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Chest wall dose assessment in stereotactic ablative radiotherapy delivered with volumetric modulated arc therapy for peripheral lung tumors

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ABSTRACT

Background: No consensus on how to best predict for chest wall injury following SABR exists. We report our experience in chest wall dose assessment when treating peri-pleural lung lesions with stereotactic ablative radiotherapy (SABR) delivered with volumetric modulated arc therapy (VMAT).
Methods: 40 patients with peri-pleural peripheral lung tumors underwent SABR between July, 2012 and February, 2015. Chest wall toxicity, dose distribution, and the influence of chest wall delineation method were investigated.
Results: After a median follow up of 16 months, no rib fracture or skin toxicity was observed. 4 patients (10%) reported persistent chest wall pain (grade 1–2). High dose rate's association with chest wall pain trended toward statistical significance ($p=0.06$). PTV exclusion and reducing chest wall expansion to 1 cm led to significant dose reduction in the chest wall dose volume parameters ($p<0.05$). Only three local failures were observed among 44 lesions treated.
Conclusions: The risk of chest wall pain following SABR delivered with VMAT is low. High dose rate, which is 1400 MU/min with flattening filter free (FFF) beams vs. 500–600 MU/min with non-flattening filter free (non-FFF) beams, may contribute to it. Chest wall dose volume parameters may vary with PTV exclusion; while chest wall expansion of 1 cm may fail to account for some high dose regions in the chest wall.

Introduction

Chest wall (CW) injury has been a more commonly encountered toxicity following stereotactic ablative radiotherapy (SABR) for lung tumors close to the chest wall [1,2]. It can present with skin erythema/necrosis, soft tissue fibrosis, chest wall pain, and/or rib fractures. Although non-life-threatening, these toxicities can be debilitating. Thus, many investigators proposed CW dose constraints based on their institutional experience [3–6]. One commonly accepted constraint was to keep the CW volume receiving 30 Gy (V_{30}) to no more than 30 cm^3 for SABR delivered in 3 to 5 fractions [4–6]. This parameter was found with the CW defined as a 3 cm expansion of the normal lung from the sternum to the edge of the vertebral bodies excluding any mediastinal tissue. In a subsequent study, a 2 cm expansion was shown to be more predictive of CW toxicity [7]. In contrast to previous studies, the CW only extended to 1.2 cm above and below the planning target volume (PTV) in this study, and $V_{30} > 30$ cm^3 was not predictive of CW pain for both $CW_{2\ cm}$ and $CW_{3\ cm}$. This suggests that parameters for CW dose assessment may depend on how it is delineated, and multiple factors may need to be considered when estimating the risk of CW injury. As of current, no consensus on how to best predict CW toxicity following SABR exists.

Here, we present our experience with CW dose assessment in the treatment of mostly peri-pleural peripheral lung tumors with SABR delivered with volumetric modulated arc therapy (VMAT). As previously shown, VMAT may provide a dosimetric advantage in chest wall sparing when compared with other 3D conformal techniques [8]. Due to the PTV's vicinity to the CW, meeting CW dose

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constraints constantly imposed a challenge in clinical practice. Thus, they were considered only relatively with more priority given to adequate PTV dose coverage during treatment planning. To investigate how to best delineate the CW, the impact of different delineation methods on CW dose distribution was also explored with the patients' clinical outcome reported.

Materials and methods

Patient selection

Consecutive patients with peripheral lung tumors near the CW treated with SABR in the Department of Radiation Oncology, West Virginia University, between July, 2012 and February, 2015 were included. This study was approved by the Institutional Review Board, and informed consent was not required due to its retrospective nature. Treated tumors include primary/recurrent cT1-T3, N0, M0 or oligometastatic (involving bilateral lungs) non-small cell lung cancer (NSCLC), and isolated lung metastases from other primaries. All patients were staged with fluoro-deoxyglucose positron emission tomography-computed tomography (FDG PET/CT). Most tumors were peri-pleural with PTV (planning target volume) to chest wall distance of 0–1 cm (89%). Patients who received prior thoracic irradiation were excluded.

Stereotactic ablative radiotherapy

SABR was administered with VMAT (Rapid Arc, Varian Medical Systems, Palo, Alto, CA) on Triology or Trubeam (Varian Medical Systems, Palo Alto, CA) with 6 MV photons under daily cone-beam CT (CBCT) image guidance. All patients were simulated and treated supine in the Pro-Lok immobilization device (CIVCO Medical Solutions, Coralville, IA). Patients were simulated with 4D CT or 4D FDG PET/CT. Target/normal structure delineation and treatment planning were performed in the Eclipse treatment planning system (Varian Medical Systems, Palo Alto, CA). The gross tumor volume (GTV) was delineated at the lung window level on the non-contrasted, free-breathing treatment planning CT. The internal target volume (ITV) was contoured to include the tumor from all 10 phases of the 4D CT or 4D FDG PET/CT. The PTV was created by 3–5 mm expansion of the ITV.

