.47 ± 1.48 and 2.28 ± 1.35%) respectively. Average gamma agreement for portal dose measured was 97.07%.

Conclusion: h-VMAT achieves better sparing of DARS with no matchline dose uncertainty. Since these patients have swallowing dysfunction post-operatively, attempts should be made to spare these critical structures as much as possible.

1. Introduction

Cancer of the oral cavity (OCC) and oropharynx are among the most common cancers all over the globe. In developed countries (United States, United Kingdom, Denmark, Australia, Canada, Japan, and Slovakia) there has been a significant decline in OCC incidence, consistent with decline in tobacco use while there has been a rise in oropharyngeal cancer incidence [1].

Oral cancer accounts for over 30% of all cancers in India [2]. Most of the patients are diagnosed with advanced stage disease which demands multi-modality approach comprising of surgery, followed by adjuvant radiation or chemoradiation. Patients undergoing surgery and neck dissection prior to adjuvant treatment are at an increased risk of aspiration as well as gastrostomy tube dependence [3,4]. Chemoradiation improves locoregional control at the expense of increased toxicity. Damage of Dysphagia/aspiration related structures (DARS) namely the pharyngeal constrictors, larynx and esophageal inlet results in swallowing difficulty which adversely affects quality of life. Clinical studies with dosimetric correlation have shown good locoregional control with sparing of the above uninvolved swallowing structures with conformal radiotherapy technique like intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) [5,6].

Split-field IMRT (SF-IMRT) which is a combination of IMRT and anterior neck field (anterior-posterior to posterior-anterior (AP/PA) technique) has been used for sparing these midline DARS. Most of the studies have used IMRT matched to an anterior neck field with a mono isocentric technique. Common problem encountered with SF-IMRT was that of dose uncertainties near the matchline [7,8]. Innovative hybrid VMAT (h-VMAT) technique commonly used in breast cancer and locally advanced lung cancer patients reduces

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low dose spillage to organs at risk (OARs) like lung and heart (V_{5Gy}/V_{20Gy}) compared to pure VMAT/IMRT technique while achieving comparable target coverage and homogeneity [9–12]. h-VMAT has not been explored widely in head and neck cancer patients. This study assesses the utility of h-VMAT technique in sparing the midline DARS in postoperative OCC patients and compares it with VMAT.

2. Methods and materials

2.1. Patient selection

Ten consecutive postoperative locally advanced OCC patients (9 males and 1 female – mean age of 52 years, ranging 32–72 years) who were given radiotherapy to the tumor bed along with bilateral neck at our institution from August 2013 to July 2015 were identified for this dosimetric comparison study, where only planning CT scan data set was used.

2.2. Target and OARs delineation

All the 10 patients treated were immobilized with a thermoplastic head and neck mask for accuracy and reproducibility. Planning CT scan had been done with 2.5 mm slice thickness. The clinical target volume (CTV) was delineated in accordance with the nodal and CTV guidelines proposed by RTOG [13]. The planning target volume (PTV) was defined as CTV plus margin of 0.3 cm. Esophageal inlet was contoured as the first 2 cm of the esophagus commencing from the inferior border of the cricoid cartilage. Pharyngeal constrictors (PC) and esophagus were contoured using standard delineation guidelines [14]. The PC includes superior PC (SPC), middle PC (MPC) and inferior PC (IPC). Larynx and its substructures were contoured in all the ten patients using the step by step approach proposed by Choi et al. [15]. The authors proposed an eleven step approach in which the initial five steps thyroid cartilage, cricoid cartilage, arytenoid cartilage, glottis and subglottic larynx are delineated on the bone window. Epiglottis, aryepiglottic folds, false vocal cords & supraglottic larynx are delineated on the soft tissue window. Larynx structure is finally created by combining these substructures using Boolean function. The average larynx volume was 32 cc (range: 29.1–37.5 cc). The OARs other than DARS delineated included left and right parotids, spinal cord, brain stem, brain, eye lens, trachea and mandible.

