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Dosimetric comparison between step-shoot intensity-modulated radiotherapy and volumetric-modulated arc therapy for upper thoracic and cervical esophageal carcinoma

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ABSTRACT

To compare and analyze the dosimetric characteristics of volumetric modulated arc therapy (VMAT) *vs* step-shoot intensity-modulated radiation therapy (sIMRT) for upper thoracic and cervical esophageal carcinoma. Single-arc VMAT (VMAT1), dual-arc VMAT (VMAT2), and 7-field sIMRT plans were designed for 30 patients with upper thoracic or cervical esophageal carcinoma. Planning target volume (PTV) was prescribed to 50.4 Gy in 28 fractions, and PTV1 was prescribed to 60 Gy in 28 fractions. The parameters evaluated included dose homogeneity and conformality, dose to organs at risk (OARs), and delivery efficiency. (1) In comparison to sIMRT, VMAT provided a systematic improvement in PTV1 coverage. The homogeneity index of VMAT1 was better than that of VMAT2. There were no significant differences among sIMRT, VMAT1, and VMAT2 in PTV coverage. (2) VMAT1 and VMAT2 reduced the maximum dose of spinal cord as compared with sIMRT ($p < 0.05$). The rest dose-volume characteristics of OARs were similar. (3) Monitor units of VMAT2 and VMAT1 were more than sIMRT. However, the treatment time of VMAT1, VMAT2, and sIMRT was (2.0 ± 0.2), (2.8 ± 0.3), and (9.8 ± 0.8) minutes, respectively. VMAT1 was the fastest, and the difference was statistically significant. In the treatment of upper thoracic and cervical esophageal carcinoma by the AXESSE linac, compared with 7-field sIMRT, VMAT showed better PTV1 coverage and superior spinal cord sparing. Single-arc VMAT had similar target volume coverage and the sparing of OAR to dual-arc VMAT, with shortest treatment time and highest treatment efficiency in the 3 kinds of plans.

Introduction

Radiotherapy with concurrent chemotherapy is a main treatment of choice for upper thoracic and cervical esophageal carcinoma. The anatomical location of upper thoracic and cervical esophagus is close to the spinal cord, and the contour of the outer body surface changes rapidly, so it becomes a crucial challenge to make dose coverage for target to be even and reduce the dose to the spinal cord and lungs. Comparing with the 3-dimensional conformal radiotherapy, step-shoot intensity-modulated radiation therapy (sIMRT) has dosimetric advantage, but the prolonged delivery time of sIMRT can decrease efficiency and increase intrafraction uncertainty of target volume localization and dosimetry.[1-3]

As a new IMRT technology, volumetric modulated arc therapy (VMAT) can generate precise conformal dose distribution through rotational delivery accompanied by variability of the multileaf collimator (MLC) position, dose rate, and gantry rotation velocity.[4] Compared with sIMRT, VMAT can improve the dose distribution, reduce the dose to normal tissues, and shorten the delivery time. It has been reported that, for the upper thoracic and cervical esophageal carcinoma radiotherapy, dual-arc VMAT produced superior results in planning target volume (PTV) coverage and organs at risk (OARs) sparing, but was slightly less efficient than single-arc VMAT.[5-8] Elekta Axesse linear accelerator (linac) is equipped with the improved Integrity treatment control system and the newly designed Agility head. Integrity supports continuous variable dose rate (CVDR), and Agility has a 160-leaf MLC of projected width 0.5 cm at the isocenter, designed to allow for complete interdigitation and noncontiguous field shape.[9] The improvement of these techniques helps to raise optimization space

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of the single-arc VMAT. This article addresses the question whether single-arc VMAT, with technical improvements, is adequate for upper thoracic and cervical esophageal carcinoma radiotherapy with no compromise PTV coverage and OARs sparing.

Materials and Methods

General clinical data

This study was approved by the Institutional Review Board of the First People's Hospital of Changzhou (the Third Affiliated Hospital of Soochow University), and written informed consent was obtained from the patients before treatment. A total of 30 cases of patients with upper thoracic and cervical esophageal carcinoma, who accepted the first course of radiotherapy between October 2012 and January 2014 at our department were enrolled in this study, including 23 males and 7 females. The distribution of clinical stages according to the clinical staging of nonsurgical treatment of esophageal carcinoma[10] was as follows: stage I, 1; stage II, 12; stage III, 15; and stage IV, 2.

Computed tomography scanning

Patients were immobilized with thermoplastic mask on the head, neck, shoulders, and chest. Planning computed tomography (CT) scans were performed at 5-mm slice thickness using Siemens Sensation (Munich, Germany). The entire lungs were scanned for further plan evaluation. CT images were imported into treatment planning system (TPS, MONACO v3.2.01, Elekta, Stockholm, Sweden) through the private network (MOSAIQ, Elekta, Stockholm, Sweden).

Target definition and contouring

Target volume was contoured by radiotherapy physician and radiologist according to the consensus of the clinical target volume of esophageal carcinoma.[11] Gross tumor volume (GTV) covers gross tumor. GTVnd covers adjacent lymph nodes. Clinical target volume (CTV) includes correlated lymphatic drainage regions and supraclavicular region. The PTV encompassed the CTV with a 0.5-cm margin. CTV1 includes GTV with a margin of 2.5 cm in superior and inferior directions and 0.5 to 0.8 cm in other directions. CTV1 and GTVnd are both expanded by a 0.5 cm margin for PTV1. Appropriate adjustments are made according to the OARs and the surface contours. The average volume of PTV and PTV1 are 456.0 and 172.5 cm^3, respectively. OARs include the spinal cord, lungs, and heart.

