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Dosimetry Contribution:

Identification of the suitable leaf margin for liver stereotactic body radiotherapy with flattening filter-free beams

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A B S T R A C T

The purpose of this study is to identify the suitable leaf margin for liver stereotactic body radiotherapy (SBRT) with flattening filter-free (FFF) beams, as compared with that with flattening filter (FF) beams. SBRT treatment planning for 10 patients with liver cancer was performed using 10-MV FFF and FF beams obtained from a Varian TrueBeam (Varian Medical Systems, Palo Alto, CA) linear accelerator. Each plan was generated with the leaf margin to the planning target volume (PTV) ranging from –3 to 5 mm. The prescription dose at D95 (dose covering 95% of the volume) was 48 Gy in 4 fractions to the PTV. The following dosimetric parameters were evaluated quantitatively: homogeneity index (HI), conformity index (CI), gradient index (GI), the normal liver receiving a dose greater than or equal to 20 Gy (V20), and the mean normal liver dose. The HI for FFF and FF beams increased as the leaf margin decreased. The leaf margins that achieved the best CI and GI were 0.1 and –0.3 mm for FFF beams, and 0.1 and –0.9 mm for FF beams. The liver V20 and the mean liver dose reached their minimum values at leaf margins of –0.8 and 0.0 mm for FFF beams, and –0.8 and 0.0 mm for FF beams. The suitable leaf margin for SBRT planning did not differ significantly for FFF and FF beams. Our data showed that, for both FFF and FF beams, a leaf margin of 0 or –1 mm was optimal for liver SBRT planning in terms of both target coverage and normal tissue sparing.

Introduction

Stereotactic body radiotherapy (SBRT) is an emerging treatment modality that enables high dose conformity and normal tissue dose sparing with short fractionation schemes. In recent years, several studies have shown that SBRT was safe and provided excellent outcomes as a treatment for primary and metastatic liver tumors.[1,2]

Flattening filter-free (FFF) beams have recently become available for commercial C-arm linear accelerators. As compared with flattening filter (FF) beams, the advantages of FFF beams include a reduced peripheral dose, as a result of lower head scatter and leakage, and reduced variation in the energy spectrum in the off-axis position.[3] Furthermore, FFF beams

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are advantageous because they shorten the time that is needed to deliver plans, owing to an increased dose rate.[4] The high dose rate offers a significant speed benefit for hypofractionated SBRT with higher fraction doses. Because the application of breath hold and respiratory gating techniques can extend treatment times, a shorter treatment delivery time is needed to improve both the patient's comfort and intrafraction organ motion. Recently, several planning studies have demonstrated that SBRT plans with FFF beams have a treatment plan quality that is equivalent to that of FF beams, but require less delivery time.[5,6]

High dose conformity and sharp dose falloff outside of the target are essential for SBRT plans because they use higher fraction doses. Wakai *et al.* assessed the optimal leaf margin in SBRT using 7-MV FFF and 6-MV FF beams for lung tumors.[7] They reported that a leaf margin of –1 mm provided the best target coverage and sparing of normal tissues for both FFF and FF beams. However, no published studies have assessed suitable leaf margins for FFF SBRT plans that use 10-MV photons in the treatment of liver cancer. In the present study, we determined the appropriate leaf margin for liver SBRT plans with FFF beams, as compared with those with FF beams.

Methods and Materials

Patients

We recruited 10 patients with liver cancer for this retrospective study. All patients were immobilized using a vacuum cushion in the supine position and computed tomography (CT; slice thickness: 2.0 mm) was performed from the trachea to below the L5 spine for treatment planning. Four-dimensional CT images binned into 10 respiratory phases were obtained using a real-time position management (RPM) respiratory gating system (Varian Medical Systems, Palo Alto, CA). The internal target volume was defined using the 4-dimensional CT motion and individualized treatment margins were applied to generate the planning target volume (PTV). The prescription doses at D95 (dose covering 95% of the volume) were 48 Gy in 4 fractions to the PTV. The PTV size ranged from 7.8 to 92.9 cm^3, with a median of 22.4 cm^3.

SBRT planning

The treatment plans were prepared using Eclipse software (version 11.0.31, Varian Medical Systems) for delivery on a TrueBeam linear accelerator (Varian Medical Systems) with 10-MV FFF beams and FF beams. Three-dimensional conformal radiotherapy (3D-CRT) plans were generated using 7 to 9 coplanar static fields. Each plan was generated with the leaf margin to the PTV ranging from –3 to 5 mm. For dose calculation, we used the anisotropic analytical algorithm with a dose calculation grid of 2.0 mm. The maximal dose rates were set to 2400 MU/min for FFF beams and 600 MU/min for FF beams.

Evaluation tools

Quantitative evaluations and comparisons of the plans were performed based on cumulative dose-volume histograms. For the PTV, the homogeneity index (HI), conformity index (CI), and gradient index (GI) were used as comparison metrics for the FFF and FF plans. HI was defined as $(D_{2\%} - D_{98\%})/D_{50\%}$, where $D_{2\%}$, $D_{98\%}$, and $D_{50\%}$ indicate the doses received by 2%, 98%, and 50% of the volume, respectively.[8] CI was calculated as V_{pi}/PTV, where V_{pi} and PTV represent the volume receiving a dose equal to or greater than the prescribed dose and the PTV, respectively.[9] The GI was defined as the ratio of the volume receiving a dose equal to or greater than the 50% prescribed dose to the V_{pi}.[10] In the evaluation of the dose to organs at risk (OAR), the mean dose to the normal liver and the percentage of the normal liver volume receiving ≥ 20 Gy (V20) were recorded. Normal liver was defined as the whole liver minus the gross tumor volume.

Statistical analysis

Comparisons between pairs of groups were performed using the nonparametric Mann-Whitney U test because of the small sample size. A p-value of < 0.05 was considered to indicate statistical significance.

Results

The typical transversal dose distributions that were obtained using the FFF and FF plans are presented in Fig. 1 for various leaf margins. The dose distributions of the FFF and FF plans appear visually identical for the same leaf margin. Figure 2 shows the PTV and the normal liver dose-volume

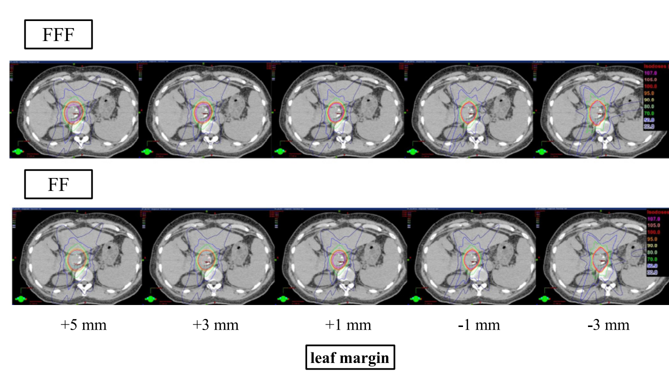

Fig. 1. The typical transversal dose distributions obtained using FFF beams (upper row) and FF beams (lower row) for various leaf margins. (Color version of figure is available online.)