The CW was delineated by a 2 cm expansion of the ipsilateral lung, excluding the normal lung parenchyma, mediastinal soft tissue, and the vertebral bodies at the time of target volume delineation. CW's external boundary was not to extend outside the skin surface. Anteriorly, it ends at the edge of the sternum. Postero-medially, it stops at the edge of the vertebral body with inclusion of the spinal nerve root exit site. The cranio-caudal extent expands from the thoracic inlet to the diaphragm. To better account for the CW dose in patients with PTVs that were immediately adjacent to the CW, a structure named "high-risk CW (HR-CW)" was also delineated in these patients. HR-CW was delineated by a 1 cm expansion of the ipsilateral lung as the CW. However, its anterior and postero-medial extents were decided by estimating the arc of high dose engulfing the PTV based on clinical judgement (Fig. 1). Both structures were used to assess the CW dose in the actual treatment plan evaluation. The PTV was excluded from them whenever it extended into these structures.

The influence of the cranio-caudal extent and PTV exclusion on CW dose was also investigated. The dose parameter analyzed was D_x, the dose to x cm^3 of the CW (D_{max}, $D_{0.01}$, $D_{0.1}$, D_1, D_2, D_5, D_{10}, D_{20}, D_{30}, D_{40}, D_{50}, D_{60}, D_{70}, D_{80}, D_{90}, D_{100}). Any missing CW structures were added retrospectively if necessary with re-calculation of the same treatment plans that were used to deliver the actual treatments. Dose volume parameters for the CW (CW without PTV exclusion), the CW-PTV (CW with PTV exclusion), the CW-RTOG (CW with cranio-caudal extent of 3 cm above and below the superior and inferior edges of the PTV), and the CW-RTOG-PTV (CW-RTOG with PTV exclusion) were compared in this analysis; then further compared with that for the HR-CW.

Lesions less than 3 cm in size were treated with 50 Gy in 4 daily fractions. Lesions over 3 cm were treated with 70 Gy in 10 daily fractions. The Acuros XB (AXB) algorithm was used for dose calculation with tissue heterogeneity correction after December, 2012. The anisotropic analytical algorithm (AAA) with tissue heterogeneity correction was used prior to that. The dose was prescribed to the 75–80% iso-dose at the PTV's edge. All plans were optimized to have at least 95% of the PTV receiving the prescription dose. The dose volume constraints used are described in previous publications [9,10]. CW V_{42} was kept to < 30 cm^3 whenever possible if 70 Gy was prescribed. The linear-quadratic

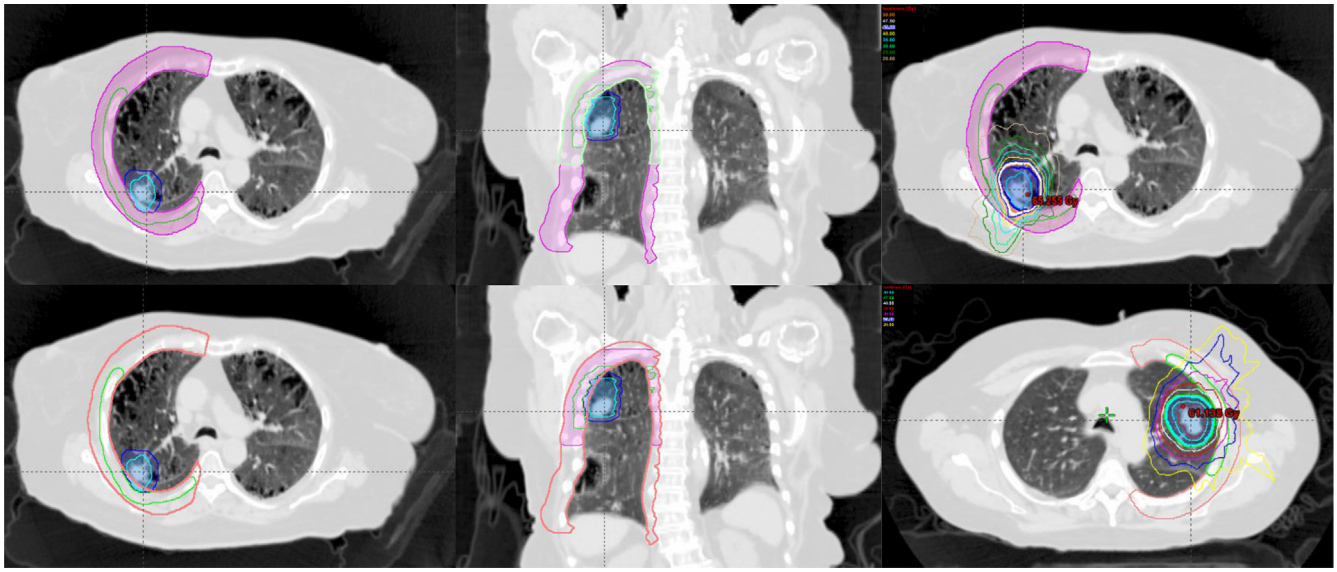

Fig. 1. Axial images of HR-CW (green), CW-PTV (purpose, top), and CW (pink, bottom) are shown on the left. Coronal images of the HR-CW, CW-PTV (purple top), CW-RTOG-PTV (light green, top); CW (pink, bottom), and CW-RTOG (purple, bottom) are shown in the middle. Dose distribution in the vicinity of the chest wall for the same patient (top) and a different patient (bottom) are shown on the right. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)