PhD Thesis Title: Towards optimizing quality assurance outcomes of knowledge-based radiation therapy treatment plans using machine learning

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ABSTRACT:

Knowledge-based planning (KBP) techniques have been shown to provide improvements in plan quality, consistency, and efficiency for advanced radiation therapies such as volumetric modulated arc therapy (VMAT). While the potential clinical benefits of KBP methods are generally well known, comparatively less is understood regarding the impact of using these systems on resulting plan complexity and pre-treatment quality assurance (QA) measurements, especially for in-house KBP systems. Therefore, the overarching purpose of this work was to assess QA implications with using an in-house KBP system and explore data-driven methods for mitigating increased plan complexity and QA error rates without compromising dosimetric plan quality. Specifically, this study evaluated differences in dose, complexity, and QA outcomes between reference clinical plans and plans designed with a previously established in-house KBP system. Further, a machine learning model – trained and tested using a database of 500 previous VMAT treatment plans and QA measurements – was developed to predict VMAT QA measurements based on selected mechanical features of the plan. This model was deployed as a feedback mechanism within a heuristic optimization algorithm designed to modify plan parameters (identified by the machine learning model as important for accurately predicting QA outcomes) towards improving the predicted delivery accuracy of the plan. While KBP plans achieved average reductions of 6.4 Gy ($p < 0.001$) and 8.2 Gy ($p < 0.001$) in mean bladder and rectum dose compared to reference clinical plans across thirty-one prostate patients, significant ($p < 0.05$) increases in both complexity and QA measurement errors were observed. A support vector machine (SVM) was developed – using a database of 500 previous VMAT plans – to predict gamma passing rates (GPRs; 3%/3mm percent dose-difference/distance-to-agreement with local normalization) based on selected complexity features. A QA-based optimization algorithm was devised by utilizing the SVM model to iteratively modify mechanical treatment features most commonly associated with suboptimal GPRs. The feasibility was evaluated on 13 prostate VMAT plans designed with an in-house KBP method. Using a maximum random leaf gap displacement setting of 3 mm, predicted GPRs increased by an average of 1.14 ± 1.25% ($p = 0.006$) with minimal differences in dose and radiobiological metrics.

References to author publications that relate specifically to the dissertation:

1. **Wall PDH**, Fontenot JD. Evaluation of complexity and deliverability of prostate cancer treatment plans designed with a knowledge-based VMAT planning technique. *J Appl Clin Med Phys.* 2020;21(1):69-77. https://doi.org/10.1002/acm2.12790

2. **Wall PDH**, Fontenot JD. Application and comparison of machine learning models for predicting quality assurance outcomes in radiation therapy treatment planning. *Informatics in Medicine Unlocked.* 2020;18:100292. https://doi.org/10.1016/j.imu.2020.100292