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Technical report

Optimal beam design on intensity-modulated radiation therapy with simultaneous integrated boost in nasopharyngeal cancer

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ABSTRACT

This study aims to determine the optimal beam design among various combinations of field numbers and beam trajectories for intensity-modulated radiation therapy (IMRT) with simultaneous integrated boost (SIB) technique for the treatment of nasopharyngeal cancer (NPC). We used 10 fields with gantry angles of 155°, 130°, 75°, 25°, 0° L, 0° R, 335°, 285°, 230°, and 205° denoted as F10. To decrease doses in the spinal cord, the F10 technique was designed by featuring 2 pairs of split-opposed beam fields at 155° to 335° and 205° to 25°, as well as one pair of manually split beam fields at 0°. The F10 technique was compared with 4 other common field arrangements: F7E, 7 fields with 50° equally spaced gantry angles; F7, the basis of F10 with 155°, 130°, 75°, 0°, 285°, 230°, and 205°; F9E, 9 fields with 40° equally spaced gantry angles; and FP, 7 posterior fields with 180°, 150°, 120°, 90°, 270°, 240°, and 210°. For each individual case of 10 patients, the customized constraints derived after optimization with the standard F10 technique were applied to 4 other field arrangements. The 4 new optimized plans of each individual case were normalized to achieve the same coverage of planning target volume $(PTV)_{63\ Gy}$ as that of the standard F10 technique. The F10 field arrangement exhibited the best coverage in $PTV_{70\ Gy}$ and the least mean dose in the trachea-esophagus region. Furthermore, the F10 field arrangement demonstrated the highest level of conformity in the low-dose region and the least monitor unit. The F10 field arrangement performed more outstandingly than the other field arrangements in $PTV_{70\ Gy}$ coverage and spared the central organ. This arrangement also exhibited the highest conformity and delivery efficiency. The F10 technique is recommended as the standard beam geometry for the SIB-IMRT of NPC.

Introduction

According to the World Health Organization, the incidence rate of nasopharyngeal cancer (NPC) is < 1 case per 100,000 cases worldwide. However, the incidence rate is > 20 cases per 100,000 cases in Southern Asia. In Taiwan, the incidence rate is approximately 8.29 and 2.77 for men and women, respectively, based on a 2008 report of the Cancer Registry Department of Health and Welfare, Executive Yuan, Taiwan.

NPC is radiosensitive, hence radiotherapy or combined radiotherapy and chemotherapy is the standard method. With the advancement of 3-dimensional conformal radiotherapy (3D-CRT) to intensity-modulated radiation therapy (IMRT), tumor coverage has been improved and critical structures have been clearly spared.[1] Therefore, the IMRT technique is recommended for the treatment of head and neck cancer.[2]

Clark *et al.*[3] observed that the low-dose volume in IMRT is higher than that in 3D-CRT. IMRT has been used for treatment of NPC at Taipei Veterans General Hospital (VGH) since 2002. We found that the proper arrangement of beams not only achieved the plan criteria but also improved dose conformity in high-dose and low-

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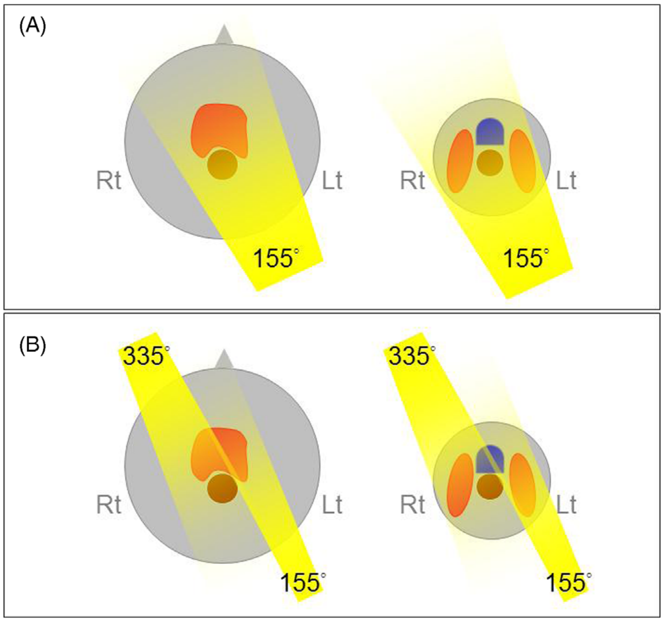

