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The field-in-field technique in esophageal cancer radiotherapy

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Summary. *Background and aim of the work:* Radiotherapy plays an important role in the treatment of esophageal cancer at most stages. Some patients undergo T-shaped irradiation that includes the subclavicular region. In this procedure, the cervical region receives a higher dose of radiation than the lower thoracic region because of differences in thickness. We asked whether the field-in-field (FIF) technique would reduce the size of the hot region in T-shaped irradiation. *Methods:* Our study consisted of 16 patients with esophageal cancer; the prescribed dose was 40 Gy in 20 fractions. The conventional radiotherapy plan included 4 fields: anterior-posterior/posterior-anterior (AP/PA) parallel-opposed fields and right-anterior oblique and left-posterior oblique fields. The FIF plan included an additional subfield, which was generated by copying the PA field. The multileaf collimators of the subfield were manipulated to shield the areas of the planning target volume (PTV) receiving doses ≥107% of the prescribed dose on the beam's eye view. After dose calculation, weight was shifted from the original PA field to the subfield until the hot spot disappeared. *Results:* The volumes of the PTV receiving 107% of the prescribed dose, the maximum doses (Dmax) to the PTV and spinal cord, and the homogeneity index of the PTV were significantly smaller in the FIF plan than in the conventional plan. *Conclusions:* These findings show that the FIF technique improves the dose homogeneity of the PTV and reduces the maximum dose to the spinal cord in thoracic esophageal cancer.

Key words: sophageal cancer, field-in-field technique, radiotherapy

Introduction

Radiotherapy plays an important role in the treatment of esophageal cancer. According to the National Comprehensive Cancer Network (NCCN) guidelines, esophageal cancer patients with clinical stages cT1b-T4a and, N0-N+ are candidates for preoperative or definitive chemoradiation. Patients with clinical stage T4b are candidates for definitive chemoradiation (1). Patients with locally advanced esophageal cancer are especially suited for definitive chemoradiotherapy (CRT) (2-4). Because of widespread lymph node distribution in esophageal cancer, approximately 27% of patients present with metastases in the subclavicular nodes, even if the primary site is located in the lower thoracic esophagus (5). Some patients require T-shaped irradiation that includes the subclavicular region. In this procedure, the cervical and the upper thoracic body receives a higher dose than the lower thoracic body because it is thicker. The usefulness of the field-in-filed (FIF) radiotherapy technique in other cancers has been reported (6), and this technique is now widely performed. It can improve dose homogeneity and reduce hot region size. Unfortunately, there are few reports about the FIF technique in esophageal cancer. The purpose of this study was to compare the FIF technique and conventional irradiation in esophageal cancer radiotherapy.

Materials and methods

This study was conducted with the approval of our institutional review board. Computed tomography (CT) images were obtained using a scanner with 16 detector arrays (LightSpeed Xtra; GE Healthcare, Waukesha, WI, USA). Scanning was performed in 2.5-mm slices from the cervical to the mid-abdomen during free breathing. The clinical target volume (CTV) was included the subclavicular and cardiac regions. The planning target volume (PTV) was defined as the CTV with 1-cm margins. The lungs, heart, and spinal cord were delineated as organs at risk by referring to the contouring atlas of "RTOG 1106 OAR" by the Radiation Therapy Oncology Group (RTOG) (7). Both lungs were contoured as one structure using a pulmonary window. Small vessels extending beyond the hilar regions were included as part of the lungs. The hila, trachea, and main bronchus were not included in the lung structure. The superior aspect of the heart was set at the level of the inferior aspect of the pulmonary artery passing the midline. The inferior aspect of the heart was set at the apex. The spinal cord was contoured based on the bony limits of the spinal canal.

