PhD Thesis Title: Treatment plan optimization and delivery using dynamic gantry-couch trajectories

Author: Joel Mullins
Email: joel.mullins@mail.mcgill.ca
Institution: McGill University
Supervisor: Jan Seuntjens
Graduation Date: February 2021
Available Online: https://escholarship.mcgill.ca/concern/theses/9z903465b

ABSTRACT:

In radiation therapy, trajectory-based delivery involves the dynamic motion of the linear accelerator components combined with a continuous arc radiation delivery. The increased complexity of the delivery may yield dosimetric advantages, but this delivery technique has not seen clinical implementation. The purpose of this thesis work is to provide support for clinical implementation of trajectory-based treatment delivery through the application of novel trajectories, the implementation of a trajectory-based optimization algorithm, and the verification of the treatment delivery accuracy under dynamic conditions.

The initial study in this thesis applied translational couch trajectories to reduce the effective source-to-axis distance (SAD), with potential benefits due to the decreased projected size of the multileaf collimator and an increased effective dose rate. A noncoplanar trajectory was applied to patients presented with cranial targets, and treatment plans were optimized at shortened and standard SAD. As compared to clinical treatment plans, the shortened SAD treatment plans demonstrated a fraction size-dependent decrease in the treatment delivery time due to the increased effective dose rate. The noncoplanar trajectories yielded comparable plan quality to the clinical deliveries.

The next study focused on the novel implementation of a trajectory optimization algorithm for concurrent gantry and couch rotation. The optimization algorithm implemented uses the column generation approach to simultaneously determine the trajectory path during volumetric modulated arc therapy optimization (simTr-VMAT). With comparisons to coplanar VMAT plans and to randomly generated trajectories that represent the solution space for the optimization problem, the simTr-VMAT optimization methodology was validated.

The complex trajectory paths resulting from the simTr-VMAT optimizations were observed as a potential source of dose delivery inaccuracy. A trajectory smoothing procedure was implemented, and the base and smoothed treatment plans were delivered on the TrueBeam linear accelerator. The trajectory smoothing retained the treatment plan quality of the base trajectories. The delivery accuracy was largely within combined standard uncertainty. A systematic difference was observed between the measurement and calculation, which requires further investigation. The smoothed trajectory plans yielded improved agreement with the measurement compared to the base trajectory plans.

The final study investigated the gantry-couch rotation angle coordinate system. Trajectory optimizations were performed under a cartesian and spherical coordinate system for seven patient cases, using an overlap score map approach. The arclength between adjacent control points showed less variation for cases where the cartesian trajectory included arc segments with couch-only rotations. The objective function value was improved for 4 out of 7 patient cases for the spherical trajectories, but limitations of two-step trajectory optimization approaches were observed.

Through the research presented in this thesis, clinical advantages of trajectory-based delivery were demonstrated, as well as the importance of trajectory smoothing to improve the accuracy of dose delivery. This work helps to pave the way towards the clinical implementation of trajectory-based treatment delivery.

References to author publications that relate specifically to the dissertation:

(1) **J. Mullins**, M.-A. Renaud, V. Heng, R. Ruo, F. DeBlois, and J. Seuntjens, “Trajectory-based VMAT for cranial targets with delivery at shortened SAD,” Med. Phys. 47(7), 3103–3112 (2020). https://doi.org/10.1002/mp.14151

(2) **J. Mullins**, M.-A. Renaud, M. Serban, and J. Seuntjens, “Simultaneous trajectory generation and volumetric modulated arc therapy optimization,” Med. Phys. 47(7), 3078–3090 (2020). https://doi.org/10.1002/mp.14155