Fig. 1. Schematic of the beam arrangement. The regions of nasal cavity and neck in the axial view are shown in left side and right side of figures, respectively. The red area indicates the PTV, the brown area indicates the brain stem or the spinal cord, and the blue area indicates the trachea-esophagus region. (A) The PTV is covered by a beam at a gantry angle of 155°. (B) The PTV is covered by a partial beam at a gantry angle of 155° and the split-opposed beam at 335°. (Color version of figure is available online.)

dose volumes. In our study, manually split or opposing partial fields were designed based on the relative position between planning target volume (PTV) and critical structures.

Critical structures receive higher doses than the PTV if they are located in front of the PTV along the beam trajectory because of the physical characteristics of a photon beam. A nonopposing field arrangement is the basic principle of beam angle selection in IMRT. However, not all critical structures of each individual field could be spared or placed at the back of the PTV. After analyzing the geometric characteristics of critical structures *vs* the PTV of NPC, we designed the F10 beam arrangement with the original F7 fields split and partially placed in opposing trajectories to relocate the critical structures at the back of the PTV (Fig. 1). The 0° field was also split in half in our F10 field arrangement to decrease dose leakage to the larynx, trachea, and spinal cord of the dynamic multileaf collimator (DMLC) motion.

This study aims to confirm that the Taipei VGH F10 field arrangement is a better IMRT beam design for NPC than 4 other popular field arrangements.

Methods and Materials

Patient selection and structure delineation

During 2005, 10 consecutive patients with NPC who were treated with 10-field simultaneous integrated boost (SIB)[4] IMRT at Taipei VGH were selected for this study. The patients immobilized with a thermoplastic mask were subjected to computed tomography simulation (5 mm/slice). The TNM categories based on the American Joint Committee on Cancer sixth edition cancer staging system for the 10 patients are shown in Table 1.

Gross tumor volume was defined using 5 sets of magnetic resonance image fusion, including axial T2-weighted image (WI), axial T1WI, postcontrast axial T1 with fat saturation, postcontrast coronal T1WI, and sagittal T1WI. Clinical target volume $(CTV)_{70\ Gy}$ was defined by gross tumor volume of both primary tumor and regional lymphadenopathy. PTV was administered at 70 Gy ($PTV_{70\ Gy}$) and created by adding margins of 3 mm for the primary tumor and margins of 5 mm for the neck lymphadenopathy. $CTV_{63\ Gy}$ encompassed the $CTV_{70\ Gy}$, whole nasopharynx, skull base, bilateral tonsils, and at least level II of lymphatics. The $CTV_{63\ Gy}$ extended to level III or level IV for patients with gross lymphadenopathy in the corresponding levels. Level Ib was included only when definitive lymphadenopathy was observed. PTV administered at 63 Gy ($PTV_{63\ Gy}$) was created with margins of 3 mm around the upper $CTV_{63\ Gy}$ above the C2-3 junction and 5 mm around the lower $CTV_{63\ Gy}$. The planning organ-at-risk volume was also created around the brain stem and at 10 cm of the spinal cord with margins of 3 and 5 mm, respectively. The dose constraints also included the inner ears and whole parotid glands. With a chin-up position, the eyes and optic nerves were excluded from the constraints, except for advanced T4 cases. These structures are shown in Fig. 2.

