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PHYSICS CONTRIBUTION

TREATMENT PLANNING OF STEREOTACTIC RADIOTHERAPY FOR SOLITARY LUNG TUMOR

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Purpose: To analyze the stereotactic radiotherapy (SRT) plans in terms of internal target volume (ITV) and organs at risk (OARs).
Methods and Materials: Treatment planning and dose distributions were analyzed using dose–volume histograms (DVHs) of ITV and OARs in 37 patients, who were treated for a solitary lung tumor with SRT. The stereotactic body frame (SBF) was used for immobilization and accurate setup. Prescription dose was 48 Gy in four fractions at the isocenter.
Results: Use of SBF limits the extent of the noncoplanar beam directions to prevent a collision with the Linac gantry. DVH analyses showed that the homogeneity index, defined as the ratio of maximum and minimum dose to ITV, ranged from 1.03 to 1.25 (mean, 1.12). The volume irradiated with 20 Gy or more (V_{20}) of the lung ranged from 0.3 to 11.6% (mean, 4.4%) of the whole lung volume. The maximum dose to the other OARs ranged from 0 to 11.8 Gy (mean, 0.5–2.7) per fraction. No clinically significant complications were encountered.
Conclusions: Despite the limitation of the beam arrangement, a homogeneous target dose distribution, while avoiding high doses to normal tissues, was obtained.

Stereotactic radiotherapy, Lung tumor, Treatment planning, Dose–volume histogram, Normal tissue.

INTRODUCTION

Stereotactic radiotherapy (SRT) has recently been applied to patients with small lung tumors. Initial clinical results including ours were favorable, and local control rates around 90% have been reported (1–9).

Few reports, however, have been made about details of treatment planning—such as beam arrangement, dose distribution to the target, and tolerance dose of normal tissues. Regarding normal tissue, the use of a single high dose rather than a conventional dose in consideration of the biologic effect may increase the risk of complication. However, few cases with severe toxicity have been reported.

At Kyoto University, we have treated more than 80 patients with this method since July 1998, with the approval of our institutional review board and written informed consent provided by all patients. Our initial reports on daily setup accuracy and clinical results have already been published (5, 10). This article reports on our treatment planning procedures and results, especially in terms of doses to internal target volume (ITV) and organs at risk (OARs) using dose–volume histograms (DVHs) for the first half of cases.

METHODS AND MATERIALS

Treatment planning procedure

A stereotactic body frame (SBF) (Elekta AB, Stockholm, Sweden) was used as an immobilization device. We have previously reported the details of its use and its effect on daily setup accuracy and reduction of respiratory tumor motion (10).

The following describes the flow chart of our treatment planning procedures. First, the body of the patient was fixed by means of a vacuum pillow in SBF. The patient was set in the supine position with both arms raised using a T-shaped holding bar. The patient and SBF were set on the couch of an X-ray simulator to measure

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tumor movement during free breathing using fluoroscopy. When the tumor moved more than 10 mm in the craniocaudal (C-C) direction, a small abdominal pressing plate called a “diaphragm control” was applied before computed tomography (CT) scanning, which suppresses the movement of the diaphragm and reduces tumor movement during respiration. CT images were then sequentially scanned from the neck to the upper abdomen with a CT simulator. The CT slice thickness and pitch were 1 to 3 mm each in the area of the tumor and 10 mm each in the other areas. Each CT slice was scanned with an acquisition time of 4 s to include the whole phase of one respiratory cycle. A series of CT images, therefore, included the tumor and its respiratory motion. The isocenter coordinate was defined using a three-dimensional radiation treatment planning system (3D RTPS) (CADPLAN R.6.0.8, Varian Associates, Palo Alto, CA). Anteroposterior (A-P) and lateral films for verification were then obtained using the X-ray simulator at a designated isocenter. Because the CT simulator and the X-ray simulator employed the same couch in our integrated system, the patient’s position on verification films was the same as that on CT images in relation to SBF (10).

The outlines of the target were delineated on 3D RTPS using lung CT window settings (window width 2000 Hounsfield units (HU) and window level −700 HU, typically). A physician delineated both the solid area (tumor itself), which could be seen even using mediastinal CT window settings (window width 350 HU and window level 40 HU, typically), and the surrounding obscure area, which could be seen only under lung CT settings. The obscure area is important because it indicates either tumor microscopic invasion or respiratory tumor motion. This target volume corresponded to the ITV in International Commission on Radiation Units and Measurements Report 62. The outlines of gross tumor volume and clinical target volume were included in the ITV, and gross tumor volume and clinical target volume could not be delineated on the planning CT in our system because the CT images already included the internal motion. Spiculation and pleural indentation were included within the ITV. Neither mediastinal nor hilar lymph nodes were included within the ITV.

