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PHYSICS CONTRIBUTION

DOSIMETRIC EFFECT OF TRANSLATIONAL AND ROTATIONAL ERRORS FOR PATIENTS UNDERGOING IMAGE-GUIDED STEREOTACTIC BODY RADIOTHERAPY FOR SPINAL METASTASES

He Wang, Ph.D.,* Almon Shiu, Ph.D.,* Congjun Wang, Ph.D.,* Jennifer O'Daniel, Ph.D.,* Anita Mahajan, M.D.,† Shiao Woo, M.D.,† Praimakorn Liengsawangwong, M.S.,* Radhe Mohan, Ph.D.,* and Eric L. Chang, M.D.†

Departments of *Radiation Physics and †Radiation Oncology, The University of Texas M.D. Anderson Cancer Center, Houston, TX

Purpose: To investigate the dosimetric effects of translational and rotational patient positioning errors on the treatment of spinal and paraspinal metastases using computed tomography image-guided stereotactic body radiotherapy. The results of this study provide guidance for the treatment planning process and recognition of the dosimetric consequences of daily patient treatment setup errors.

Methods and Materials: The data from 20 patients treated for metastatic spinal cancer using image-guided stereotactic body radiotherapy were investigated in this study. To simulate the dosimetric effects of residual setup uncertainties, 36 additional plans (total, 756 plans) were generated for each isocenter (total, 21 isocenters) on the planning computed tomography images, which included isocenter lateral, anteroposterior, superoinferior shifts, and patient roll, yaw, and pitch rotations. Tumor volume coverage and the maximal dose to the organs at risk were compared with those of the original plan. Six daily treatments were also investigated to determine the dosimetric effect with or without the translational and rotational corrections.

Results: A 2-mm error in translational patient positioning error in any direction can result in >5% tumor coverage loss and >25% maximal dose increase to the organs at risk. Rotational correction is very important for patients with multiple targets and for the setup of paraspinal patients when the isocenter is away from bony structures. Compared with the original plans, the daily treatment data indicated that translational adjustments could correct most of the setup errors to mean divergences of −1.4% for tumor volume coverage and −0.3% for the maximal dose to the organs at risk.

Conclusion: For the best dosimetric results, spinal stereotactic treatments should have setup translational errors of ≤1 mm and rotational errors of ≤2°. © 2008 Elsevier Inc.

Dosimetry, Spinal metastases, Image-guided, IG, Stereotactic body radiotherapy, SBRT, Setup errors.

INTRODUCTION

The feasibility and clinical efficacy of using stereotactic body radiotherapy (SBRT) for spinal metastases have been demonstrated (1–9). The main concern with this technique is that the boundaries of the RT targets, normally the vertebral bodies, are usually very close to the spinal cord. Because the spinal cord contains sensory and motor tracts, an overdose of radiation could lead to radiation myelitis or myelopathy. However, an underdose to the tumor could lead to disease progression. Because of the proximity of the spinal cord and the target, a high dose gradient is necessary. In addition, spinal tumors typically have a concave shape surrounding the spinal cord, which is difficult to cover with three-dimensional (3D) conformal plans. Intensity-modulated RT (IMRT) has improved the ability to deliver a highly conformal dose to irregular or concave-shaped tumors in close proximity to the spinal cord. However, because of this steep dose gradient, precise positioning and immobilization of the patient for the daily treatment of spinal cancer become paramount.

Spinal stereotactic radiosurgery critically relies on real-time image registration techniques. Alignment precision within 2 mm was reported when using a two-dimensional X-ray image comparison (5, 6, 10, 11). With in-room computed tomography (CT) imaging available, 3D–3D CT

Reprint requests to: He Wang, Ph.D., Department of Radiation Physics, Unit 94, The University of Texas M.D. Anderson Cancer Center, 1515 Holcombe Blvd., Houston, TX 77030-4009. Tel: (713) 563-2567; Fax: (713) 563-2479; E-mail: hewang@mdanderson.org