2.3. Treatment planning

VMAT and h-VMAT plans were generated for all 10 patients for this comparison study. The PTV (Tumor bed and bilateral level 1–5 nodal stations) was planned with a prescription dose of 60 Gy in 30 fractions. Isocentre was kept at the level of larynx. Upper border of the neck field was placed at this level for h-VMAT plans**.** All plans were created using Eclipse treatment planning system (V 10.0.38, Varian Medical Systems) and deliverable on Truebeam STx linear accelerator (Varian Medical Systems, USA) equipped with high definition multi-leaf collimator (HD-MLC). A single planner was employed to generate the comparative plans, in order to reduce the bias.

2.4. VMAT plan

The VMAT plans were done using 3 full arcs (179° – 181°) optimal for delivery on the Truebeam STx machine. The collimator angle was set to a value of ±10° to avoid tongue and groove effect. All plans were done using 6 MV photons with a maximum dose rate of 600 MU/ min. The normal tissue objective (NTO) was set to automatic sparing with priority value of 200, so that the optimization process improves the dose fall-off beyond the PTV. Jaw tracking was used during optimization. PTV objective was to deliver at least 95% of prescription dose to 95% of PTV. Dose objective for both parotids was mean <26 Gy. A maximum dose objective of 40 Gy was kept for spinal cord and brain stem. Other OARs, interactive objectives were used to keep the dose as low as possible without compromising PTV coverage. The final dose calculations were performed using Anisotropic Analytical Algorithm (AAA) with 2.5 mm calculation grid size. All plans were normalized to 100% in target mean.

2.5. h-VMAT plan

In h-VMAT, planning was done in two steps. First, 80% of the prescribed dose was planned for the PTV below the matchline using half beam AP/PA fields. Midline DARS below the matchline were shielded using MLC. 6 MV beam was used for the AP field with a field weight 0.8 and 10 MV for PA beam with a field weight 0.2. In the second step the total PTV above and below the matchline were optimized using 3 full arcs VMAT, with the dose delivered by AP/PA technique kept as the base dose plan. The optimization objective for the OARs above matchline and PTV were same as in VMAT and for DARS, it was made more interactive without affecting the PTV coverage**.** After the final dose calculation, plan sum was created using both the plans. For comparison, both the plans were normalized using plan normalization value by keeping the PTV mean dose equal to the prescription dose.

2.6. Dosimetric evaluations

Both planning techniques were evaluated using dose-volume histogram (DVH). PTV dosimetric parameters evaluated were PTV coverage ($D_{95\%}$), conformality index (COIN) and homogeneity index (HI). The COIN was defined as, COIN = (PTVref/PTV) × (PTVref/Vref), where PTVref was the volume of reference dose (95%) inside the PTV and Vref was the volume of reference isodose (95%). COIN value closer to 1 indicates a conformal plan. The HI was defined as, $HI = (D_{2\%} - D_{98\%})/D_{50\%,}$ where $D_{2\%}$, $D_{98\%}$, $D_{50\%}$ were the doses to 2%, 98% and 50% of the PTV volume. HI value closer to 0 indicates a homogeneous plan. Total monitor units (MU) were also recorded for comparison. For OARs above matchline, maximum doses to brain, brain stem, spinal cord, mandible and mean doses to left and right parotids, SPC and MPC were recorded. For OARs below matchline, mean doses to larynx, PC, IPC, esophageal inlet, esophagus, and trachea were recorded.

2.7. Verification of dose delivered

In order to verify the dose at the matchline in h-VMAT, absolute point dose measurements were done using slab phantom and gel bolus. Ion chambers of 0.13 cc volume were placed on either side of the midline ±3.5 cm at the isocentre level. The CT scan of this phantom setup was done and verification plans were created. Absolute point doses for all h-VMAT plans were measured on the Truebeam STx linear accelerator and compared with calculated chamber volume mean doses. Fig. 1 shows the set up used for absolute point dose measurements to verify matchline dose in h-VMAT. In addition planar portal dosimetric measurements were done for all h-VMAT plans using electronic portal imaging device (EPID). TPS predicted and measured dose was analyzed in terms of area gamma <1, maximum gamma and average gamma for each patients. 3% dose difference (DD) and 3 mm distance to agreement (DTA) criteria and global gamma evaluation with absolute normalization mode were used for gamma analysis.

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