IMRT planning technique

The SIB-IMRT for NPC at Taipei VGH had 2 dose levels: 70 Gy to $CTV_{70\ Gy}$ and 63 Gy to $CTV_{63\ Gy}$ in 35 fractions. The field arrangement was 10 fields, denoted as F10, which was developed in the era of Varian's CadPlan Radiotherapy Treatment Planning System version 6.32 (Table 2). In this study, the IMRT was planned by Varian's Eclipse Radiotherapy Treatment Planning System version 7.1. The sweeping step-and-shoot technique with 10 dose levels was adopted to convert the optimal fluence into segments of leaf motion.

The schematic of our idea is shown in Fig. 1. In Fig. 1A, the right side of the PTV at a beam trajectory of gantry 155° is found behind critical structures. If the right side of the PTV was covered with sufficient doses, the critical structures in front of the PTV receive a higher dose than the PTV. Considering this finding, we developed a split-opposed field technique (Fig. 1B). Half of the field that covered the right side of the PTV was opposed to the gantry angle at 335°; hence, the right side of the PTV was proximal to the source at 335°. Considering this idea, we featured 2 pairs of split-opposed fields at gantry angles of 155° to 335° and 205° to 25°. Furthermore, the large field size was divided into multiple subfields in Varian's system. In our study, 0° L to 0° R were manually split to prevent leakage to the central structures. The IMRT covered the nasopharynx and the upper neck, and the anterior field covered the lower neck. The center of the IMRT field was placed at the middle neck junction with the half-beam lower neck single anterior field, which was not compared in this study.

The F10 technique was compared with 4 other popular field arrangements, as shown in Table 2. The 4 other field arrangements were F7, F7E, F9E, and FP. The F7 technique, the predecessor of the F10 technique, exhibits a similar gantry angle, except for split-opposed fields. In the F7E technique, 7 equally spaced gantry angles are considered.[5] By comparison, the F9E technique uses 9 equally spaced gantry angles. The FP technique uses 7 posterior gantry angles.[6-8]

A standard template of dose-volume histogram (DVH) constraints for the inverse treatment plan of the SIB-IMRT of NPC was routinely applied for actual treatment planning using the F10 beam arrangement. The constraints of the standard template were adjusted, if desired, during the optimization process to achieve a satisfactory plan for each patient. Derived from the approved inverse optimization planning with the F10 technique for actual clinical treatment, the customized constraints were then applied to the 4 other techniques to create the respective SIB-IMRT plans for the 10 patients with NPC included in this study. The approved criteria for DVH are shown in Tables 3 and 4.

Analysis

The 4 new optimized plans of each individual case were normalized to obtain the same coverage of $PTV_{63\ Gy}$ as that of the F10 technique. The DVH of targets and other critical organs were compared among the 5 techniques (Tables 5 and 6). Plans were rejected because of inadequate coverage of $PTV_{70\ Gy}$ or excessive dose to the spinal cord or brain stem.

The conformity index[9] was used to evaluate plan conformity. The equation is expressed as follows:

$$CI = \frac{RV}{PTV\ in\ RV} \times \frac{1}{PTV\ in\ RV/PTV} \quad (1)$$

$$= \frac{RV}{PTV} \times \left(\frac{1}{PTV\ in\ RV/PTV}\right)^2 \quad (2)$$

where RV is the radiation volume. Overall, 4 conformity indices, namely, $CI_{70\ Gy}$, $CI_{63\ Gy}$, $CI_{49\ Gy}$, and $CI_{35\ Gy}$, were defined in our study. $CI_{70\ Gy}$ and $CI_{63\ Gy}$ are the conformity indices of 70 and 63 Gy, respectively and are described as the dose conformity to high-dose regions (Eqs. (3) and (4)). $CI_{49\ Gy}$ and $CI_{35\ Gy}$ are the

Table 1
TNM stages of the 10 patients in our study

T stage	N stage				
	0	1	2	3	Total
1		1			1
2		3	1		4
3	1				1
4	2	1	1		4
Total	3	5	2	0	10