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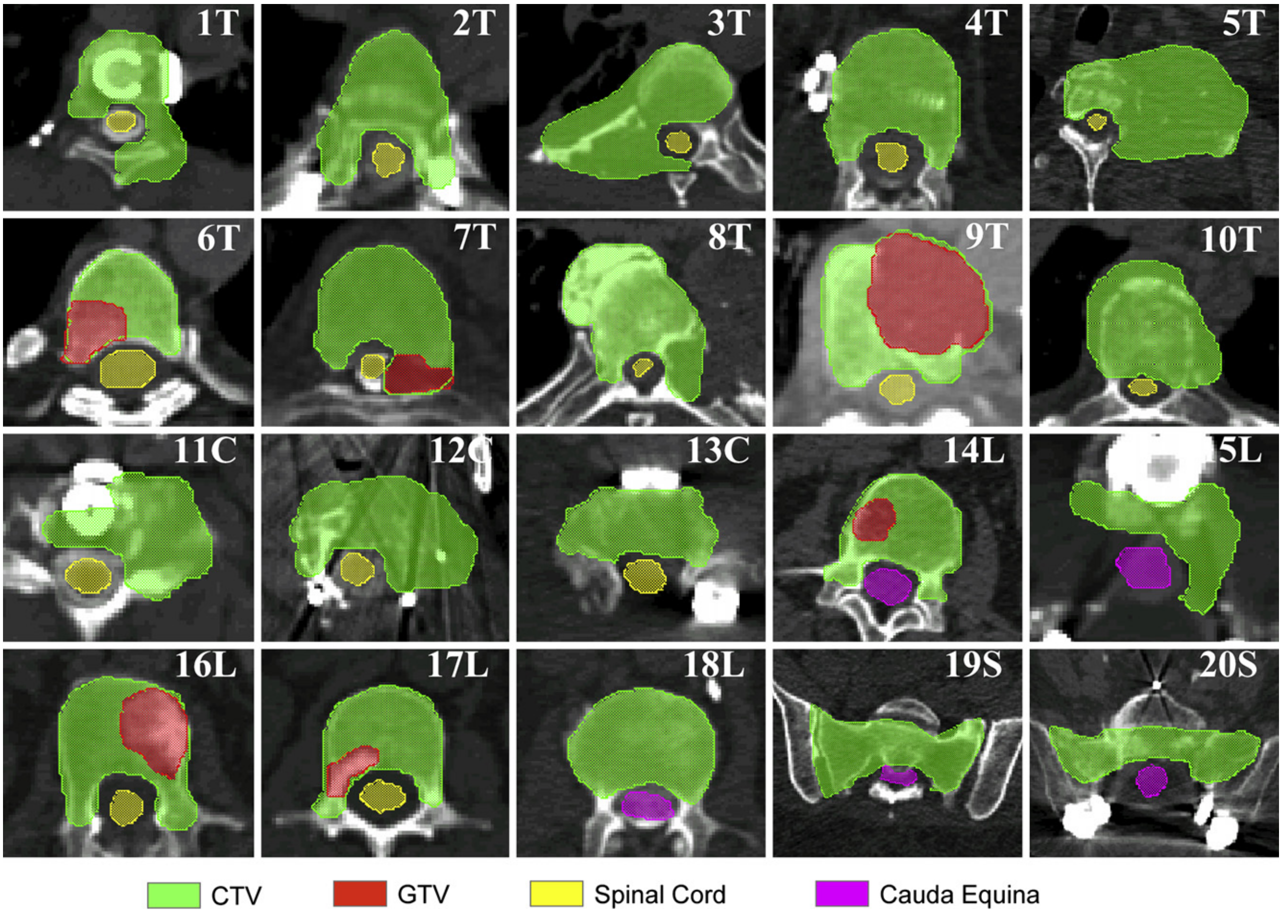

Fig. 1. Tumor sites and shapes for 20 patients. T = thoracic; C = cervical; L = lumbar; S = sacral; CTV = clinical target volume; GTV = gross tumor volume.

image registration provides additional improvement in patient setup accuracy and RT precision for spinal and paraspinal tumors (1, 3, 4). The isocenter setup accuracy can be within 1 mm for daily treatment (1). 3D–3D image registration also has the potential to detect patient rotational setup errors (12) for accurate evaluation of the treatment delivery, which cannot be done easily with two-dimensional–two-dimensional image registration. Other advanced volumetric imaging modalities, such as megavoltage (13) and kilovoltage (14) cone-beam CT and helical tomotherapy (15), have also been investigated and have the potential for extensive use in daily treatment with image-guided stereotactic body RT (IG-SBRT) for spinal metastases.

Despite great effort to achieve precise repositioning and immobilization of patients using the stereotactic body frame and image guidance, radiation delivery uncertainties still exist because of residual setup errors, including translational patient positioning errors and patient rotational errors. Residual setup error can also be caused by intrafractional involuntary patient motion during the setup verification procedure between the pretreatment CT scan and the start of treatment (typically 30 min). Our previous studies using post-treatment CT images showed an $\leq$1-mm daily setup deviation from the planned isocenter in the lateral (LR), anteroposterior (AP), and superoinferior (SI) directions. Considering the special geometric relationship between the tumor target and the spinal cord, rotations of even a few degrees can have a substantial effect on dose distribution, especially when adjacent multiple targets are treated using one isocenter. Thus, the quantitative dosimetric effects of both translational and rotational uncertainties need to be very well understood to ensure delivery of high-quality SBRT to the spine.

The purpose of this study was to investigate the translational and rotational dosimetric effects on the dose coverage of spinal tumors and the organs at risk (OARs) using recalculations of the original therapy plans with simulated setup errors. A few patient-specific cases were also evaluated.

METHODS AND MATERIALS

Patients

A total of 20 patients with spinal metastases (10 thoracic, 3 cervical, 5 lumbar, and 2 sacral) were treated at M.D. Anderson Cancer Center between January 2006 and July 2006. Figure 1 displays the cropped CT images of the clinical target volume (CTV) and OARs (spinal cord or cauda equina) for each patient. For some of these patients, the gross tumor volume (GTV) was also delineated. As shown in Fig. 1, the shape and size of the targets varied dramatically from patient to patient. Most patients had C-shaped or horseshoe-shaped tumors with the OAR in the center. We called this the tumor horseshoe-shaping effect. We could also see that the