ARTICLE IN PRESS

Medical Dosimetry ∎ (2016) ∎∎∎–∎∎∎

Medical Dosimetry

journal homepage: www.meddos.org

Dosimetric effect of beam arrangement for intensity-modulated radiation therapy in the treatment of upper thoracic esophageal carcinoma

Yuchuan Fu, Ph.D.,* Min Deng, M.D.,† Xiaojuan Zhou, M.D.,† Qiang Lin, B.S.,* Bin Du, B.S.,* Xue Tian, M.D.,† Yong Xu, M.D.,† Jin Wang, M.D.,† You Lu, M.D.,† and Youling Gong, M.D., PH.D.†

*Division of Radiation Physics, State Key Laboratory of Biotherapy and Cancer Center, West China Hospital, Sichuan University, Chengdu, P.R. China; and
†Department of Thoracic Oncology, State Key Laboratory of Biotherapy and Cancer Center, West China Hospital, Sichuan University, Chengdu, P.R. China

ARTICLE INFO

Article history:
Received 19 July 2016
Received in revised form
4 November 2016
Accepted 7 November 2016

Keywords:
Beam arrangement
IMRT
Upper thoracic esophageal carcinoma
Lung sparing

ABSTRACT

To evaluate the lung sparing in intensity-modulated radiation therapy (IMRT) for patients with upper thoracic esophageal tumors extending inferiorly to the thorax by different beam arrangement. Overall, 15 patient cases with cancer of upper thoracic esophagus were selected for a retrospective treatment-planning study. Intensity-modulated radiation therapy plans using 4, 5, and 7 beams (4B, 5B, and 7B) were developed for each patient by direct machine parameter optimization (DMPO). All plans were evaluated with respect to dose volumes to irradiated targets and normal structures, with statistical comparisons made between 4B with 5B and 7B intensity-modulated radiation therapy plans. Differences among plans were evaluated using a two-tailed Friedman test at a statistical significance of $p < 0.05$. The maximum dose, average dose, and the conformity index (CI) of planning target volume 1 (PTV1) were similar for 3 plans for each case. No significant difference of coverage for planning target volume 1 and maximum dose for spinal cords were observed among 3 plans in present study ($p > 0.05$). The average V_5, V_{13}, V_{20}, mean lung dose, and generalized equivalent uniform dose (gEUD) for the total lung were significantly lower in 4B-plans than those data in 5B-plans and 7B-plans ($p < 0.01$). Although the average V_{30} for the total lung were significantly higher in 4B-plans than those in 5B-plans and 7B-plans ($p < 0.05$). In addition, when comparing with the 4B-plans, the conformity/heterogeneity index of the 5B- and 7B-plans were significantly superior ($p < 0.05$). The 4B-intensity-modulated radiation therapy plan has advantage to address the specialized problem of lung sparing to low- and intermediate-dose exposure in the thorax when dealing with relative long tumors extended inferiorly to the thoracic esophagus for upper esophageal carcinoma with the cost for less conformity. Studies are needed to compare the superiority of volumetric modulated arc therapy with intensity-modulated radiation therapy technique.

Introduction

The incidence of esophageal carcinoma is increasing worldwide. The overall 5-year survival rate for patients with newly diagnosed esophageal carcinoma is less than 25%.[1,2] Surgery and radiotherapy had always been the main treatment strategies,[3,4] whereas surgery was not an appropriate treatment for those with locally advanced tumors owing to the difficulty of achieving clear margins. Therefore, for diseases located in the upper thoracic region, including cervical region, radiotherapy is an effective treatment strategy. To achieve a higher tumor local control, the radiation dose of 60 to 70 Gy to primary tumors and approximately 45 to 50 Gy to electively irradiated lymph nodal regions is necessary.

