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Knowledge-based treatment planning and its potential role in the transition between treatment planning systems

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ABSTRACT

Commissioning a new treatment planning system (TPS) involves many time-consuming tasks. We investigated the role that knowledge-based planning (KBP) can play in aiding a clinic's transition to a new TPS. Sixty clinically treated prostate/prostate bed intensity-modulated radiation therapy (IMRT) plans were exported from an in-house TPS and were used to create a KBP model in a newly implemented commercial application. To determine the benefit that KBP may have in a TPS transition, the model was tested on 2 groups of patients. Group 1 consisted of the first 10 prostate/prostate bed patients treated in the commercial TPS after the transition from the in-house TPS. Group 2 consisted of 10 patients planned in the commercial TPS after 8 months of clinical use. The KBP-generated plan was compared with the clinically used plan in terms of plan quality (ability to meet planning objectives and overall dose metrics) and planning efficiency (time required to generate clinically acceptable plans). The KBP-generated plans provided a significantly improved target coverage ($p = 0.01$) compared with the clinically used plans for Group 1, but yielded plans of comparable target coverage to the clinically used plans for Group 2. For the organs at risk, the KBP-generated plans produced lower doses, on average, for every normal-tissue objective except for the maximum dose to 0.1 cc of rectum. The time needed for the KBP-generated plans ranged from 6 to 15 minutes compared to 30 to 150 and 15 to 60 minutes for manual planning in Groups 1 and 2, respectively. KBP is a promising tool to aid in the transition to a new TPS. Our study indicates that high-quality treatment plans could have been generated in the newly implemented TPS more efficiently compared with not using KBP. Even after 8 months of the clinical use, KBP still showed an increase in plan quality and planning efficiency compared with manual planning.

Introduction

Advanced treatment planning methods, including intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT), have become commonplace in the modern radiation oncology clinic.

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However, both techniques can be time intensive due to the iterative process of determining trade-offs between sparing normal tissue and ensuring proper target coverage. During a period of transition from 1 treatment planning system (TPS) to another, it may be especially difficult to efficiently generate high-quality plans. Each user may require differing amounts of time and practice to be sufficiently comfortable to produce high-quality treatment plans with the new TPS.

Knowledge-based planning (KBP) is a relatively recent development in treatment planning that stems from the concept of modeling relationships between a prior set of case geometries to the achieved dose distribution to produce similar quality treatment plans for new patients. Noncommercialized versions of KBP have been reported on by various groups. Wu *et al.* used an overlap volume histogram to describe the geometric configuration of an organ at risk with respect to the target.[1,2] This group went on to study whether a planning application driven by this overlap volume histogram concept could be used for simultaneous integrated boosted IMRT treatment planning for head and neck cancer.[3] Moore *et al.* also worked on a geometry-based organ at risk dose prediction tool for IMRT treatment planning that was successful in acting as a quality control device of the treatment planning process.[4] Appenzoller *et al.* developed a mathematical framework to predict achievable organ at risk DVHs based on individual patient anatomy.[5] Zhu *et al.* used machine learning to create a tool that generates dose-volume histograms (DVHs) of organs at risk based on prior plans as a reference.[6] In-house and commercialized systems have demonstrated that KBP is an effective method to generate high-quality IMRT and VMAT treatment plans for malignancies in various body sites, including the prostate, the head and neck, the lungs, the liver, and even intracranially using stereotactic radiotherapy.[7-12]

As the literature demonstrates, the advantage in using a knowledge-based method is that treatment plans of equivalent or better quality can potentially be produced in a more efficient manner compared with manual IMRT or VMAT planning. The increased efficiency and potential improvement in quality might allow KBP to aid in TPS transitions, a time during which the efficiency in generating a quality plan could be suboptimal. In the present study, we trained a knowledge-based model with prostate and prostate bed plans originating from a clinically used in-house TPS. We then retrospectively applied this model to patients originally planned in a newly implemented commercial TPS. By using a model created from a different planning system, we aimed to determine the potential benefits associated with a knowledge-based approach to treatment planning, particularly in the setting of a TPS transition.

Methods and Materials

KBP with RapidPlan

RapidPlan is a treatment planning application developed by Varian Medical Systems that utilizes a knowledge-based approach.[13] RapidPlan uses extracted data from previously accepted clinical plans and principal component analysis to generate new plans. The extracted data can be geometric or dosimetric in nature and include the following: organ at risk and target volumes, overlap volume percentage of each organ at risk with the target, out-of-field volume percentage for each organ at risk, prescription dose, structure DVHs, and geometry-based expected dose histograms for each organ at risk. The geometry-based expected dose measures how much dose a certain organ at risk voxel would receive if only the patient anatomy, the desired target dose level, and the field setup would be considered.[13] RapidPlan then applies an algorithm on this extracted data that uses principal component analysis and is largely based on the work of Yuan *et al.* to generate the DVH estimation model.[14] RapidPlan has been assessed and described in further detail by several groups to date.[15-18]

A working RapidPlan model will create DVH estimation regions for the normal tissues, represented by the banded regions seen in Fig. 1. From these DVH estimations, a line objective (composed by a series of point objectives) is generated at the lower end of the region for each normal-tissue structure. This line objective is then utilized in the optimization cost function. One area that might be of concern when using RapidPlan is the overlap region between an organ at risk and the target. In this region, the model will default to prioritizing the target over the sparing of normal tissue. In this overlap region, the line objective stops generating point objectives to give priority to the target. As a result, there are no objectives to constrain the upper dose limit on the organ at risk, unless done so manually.

Model creation and initial validation with cases from an in-house TPS

A knowledge-based prostate model was created in RapidPlan from cases treated between January 2011 and February 2014 that were originally planned using an in-house TPS. The prostate was chosen for the present study because of the standardized geometry that is associated with it, making it an ideal site to determine if KBP would have been beneficial during the TPS transition. Although prostate planning is relatively simple compared with other sites (*e.g.,* head and neck or spine), it still presented enough challenges, especially in regions where the target and the organs at risk overlapped, that the workflow was significantly altered during the TPS transition period in our clinic. Suitable