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# Clinical Accuracy of Robotic Renal Radiosurgery

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## Abstract

Objectives: Robotic stereotactic body radiotherapy is an emerging therapy for renal tumors. We assess intrafraction tumor motion patterns and accuracy of robotic renal radiosurgery with real-time respiratory tracking in order to derive appropriate planning target volume (PTV) margins.

Methods: We retrospectively collected delivery log files from 165 consecutive treatments of renal lesions between 02/2013 and 09/2019. All patients underwent placement of one to four radio-opaque gold fiducials in the affected kidney prior to treatment. A stereoscopic kV-X-ray system detects the three-dimensional position of the fiducials which is correlated with the patient breathing signal provided by up to three optical markers attached to the patient chest. This correlation model continuously predicts the tumor position and is updated with further image acquisitions throughout the treatment. A prediction algorithm for the breathing signal compensates the system latency of 115 ms and guides the robot motion during beam-on. To derive target motion characteristics, fiducial positions in X-ray images are utilized. The 5th to 95th displacement percentile in three dimensions is calculated to exclude erratic motion such as coughing. The error of respiratory tracking consists of three separate components: First, the model correlation error, i.e. the difference between the expected target position from the model and the actually measured position in current X-ray images. Second, the prediction error, i.e. the discrepancy between the predicted and the actual breathing pattern, which is only relevant during beam on. Third, we assume a total system accuracy of the treatment machine of less than 0.95 mm in accordance with quality assurance tolerance levels, including fiducial localization and registration errors. To estimate treatment margins, the 95th percentiles of these errors were calculated.

Results: Most treatments were performed in a single session (85.5%), with 13.3% in three and 1.2% in five fractions. Mean fraction delivery time was 34 min with 10 min of beam on. Median tumor displacement was 10.5 (range 1.5 to 32.5) mm, 4.6 (0.6 to 14.7) mm and 2.4 (0.7 to 9.2) mm in superior-inferior (SI), anterior-posterior and left-right direction, respectively. The radial correlation error, i.e. the Euclidian distance of the correlation error, averaged over all treatments and its 95th percentile were 1.1 mm and 2.9 mm, respectively. The correlation error increased with tumor displacement and was therefore largest in SI direction (mean 0.8 mm, 95th percentile 2.0 mm). The mean prediction error and 95th percentile were 0.3 mm and 0.6

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mm. The root of squared sums of the total system accuracy and 95th percentiles from prediction and correlation errors results in a minimum PTV margin estimation of 3.1 mm.

Conclusions: The clinical accuracy of respiratory tracking in robotic radiosurgery can be derived from three sources of errors. For renal targets, the contribution is largest from the correlation model error, followed by total system accuracy and the breathing prediction error. Assuming optimal fiducial position and neglecting target rotation and deformation, we suggest a minimal PTV margin of 3 mm for renal lesions based on 95th percentiles of tracking errors.