In Japan, the total dose usually used in definitive radiotherapy for esophageal cancer is 60 Gy. The first 40 Gy is delivered in 20 fractions to the area of gross tumor involvement and the regional lymph node area. The additional 20 Gy is delivered to only the margins of the gross tumor (excluding the spinal cord). Therefore, in our study, the prescribed dose was 40 Gy in 20 fractions, and the photon energy was 10 MV. The leaf margin was 3 mm. The conventional radiotherapy plan included 4 fields: anterior-posterior/posterior-anterior (AP/PA) parallel-opposed fields and right-anterior oblique and left-posterior oblique fields. The beam weights of the oblique fields were approximately half of the beam weight of the AP/PA fields. The FIF plan included an additional subfield, which was generated by copying the PA field. The multileaf collimators of the subfield were manipulated to shield the areas of the PTV receiving doses ≥107% of the prescribed dose on the beam's eye view (Figure 1). After dose calculation, weight was shifted from the original PA field to the subfield until the hot spot disappeared.

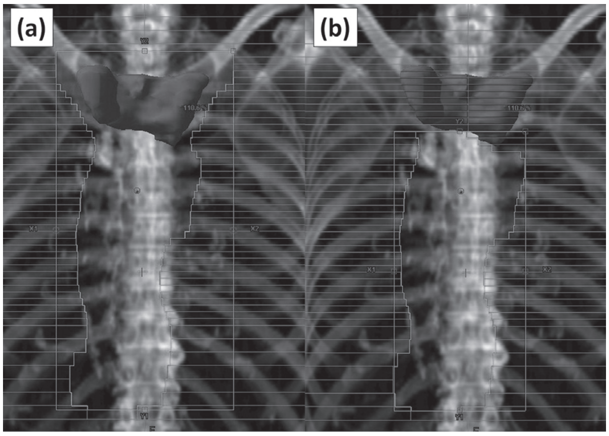

Figure 1. Beam's eye views of a typical original field and subfield. The typical original posterior-anterior field (a) is shown. The subfield was manipulated to shield the areas of the planning target volume receiving doses ≥107% of the prescribed dose (b)

A dose-volume histogram was calculated for each patient. The volumes of the PTV receiving 107% and 95% of the prescribed dose (V107% and V95%, respectively) and the maximum dose (Dmax) to the PTV were calculated. The homogeneity index (HI) was defined as (D2 - D98)/Dprescription, where D2 is the dose delivered to 2% of the PTV, D98 is the dose delivered to 98% of the PTV, and Dprescription is the prescribed dose. The maximum dose to the spinal cord was also calculated. The volumes of the lung receiving 20 Gy (V20Gy) and the mean dose to the lungs (MLD) were also calculated. Dosimetric parameters were compared using the Wilcoxon signed-rank test. A p value less than 0.05 was considered to indicate a statistically significant difference.

Results

Sixteen patients (12 men and 4 women) with esophageal cancer were enrolled in this planning study. All patients provided informed written consent before the radiotherapy. The median age of the patients was 66 years (range, 38-85 years). All esophageal cancers were squamous cell carcinomas. The patient characteristics are shown in Table 1.

The averages of the dose parameters for the PTV and spinal cord are shown in Table 2. The V107%, V95%, and Dmax values for the PTV were significantly

Table 1. Patients characteristics

Median age (range) (years)		66 (38-85)
Male / Femal		12 / 4
Tumor site	Upper thoracic	5
	Middle thoracic	11
Stage	IA	1
	IB	1
	IIA	1
	IIB	1
	IIIA	3
	IIIB	2
	IIIC	7
Median height (cm)		164.9 (147.7-174.0)
Median weight (kg)		52.0 (36.6-72.4)
Median body mass index (kg/m^2)		18.6 (15.6-26.0)

Table 2. Dose parameters of the PTV[a] and the spinal cord

	Conventional plan	FIF[b] plan	p value
PTV			
Dmax[c] (Gy)	43.9 ± 0.5	42.4 ± 0.3	<0.0001
V107%[d] (cc)	7.7 ± 4.5	0	<0.0001
V95%[e] (cc)	91.4 ± 4.3	89.2 ± 3.7	0.0131
HI[f]	0.182 ± 0.067	0.167 ± 0.073	0.0308
Spinal cord			
Dmax (Gy)	43.2 ± 0.6	41.7 ± 0.6	<0.0001

Valus are expressed as mean ± standard deviation
[a]PTV = planning target volume, [b]FIF = field-in-field, [c]Dmax = maximum dose, [d]V107% = percentage of the PTV receiving 107% of the prescribed dose, [e]V95% = percentage of the PTV receiving 95% of the prescribed dose, [f]HI = homogeneity index

smaller in the FIF plan than in the conventional plan. V107% in the FIF plan was 0 in all patients. The HI was also significantly smaller in the FIF plan than in the conventional plan, as was Dmax in the spinal cord.

