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Dosimetric evaluation of MLC-based dynamic tumor tracking radiotherapy using digital phantom: Desired setup margin for tracking radiotherapy

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The purpose of this study is to evaluate the dosimetric impact of the margin on the multileaf collimator-based dynamic tumor tracking plan. Furthermore, an equivalent setup margin (EM) of the tracking plan was determined according to the gated plan. A 4-dimensional extended cardiac-torso was used to create 9 digital phantom datasets of different tumor diameters (TDs) of 1, 3, and 5 cm and motion ranges (MRs) of 1, 2, and 3 cm. For each dataset, respiratory gating (30% to 70% phase) and tumor tracking treatment plans were prepared using 8-field 3-dimensional conformal radiation therapy by 4-dimensional dose calculation. The total lung V20 was calculated to evaluate the dosimetric impact for each case and to estimate the EM with the same impact on lung V20 obtained with the gating plan with a setup margin of 5 mm. The EMs for {TD = 1 cm, MR = 1 cm}, {TD = 1 cm, MR = 2 cm}, and {TD = 1 cm, MR = 3 cm} were estimated as 5.00, 4.16, and 4.24 mm, respectively. The EMs for {TD = 5 cm, MR = 1 cm}, {TD = 5 cm, MR = 2 cm}, and {TD = 5 cm, MR = 3 cm} were estimated as 4.24 mm, 6.35 mm, and 7.49 mm, respectively. This result showed that with a larger MR, the EM was found to be increased. In addition, with a larger TD, the EM became smaller. Our result showing the EMs provided the desired accuracy for multileaf collimator-based dynamic tumor tracking radiotherapy.

Introduction

Lung cancer is the leading cause of cancer-related mortality in Japan.[1] At present, surgical resection remains the standard curative treatment of early stage non–small cell lung cancer (NSCLC).[2] However, some patients are contraindicated

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for surgery because of advanced age or the presence of comorbidities, such as emphysema or heart disease. Thus, aggressive stereotactic body radiotherapy (SBRT) at a high hypofractionated dose plays a key role in the treatment of early-stage NSCLC. SBRT for the treatment of lung cancer results in high local control rates by focusing a high radiation dose on the target while sparing normal surrounding tissues.[3-5]

Lung toxicity continues to be a severe side effect of SBRT for early stage NSCLC. Fakiris *et al.* reported grades 3 to 5 toxicity in 17.1% of patients, and Timmerman *et al.* reported a rate of grade 3 toxicity of 12.7%.[6,7] To reduce the extent of lung toxicity, several research groups have developed multileaf collimator (MLC)-based dynamic tumor tracking radiotherapy techniques.[8-10] Our group has also been developing the MLC-based dynamic tumor tracking radiotherapy technique for the treatment of lung cancer.[11,12] It is well known that dynamic tumor tracking radiation therapy can potentially reduce the internal margin without prolonging irradiation time.[13-15] Saito *et al.* demonstrated that the gated delivery for 50% and 30% of the respiratory cycle required 20 seconds and 33.3 seconds for 100 monitor units (MU) using dose rate of 600 MU/min, compared with the nongated delivery with 10 seconds for 100 MU.[15] In addition, Takao *et al.* showed that the incidence of baseline shift/drift exceeding 3 mm was 14.0% for the craniocaudal (C-C) direction within 10 minutes of the start of treatment.[16] This result suggested that gated radiotherapy required more treatment time due to intrafractional baseline shift or drift of lung tumor motion during gated radiotherapy in clinical care. Linear accelerator (Linac) has begun to use high dose rate of a flatting filter free mode (*e.g.,* 2400 MU/min) for lung cancer patients in clinical practice.[15,17,18] This technique can reduce the treatment time, compared with Linac with normal dose rate of a flatting filter mode (*e.g.,* 600 MU/min). Thus, the high dose rate of the flatting filter free mode has the potential for solving the issue of prolonging irradiation time caused by the gated delivery. However, we used Linac beam with flatting filter in this study because at present, normal dose rate of the flatting filter mode was still commonly used in clinical practice in Japan.

The MLC-based dynamic tumor tracking technique requires an extra margin because of the uncertainty of the tumor location and for the prediction of respiratory motion and beam repositioning. The dosimetric impact of MLC-based dynamic tumor tracking is dependent on the setup margin of the tracking plan. Thus, the main focus of this study was to estimate a setup margin equivalent to that for respiratory-gated radiotherapy using different setup margins with tumors of different tumor diameters (TDs) and motion ranges (MRs). An equivalent or smaller setup margin provides the desired accuracy for MLC-based dynamic tumor-tracking radiotherapy because it provides the dosimetric impact better than or comparable with the gated plan, with a shorter irradiation time. An equivalent setup margin is expected to be helpful in further improving dynamic tumor tracking radiotherapy.

For irradiation technique, in early-stage lung cancer for SBRT, 3-dimensional conformal radiotherapy (3D-CRT) has often been used in Japan.[19,20] Furthermore, SBRT with 3D-CRT has been focused on in light of the small effect of patient movement resulting from lack of modulated beam.[21] Thus, we used 3D-CRT for MLC-based dynamic tracking planning in this study.

The aim of the present study was to evaluate an equivalent setup margin of respiratory-gated radiotherapy for MLC-based dynamic tumor tracking radiotherapy using a digital phantom with different TDs and MRs using 3D-CRT.

Material and Methods

Digital phantom

Nine digital phantom datasets of different TDs of 1, 3, and 5 cm and MRs of 1, 2, and 3 cm were created using 4-dimensional extended cardiac-torso phantom (Duke University, NC).[22] The voxel dimension was 1 mm (approximate) × 1 mm (approximate) × 2.5 mm. In this phantom, the tumor was set in the left lower lobe, as shown in Fig. 1. The 4D computed tomography (4D-CT) dataset consisted of 10 discrete respiratory phases (0% to 90% phase). In evaluating the equivalent setup margins for various TDs and MRs, digital phantom is a suitable tool because the TD and MR can be changed arbitrarily. If we use patient data for this study, TD and MR cannot be changed arbitrarily. Thus, we used digital phantom for this study.

Treatment planning

To create a treatment plan for MLC-based dynamic tumor tracking radiotherapy and gated radiotherapy, 4D dose calculation with deformable image registration (DIR) was used to calculate the accurate irradiated dose to total lung. As the MLC-based dynamic tumor tracking plan had different 10 dose distributions on each phase (0% to 90%) with different MLC apertures, DIR is essential for summation of all 10 dose distributions, resulting in 1 dose distribution (*i.e.,* 4D dose) on reference image. In the same manner, as gated plan had different 5 dose distributions on each phase (30% to 70%) with same MLC apertures, DIR is essential for summation of all 5 dose distributions. RayStation version 4.5.1 (RaySearch Laboratories, Stockholm, Sweden) was used as the treatment planning system combined with the collapsed cone dose calculation algorithm and a hybrid intensity and structure-based DIR algorithm (the Anatomically constrained deformation algorithm (ANACONDA) algorithm).[23]