Owing to the significant anatomical variation in the upper thoracic region, it was a big challenge to deal with the target conformity and risk organ sparing with three-dimensional conformal radiotherapy (3D-CRT) in treating upper thoracic esophageal carcinoma (UTEC). As intensity-modulated radiation therapy (IMRT) represents a fundamentally new approach to the planning and delivery of radiation therapy, it combines 2 advanced concepts

Reprint requests to Youling Gong, M.D., PH.D., Department of Thoracic Oncology, State Key Laboratory of Biotherapy and Cancer Center, West China Hospital, Sichuan University, Chengdu 610041, P.R. China.
E-mail: gongyouling@hotmail.com

http://dx.doi.org/10.1016/j.meddos.2016.11.002

to deliver 3D-CRT: inverse treatment planning with computerized optimization and computer-controlled intensity modulation of the treatment beams, demonstrating the dosimetric superiority over 3D-CRT approaches in nearly all of the major tumor sites.[5,6]

So far, there are some studies focused on IMRT techniques in middle or distal esophageal carcinoma,[7-9] whereas few reports evaluated the lung dose sparing in the treatment of UTEC in detail. In a recent study, Fenkell *et al.*[10] compared IMRT and 3D-CRT with respect to conformity of target coverage and normal tissue sparing for cervical esophageal carcinoma, but lung dose has not been analyzed well because they focused on the patients with gross tumor limited in cervical region. In another study by Fu *et al.*,[11] they concluded that 5 equal-spaced coplanar intensity-modulated beams produce desirable dose distributions, whereas their study only depended on 5 patients' data and the evaluation was somewhat simple.

For esophageal carcinoma, where the planning target volume (PTV) is approximately cylindrical instead of concave, the benefit that IMRT offers is, therefore, expected to be smaller when compared with concave tumor. The standard beam arrangement of IMRT plans may not be the optimal selection. In this study, we conducted a comparative study to evaluate the dosimetric effect of beam-orientation selection for IMRT plans for UTEC. A total of 3 types of IMRT beam arrangements were made to assess optimal beam angles with relative long PTV (in superior-inferior direction) where the dose received by lungs must be taken into account as that in distal esophageal cancers. The volumes of lung treated to low and medium doses were evaluated whereas the other planning conditions were controlled equally.

Methods and Materials

Patients' data

This retrospective study was conducted in our treatment center, West China Hospital, Sichuan University, China. Overall, 15 patients who underwent treatment for nonsystematic metastatic UTEC between October 2007 and October 2008 in our center were selected in present study. The basic and clinical characteristics of these patients were shown in Table 1. All patients were staged according to the modified 1997 AJCC staging system.[12] All of them had unresectable gross tumors and corresponding clinical target volumes (CTV), which extended to the upper thoraxes. This retrospective study was conducted with the approval of the ethics committee of West China Hospital, Sichuan University. Clinically, all patients accepted 5- or 7-beams IMRT treatment.

Target delineation

Patients were immobilized in supine position. Planning CT scans were performed at 3 mm slice thickness using a dedicated helical CT scanner (Siemens, Somatom Plus[4]) throughout the entire neck and thorax. The entire lungs were scanned for further plan evaluation. All patients underwent CT simulation with normal breathing; however, 10 of the patients were immobilized with a head and neck/upper thoracic thermoplastic mask, and 5 of them with a vacuum-locked cradle.

Table 1
Characteristics of upper cervical esophageal patients in the study

Age (y)	Average: 49.5 (range: 37 to 62)
Sex (female/male)	3/12
Stage	T2N1M0: 1
	T3N0M0: 6
	T3N1M0: 5
	T4N0M0: 1
	T4N1M0: 2
Length of PTV1	Mean: 11.4 cm (range: 9.3 to 13.5 cm)
Length of PTV2	Mean: 18.0 cm (range: 16.2 to 19.5 cm)
Volume of PTV1	Mean: 114.1 cc (range, 62.9 to 201.8 cc)
Volume of PTV2	Mean: 478.5 cc (range: 267.4 to 620.9 cc)
Total lung volume	Mean: 3564.6 cc (range: 2274.2 to 5888.1 cc)

The gross tumor volume (GTV), CTV, PTV, spinal cord, and lung parenchyma were delineated by single radiation oncologist on each slice of CT images. The GTV was defined as any visible tumor on the image. The CTV included correlated lymphatic drainage regions and extended to cricothyroid membrane. It was approximately defined as the GTV plus a 3- to 4-cm margin superior to the highest extension of the tumor and a 4-cm margin inferior to the lowest extension of the tumor with a 2-cm radial margin. Uninvolved bony structure and lung tissue were kept outside the CTV. The PTV1 and PTV2 were defined as the GTV and CTV plus a 0.3 cm margin in all direction, respectively; therefore, the PTV1 was included in PTV2. The spinal cord and lungs were contoured as the organ at-risk (OAR). A planning organ at-risk volume (PRV) was extended as 5 mm to the spinal cord (PRVcord).