The mean (± standard deviation [SD]) value of V20Gy for the conventional plan was 17.3 (±6.3) and for the FIF plan was 17.3 (±6.1). The mean (±SD) value of MLD for the conventional plan was 9.3 (±2.3) and for the FIF plan was 9.8 (±2.2). The difference in MLD was statistically significant (p = 0.0003).

Discussion

Esophageal cancer is often treated via radiotherapy regardless of stage. Definitive CRT is particularly useful for treating locally advanced esophageal cancer, even if it is resectable (2-4). In resectable T1-3N0-1M0 thoracic esophageal cancer, outcomes were better after CRT (and salvage therapy if needed) than surgery alone in a study by Ariga (8); in a study by Hironaka, outcomes were comparable in T2-3NanyM0 thoracic esophageal cancer (9). Kato reported high complete response and survival rates in patients with T1 disease receiving CRT (10), and Hölscher showed that preoperative CRT significantly improved 5-year survival rates in patients with T3 disease (11). CRT has also been found to be an effective salvage treatment for postoperative locoregional recurrent esophageal cancer (12, 13).

Japanese surgeons have improved survival using 3-field regional lymph node dissection for esophageal cancer (14, 15). This procedure is thought to reduce regional lymph node recurrence by eliminating micrometastases. Elective nodal irradiation is another radiotherapy method that has been useful in Japan, although its benefits elsewhere are controversial.

As noted in the Introduction, dose distribution in the thoracic area is not inhomogeneous in T-shaped irradiation (i.e., the cervical and upper thoracic region receives a higher dose than the lower thoracic region). The hot spot in the cervical cord makes it difficult to create effective radiotherapy plans. The FIF technique can improve dose homogeneity and reduce the size of the hot region in some cancers (6), and the effect of respiratory motion on its accuracy is within the acceptable range (16). To our knowledge, there is only one publication (in Japanese) describing the FIF technique in esophageal cancer (17). Ours is the first report to do so in English.

Our results show that the FIF technique increases dose homogeneity and reduces hot region size in esophageal cancer. The HI of the PTV was significantly lower in the FIF plan than in the conventional plan, as was Dmax and V107%. On the other hand, V95% in the PTV was slightly lower in the FIF plan than in the conventional plan. However, the boost irradiation planned for the gross tumor with appropriate margins may compensate for this dose reduction.

The Dmax value for the spinal cord was also significantly lower in the FIF plan than in the conventional plan. In the study by Chan, delivery of 44 Gy to the spinal cord resulted in radiation myelitis in some patients (18). Therefore, reducing the dose to the spinal cord is important to avoid radiation myelitis. In our study, the dose to the spinal cord was >44 Gy in some patients in the conventional plan; however, the Dmax to the spinal cord did not exceed 44 Gy in any of the patients in the FIF plan.

Although the MLD in the FIF plan was significantly smaller than that in the conventional plan, the difference was very small. The dose to the lungs seemed to be equal between both methods.

The mean (±SD) value of monitor units (Mus) was 221.6 (±8.1) for the conventional plan and 222.2 (±8.3) for the FIF plan. Although the difference was statistically significant (p = 0.0004), it was a small difference. The merits of the conventional plan are that the treatment planning time is short and Mus are slightly low. However, these advantages were not far from the advantages of the FIF plan.

Recent articles, mostly from western countries, report the usefulness of intensity-modulated radiotherapy (IMRT) in esophageal cancer (19-22). However, many institutes do not use IMRT because of the shortage of manpower. The FIF technique offers a reasonable alternative to IMRT.

In conclusion, the FIF technique improves the dose homogeneity of the PTV and reduces the maximum dose to the spinal cord in thoracic esophageal cancer.

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