The physician also delineated the outline of the following OARs: lung, spinal cord (canal), pulmonary artery, heart, and esophagus. The outline of the lung included that of the target. The pulmonary artery, heart, and esophagus were delineated with each outer contour and included both the wall and content of each organ. The pulmonary artery was delineated from its origin to the pulmonary hila. The esophagus was delineated from the level of the sternal notch to the esophagocardial junction.

Treatment planning was performed using the 3D RTPS, and 5–10 noncoplanar static ports were selected. Edges of the multileaf collimator (MLC) were located 8–10 mm outside of the ITV in the C-C direction and 5 mm in the A-P and lateral directions. The distance in the C-C direction was larger than that in the other directions, because the former was set to compensate for an irregular respiratory motion which could not be included in the ITV using the CT scan with the acquisition time of 4 s. The prescribed dose was 12 Gy per fraction at the isocenter, and the total dose was 48 Gy with four fractions. The dose was delivered by a linear accelerator (CLINAC 2300 C/D, Varian medical systems) with 6-MV photons. Each MLC had a 1-cm leaf width at the isocenter. One of the planning goals was to maintain a dose homogeneity of ITV within 10%, which meant a dose to ITV ranging from 90% to 110% of the isocenter dose. Another goal was to maintain V_{20} (the volume irradiated with 20 Gy or more) of the bilateral lung at less than 25%. Beam arrangement was also selected to minimize doses to OARs. The use of the beam that passed directly through the spinal cord was avoided.

Beam arrangement

The applicable area of noncoplanar beam directions is more limited in SRT for extracranial tumors compared with intracranial tumors. There are three main causes: *(1)* risk of collision of the couch and the gantry; *(2)* blockade of the contralateral posterior beams by the supporting metal bar at the couch center; and *(3)* usage of the SBF that might cause the additional collision with the gantry. Figure 1 shows examples of the applicable gantry angle range that varies depending on the couch angle. We usually shift the position of the supporting couch and SBF in the lateral direction to avoid the metal bar on the center of the couch for a posterior beam, as shown in Fig. 2a. The figure shows the scheme of the couch and SBF shift from the foot-side view, in which the couch is shifted to the left side by 16.5 cm, and the SBF is shifted to the right side by 6.5 cm to put the center of the right-sided target on the isocenter. To find the applicable beam directions on the 3D RTPS more easily, we made diagrams that indicated applicable combinations of couch and gantry angles (11). Fig. 2b shows the diagram for the right-sided tumor. The area between an upper line and a lower line presents the applicable combination of the gantry and couch angles in each different isocenter height from the SBF base that determines the couch height. The diagrams were very useful in finding applicable beam directions at the time of treatment planning.

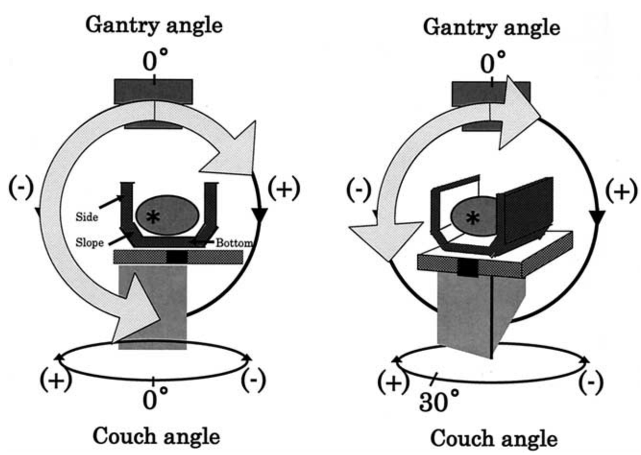

Fig. 1. Limitation of the couch and gantry angles. The left figure shows the applicable gantry position when the couch is set to the standard position (0° of the couch angle) and the tumor is in the right lung. The beam from the left direction cannot be used either because of the collision of the gantry and the couch or SBF. The beam from the posterior direction cannot be used either because of the interference of the supporting bar that lies in the center of the couch. Therefore, the applicable gantry angles are limited in the range of the thick arrow. Larger we set the couch rotation angle (e.g., 30° as shown in the right figure of Fig. 1), wider gets the zone in which the gantry and either the couch or stereotactic body frame mutually interfere. The range of the applicable gantry angle, therefore, is limited further as the thick arrow shows in the right figure. The supporting bar at the couch center is shown as a black square. The outer stiff frame of the stereotactic body frame consists of bilateral “side” walls, a “bottom” wall, and “slope” walls between the side and the bottom.