Dose prescription and planning techniques

The simultaneous integrated boost approach was applied to all patients, where different dose were described to PTV1 and PTV2-PTV1 within single fraction. For all patient cases, the prescription dose to PTV1 was 63.8 Gy, which divided into 29 fractions with 2.2 Gy per fraction, whereas the prescription dose to PTV2-PTV1 was 52.2 Gy with 1.8 Gy per fraction.

CT images were transferred to the treatment planning system (Piannacle 8.0, Philips Inc., USA) through network. All IMRT plans were generated by direct machine parameter optimization (DMPO) developed by RaySearch Laboratories (Stockholm, Sweden), which implemented in the planning system. DMPO based on the direct aperture optimization techniques.[13,14] Using DMPO, the segments were created after initial optimization of the fluency map using a pencil beam model during the first iterations. The DMPO approach used in this study made it possible to evaluate on the effect of beam arrangement to IMRT plans under equal treatment parameters, because deliverable segments after optimization could be obtained directly without the step for leaf sequence that usually declined the optimized plan quality somewhat.

For all plans, the inverse planning parameters were as following number of initial iterations was set to 25; the maximum number of segments was set to 40; the minimum segment MU was set to 6 MU; the minimum segment area was set to 5 cm^2; and the photon energy was 6 MV, which was delivered by an Elekta accelerator (Precise Treatment SystemTM, Elekta Oncology, UK).

For each patient case, 3 IMRT plans with different beam arrangement were generated. The beam arrangement of these plans are shown in Table 2.

The goals for inverse planning were to ensure 95% coverage of the PTV1 and PTV2-PTV1 to the prescribed doses (63.8 Gy at 2.2 Gy per fraction to PTV1 and 52.2 Gy at 1.8 Gy per fraction to PTV2-PTV1). Desired dose constraints for all OARs were as follows: spinal cord (max dose 45 Gy), PRV_{cord} (max dose 50 Gy), and lungs ($V_{20} < 35\%$).

To assess the plan quality with respect to the dose delivered to the target, the conformity index (CI) and heterogeneity index (HI) were calculated as Chandra *et al.*[8] reported. CI was defined as "VDp/PTV," in which VDp is the volume enclosed by the prescription isodose curve. CI was usually > 1. Larger values indicate greater volumes of the prescription dose delivered outside the PTV (i.e., less dose conformity in the PTV). HI was defined as "D_5/D_{95}," in which D_5 and D_{95} correspond to the dose delivered to 5% to 95% of the PTV, respectively. Greater HI values indicate doses exceeding the prescription dose and, thus, a greater degree of dose heterogeneity in the PTV. Target coverage index was calculated as "D_{95}/D_{RX}," which indicated the coverage of prescribed dose to treatment target. Greater D_{95}/D_{RX} means better coverage of prescribed dose to a certain target.

To evaluate the volume of normal tissue outside of the PTV irradiated to prescribed dose level, we measured an excess volume index (EVI) as Mayo *et al.*[9] did. It was defined as

$EVI = 100 \times (V_{RX}-V_{PTV})/V_{PTV}$, where V_{RX} is the volume of patient volume (body) receiving the prescribed dose and V_{PTV} is the volume of PTV.

To assess the effect on normal lung irradiation, we computed several different dosimetric indices, including V_5, V_{13}, V_{20}, and V_{30} for the lung (the volume of lungs that receives 5, 13, 20, and 30 Gy, respectively), mean dose delivered to the lung (mean lung dose [MLD]) because of observations that lung tissue tended to have a low-dose tolerance.[15] In addition, the generalized equivalent uniform dose (gEUD) was calculated as a value of $a = 1.15$.[16]

Statistical analysis

The statistical analysis was performed using the SPSS software (version 13.0, Chicago, USA). All data were analyzed applying "mean ± standard deviation." The

Table 2
Beam arrangement of IMRT plans

Number of beams	Gantry angles
4	240°, 0°, 120°, 180°
5	216°, 288°, 0°, 72°, 144°
7	207°, 258°, 309°, 0°, 51°, 102°, 153°