

**Purpose:** Beam tracking of moving tumors with scanned carbon ion radiotherapy achieves uniform target dose by adapting carbon pencil beams to follow moving tissues using real-time lateral magnetic deflection and range modulation. The purpose of the current study was to establish the robustness of target dose coverage that can be achieved in the presence of changing target motion characteristics and uncertainties in the motion tracking system.

**Methods:** A 4D research treatment planning system code for ion therapy was extended to compute the resulting target dose coverage when various random and systematic uncertainties were introduced to ideal tracking dose simulations. Treatment plans were prepared using the in-house code for a hypothetical sphere target volume with sinusoidal motion in a water phantom. Uncertainties were simulated by shifting pencil beam coordinates and modifying target motion signals. To simulate imperfect tracking, we considered variations to the following: (1) respiratory period, (2) starting respiratory phase, (3) target position drift, (4) random tracking offsets, (5) range tracking wedge acceleration, and (6) external respiratory motion signal phase delay. We also considered imperfect tracking with combinations of varying target motion characteristics and tracking uncertainties. A total of 13713 dose distributions were computed. For all cases, mean, standard deviation, minimum, and maximum of target dose were analyzed.

**Results:** For perfect tracking of the moving sphere, mean and standard deviation of target dose were 98.2 and 0.8 % of the prescription dose, respectively. Of the variations considered, systematic drifts of target position of up to 5 mm had the most significant effect on target coverage ( $(6.6 \pm 20.3)$  % decrease), and range tracking wedge accelerations above 1.0 g had the least effect on target dose ( $(0.0 \pm 1.1)$  %).

**Conclusions:** The results provide insight into beam tracking precision requirements and the need to monitor and mitigate changes in patient motion.

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