Characterization of Interplay Errors in Step-and-Shoot Intensity-Modulated Radiation Therapy of the Lung

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Radiation therapy is used for the treatment of inoperable early-stage and advanced-stage lung cancer. Target motion during these treatments due to respiration causes delivery errors relative to the planned dose. Current recommendations for the use of motion management techniques to mitigate these errors are based on the measured amplitude of target motion. However, frequency-dependent errors due to interplay between target motion and intensity modulation of the treatment delivery may not be adequately managed by these recommendations.

A radiochromic film stack dosimeter (FSD) was developed to verify Monte Carlo simulations of interplay errors in step-and-shoot intensity-modulated radiation therapy (SS-IMRT). The energy dependence, orientation dependence, and water equivalence of the FSD were characterized. The accuracy of the FSD was verified by comparison with thermoluminescent dosimeter measurements and treatment planning software dose calculations. The FSD was shown to be capable of accurate and precise three-dimensional dose measurements.

A Monte Carlo model of a linear accelerator was developed using the EGSnrc transport code for the simulation of interplay errors. The model was verified with the comparison of measured and simulated dose profiles.

Conventionally fractionated and hypofractionated SS-IMRT treatment plans were prepared for the investigation of interplay errors. The delivery of each plan was measured with the FSD undergoing modeled respiratory motion. These measurements were reconstructed using the Monte Carlo accelerator model to verify the methodology for the simulation of interplay errors. For each treatment plan, deliveries were simulated for target motion periods from 1s to 180s to identify characteristic modulation frequencies for which interplay errors were greatest. The impact of respiratory motion irregularity on interplay errors was investigated, and cumulative interplay errors over a fractionated treatment course were quantified.

It was demonstrated that interplay errors are greatest for longer motion periods, representative of drifts in the baseline target position, corresponding with the low-frequency intensity modulations of the treatment. For motion amplitudes of 5mm, for which the use of motion management is currently recommended,

interplay errors were minimal. Based on the results of this work, amplitude-based motion management criteria are sufficient to mitigate interplay errors in SS-IMRT.