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Original Article

Robustness quantification methods comparison in volumetric modulated arc therapy to treat head and neck cancer

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Abstract

Background: To compare plan robustness of volumetric modulated arc therapy (VMAT) with intensity modulated radiation therapy (IMRT) and to compare the effectiveness of 3 plan robustness quantification methods.

Methods and materials: The VMAT and IMRT plans were created for 9 head and neck cancer patients. For each plan, 6 new perturbed dose distributions were computed using ±3 mm setup deviations along each of the 3 orientations. Worst-case analysis (WCA), dose-volume histogram (DVH) band (DVHB), and root-mean-square dose-volume histogram (RVH) were used to quantify plan robustness. In WCA, a shaded area in the DVH plot bounded by the DVHs from the lowest and highest dose per voxel was displayed. In DVHB, we displayed the envelope of all DVHs in band graphs of all the 7 dose distributions. The RVH represents the relative volume on the vertical axis and the root-mean-square-dose on the horizontal axis. The width from the first 2 methods at different target DVH indices (such as $D_{95\%}$ and $D_{5\%}$) and the area under the RVH curve for the target were used to indicate plan robustness. Results were compared using Wilcoxon signed-rank test.

Results: The DVHB showed that the width at $D_{95\%}$ of IMRT was larger than that of VMAT (unit Gy) (1.59 vs 1.18) and the width at $D_{5\%}$ of IMRT was comparable to that of VMAT (0.59 vs 0.54). The WCA showed similar results between IMRT and VMAT plans ($D_{95\%}$: 3.28 vs 3.00; $D_{5\%}$: 1.68 vs 1.95). The RVH showed the area under the RVH curve of IMRT was comparable to that of VMAT (1.13 vs 1.15). No statistical significance was found in plan robustness between IMRT and VMAT.

Conclusions: The VMAT is comparable to IMRT in terms of plan robustness. For the 3 quantification methods, WCA and DVHB are DVH parameter–dependent, whereas RVH captures the overall effect of uncertainties.

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Conflicts of Interest: None.

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Introduction

Volumetric modulated arc therapy (VMAT) is an advanced form of intensity modulated radiation therapy (IMRT) that delivers a precisely sculpted 3-dimensional dose distribution using a single- or multiarc treatment. VMAT has rapidly gained popularity in treating head and neck (HN) cancer patients because of its lower integral dose and faster delivery compared with conventional static-field IMRT (hereinafter referred to as IMRT).[1-5] Despite technological advances in radiation treatment of HN cancer, local relapse still remains a significant problem because of various factors.[6-11] Among them, treatment delivery uncertainties such as patient setup uncertainties and organ motion might lead to target underdose and therefore are considered to be important factors contributing to local relapse.[12,13] To ensure sufficient dose coverage to the treatment target and meet the clinical requirement for normal tissues, it is critically important to evaluate sensitivity of treatment plans to uncertainties.

Plan robustness quantification is a quantitative way to evaluate treatment plan sensitivity to uncertainties. Representative plan robustness quantification methods previously discussed in the literatures include worst-case analysis (WCA),[14,15] dose-volume histogram (DVH) band (DVHB),[16,17] and root-mean-square dose-volume histogram (RVH).[18-21] The need for plan robustness quantification has been articulated for almost 3 decades,[22] but was not implemented in routine clinical practice because of high computational cost. In external beam therapy planning, the influence of setup uncertainties and organ motion is addressed by adding predefined fixed margins to the clinical target volume (CTV) to form the planning target volume (PTV) in treatment planning and evaluated by the PTV dose distribution after planning.[23] The PTV concept relies on the assumption that dose cloud is static relative to the room coordinate system.[24] The validity of this assumption in photon therapy remains an active research topic. Recently, some groups have proposed to use robust probabilistic planning to replace the concept of PTV in photon therapy.[25-31] For HN cancer treatment, sensitivity of IMRT plans generated using PTV margins to patient setup uncertainties and organ motion has been extensively studied.[32-42] However, there are few studies investigating sensitivity of VMAT plans to uncertainties.[34] It is important to make sure that the superior dose distribution of VMAT can be delivered in the presence of uncertainties.

The goal of this study is to evaluate sensitivity of VMAT to patient setup uncertainties and to compare plan robustness of VMAT with IMRT for HN cancer patients. A secondary goal of this work is to compare the performance between plan robustness quantification methods for photon therapy.

Methods and materials

Patient data and treatment planning

We retrospectively evaluated treatment plans for 9 HN cancer patients who were treated at our institution using VMAT. Patient and treatment characteristics for these patients are shown in Table 1. Institutional review board approval was obtained for the use of these data (Institutional Review Board No. 13-005709). Patients were treated with radiation alone, or as part of multimodal therapy in combination with surgery with or without chemotherapy (Table 1).

As for the radiation therapy, VMAT with 2 or 3 arcs was used (Table 1). All 9 patients had been prescribed at 2 dose levels administered using simultaneous integrated boost technique. The target region receiving a high prescribed dose was referred to as CTV_{high} and the region receiving a low prescribed dose as CTV_{low}. CTVs were delineated by a physician, with CTV_{high} defined as the high-risk microscopic disease volume (gross tumor volume or postoperative tumor bed with nonuniform 5- to 10-mm margin) including the high-risk nodal volume adjacent to gross disease considered to be at risk of harboring subclinical disease. CTV_{low} typically encompassed a 10- to 15-mm margin beyond CTV_{high} and low-risk nodal volumes. PTV_{high} and PTV_{low} were formed by uniform expansion of the corresponding CTV by 3 mm. Doses to targets and critical normal structures (eg, brainstem, optic chiasm, optic nerves) were constrained to meet acceptable tolerance dose values whenever possible as defined in the departmental HN cancer treatment protocol (Appendix 1; available as supplementary material online only at www.practicalradonc.org). The dose covering a percentage of the structure's volume ($D_{\%}$) and the volume of the structure receiving a certain dose were used for dosimetric evaluation and planning purposes.

All patients were replanned using IMRT with 7 or 9 nonopposed, equally spaced, coplanar fields. Both VMAT and IMRT plans used the same structure sets, prescription doses, and numbers of fractions as shown in Table 1. IMRT plans were normalized to have the same $D_{95\%}$ of the PTV_{high} as in the VMAT plans. All VMAT and IMRT plans were generated using Eclipse, version 11 (Varian Medical Systems), by experienced dosimetrists or physicists and were approved by physicians.

Robustness quantification methods

Interfractional patient setup uncertainties were modeled by applying both positive and negative shifts of the isocenter of the patient in the anteroposterior, superoinferior, and lateral directions by the same margin as was used for defining the PTV (ie, 3 mm). The original VMAT and IMRT plans were used for all the recalculations,

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