Dose prescription

The goal of the treatment was to deliver a prescribed dose of 60 Gy to at least 95% of PTV1 in 28 fractions, and 50.4 Gy to at least 95% of PTV in 28 fractions. The maximum dose to spinal cord was 45 Gy. For the lungs, V_5 (the volume of the lung received more than 5 Gy) should be less than 60% of lung volume, V_{20} should be less than 28%, and V_{30} should be less than 18%.

Planning technique

sIMRT, VMAT1, and VMAT2 are all generated by Monaco 3.2 TPS on the AXESSE linac. SIMRT plans are generated with 7 equidistant coplanar beams uniformly distributed into 0°, 51°, 103°, 154°, 206°, 257°, and 309°. The minimum segment area and the minimum segment monitor unit (MU) are set as 2 cm^2 and 4, respectively. VMAT's rotating arc is set from −180° to 180°. The maximum control points (CPs) for VMAT1 is 180, and the maximum CPs per arc for VMAT2 is 100. The minimum segment width is set as 0.5 cm with the minimum MUs per CP as 1. The parameters of the 3 plans for each case are the same. The Elekta AXESSE linac 6 MV photon beams are applied to all plans. The Agility has 80 pairs of MLC of projected width 0.5 cm at the isocenter. The maximum speed of the dynamic leaf guide is 3 cm/s. The maximum speed of MLC is 3.5 cm/s and can approach 6.5 cm/s with the aid of dynamic leaf guide. The gantry maximum rotation velocity is 6°. CVDR of the AXESSE linac ranges from 45 to 660 MU/min.

Plan evaluation

All the data are based on dose-volume histogram calculated using the Monaco 3.2 TPS. According to the ICRU83 report,[12] $D_{2\%}$ (near maximum dose), $D_{98\%}$ (near minimum dose), $D_{50\%}$ (median dose), conformity index (CI), and homogeneity index (HI) were used for the evaluation of the PTV and PTV1 coverage. The equations for calculating HI and CI are as follows:

$$HI = (D_{2\%} - D_{98\%})/D_{50\%}$$
$$CI = (TV_{RI} \times TV_{RI})/(TV \times V_{RI})$$

where, V_{RI} is the treatment volume of the body receiving the prescribed dose, TV is the volume of PTV, and TV_{RI} is the volume of TV within the V_{RI}. CI value would be less than 1, and the closer the CI to 1, the better the conformality. HI value would be more than 0, and the closer the HI to 0, the better the homogeneity. The evaluation parameters of OARs include the maximum dose (D_{max}) of the spinal cord, V_5, V_{20}, V_{30}, the mean dose (D_{mean}) of the lungs, and D_{mean}, V_{30}, V_{40} of the heart.

Delivery efficiency and dose verification

MUs and treatment time for all the plans were recorded. Dosimetric validation was performed for all plans. The delivered dose was measured by the 2-dimensional ionization chamber array MatriXX (IBA Dosimetry, Schwarzenbruck, Germany). The calculated dose and the measured dose were compared by the OmniPro I'mRT software (IBA Dosimetry, Schwarzenbruck, Germany) that employs the gamma evaluation criteria of 3% and 3 mm.[13]

Statistical analysis

All the analysis was performed using the SPSS version 16.0 statistical software (IBM SPSS Statistics, New York, America). The parameters were analyzed using one-way analysis of variance and within-group differences between techniques were analyzed by the least-significant difference method.

Results

PTV coverage

Dose distribution in all VMAT1, VMAT2, and sIMRT plans for all 30 patients satisfied clinical requirements. Specific results are shown in Table 1 and Fig. 1. A total of 3 sets of plans of all cases meet the clinical requirements. Specific results are shown in Table 1 and Figs. 1 and 2.

Dose to OARs

VMAT1 and VMAT2 reduce the maximum dose of spinal cord as compared with sIMRT ($p < 0.05$). The rest of the dose-volume characteristics of OARs are similar. Specific results are shown in Table 2 and Fig. 3.

Table 1
Comparison of target dose-volume parameters in all 3 radiotherapy plan groups

	sIMRT	VMAT1	VMAT2	F	*p* Value
PTV					
$D_{2\%}$ (Gy)	62.97 ± 0.48[a]	62.30 ± 0.43[b]	62.50 ± 0.41[b]	18.800	< 0.001
$D_{98\%}$ (Gy)	50.53 ± 0.41	50.48 ± 0.23	50.50 ± 0.18	0.084	0.920
$D_{50\%}$ (Gy)	57.85 ± 2.49	57.64 ± 2.55	57.46 ± 2.59	0.184	0.833
HI	0.22 ± 0.01[a]	0.21 ± 0.01[b]	0.21 ± 0.01[b]	6.150	0.004
CI	0.73 ± 0.03	0.73 ± 0.03	0.73 ± 0.03	0.683	0.509
PTV1					
$D_{2\%}$ (Gy)	63.37 ± 0.42[a]	62.65 ± 0.41[b]	62.89 ± 0.36[c]	29.345	< 0.001
$D_{98\%}$ (Gy)	59.64 ± 0.10[a]	59.78 ± 0.07[b]	59.75 ± 0.08[b]	21.489	< 0.001
$D_{50\%}$ (Gy)	61.48 ± 0.23[a]	61.08 ± 0.21[b]	61.20 ± 0.19[c]	35.096	< 0.001
HI	0.06 ± 0.01[a]	0.04 ± 0.01[b]	0.05 ± 0.01[c]	30.373	< 0.001
CI	0.78 ± 0.03[a]	0.81 ± 0.03[b]	0.81 ± 0.03[b]	14.374	< 0.001

[a,b,c]The same indicators marked with the same letter (a, b, or c) indicate that the difference was not statistically significant ($P > 0.05$).