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Abstract

Performance evaluation of the first two generations of multi-leaf collimators for a robotic radiosurgery system

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Objectives: In 2014 and 2015, the first two generations of multi-leaf collimators (MLCs) to be mounted on a robotic SRS/SBRT platform were introduced. Prior to clinical release, we assessed characteristics and performance of both devices on two test sites.

Methods: The CyberKnife® M6 with InCise™ 1 and InCise™ 2 MLCs operates in a flattening-filter-free mode with no jaws. Both MLCs produce a maximum field size of approximately 12 x 10 cm^2. Incise 1 and 2 leaves share the same height (90 mm), shape (3-sided leaf ends) and bank tilt to reduce interleaf leakage (0.5°), but differ in terms of width and number, with 2.5 mm width @ SAD 800 mm / 41 pairs for Incise 1 and 3.85 mm / 26 pairs for Incise 2. Secondary monitoring of leaf position is only available in Incise 2, which uses an integrated camera subsystem. Commissioning beam data was acquired with unshielded diodes. Leaf / bank position accuracy was determined in Bayouth (Garden Fence) tests with leaves travelling perpendicular and parallel to gravity, as well as before and after exercising the MLCs. Transmission / leakage through both banks (X1 and X2) and total accuracy (End-to-End tests) were measured using EBT3 radiochromic film. Cyberknife MLC node space, which is identical for Incise 1 and 2, but differs from previous paths for circular apertures, was assessed analytically by transformation to an Euler geometry ("plane", "gantry", "collimator" angles) and by measuring pointing accuracy (path verification) at each node. Stability over time was evaluated in Picket-Fence- and adapted Winston-Lutz-tests (AQA)."

Results: Beam penumbrae (80-20%, with 100% = 2 x dose at inflection point for field sizes = 50 x 50 mm^2) depended on field size, with similar ranges of 2.2 to 3.7 mm (Incise 1) and 2.1 to 3.6 mm (Incise 2) for square fields in reference condition (SAD 800 mm, depth 15 mm). Maximum transmission and leakage did not exceed 0.5% for both systems, with an average transmission of 0.21% (X1) and 0.29% (X2) for Incise 1 and 0.24% (X1) and 0.27% (X2) for Incise 2. Accessible clinical workspace with MLC covered non-coplanar "gantry" angles of [-113°; +112°] and "collimator" angles of [-100°; +107°]. Path verification yielded an average robot pointing accuracy of 0.12 ± 0.09 mm for the Incise 1 and 0.24 ± 0.14 mm for the Incise 2 system. For vertical beams, all garden fence tests (20+ tests for each MLC) exhibited an average leaf positioning error of <=0.2 mm at SAD 800 mm. With leaves travelling in vertical direction, an average displacement of leaf position by 0.3 mm (Incise 1) and 0.1 mm (Incise 2) due to gravity

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pull was observed. Execution of a leaf motion stress routine prior to garden fence test allowed identifying one malfunctioning leaf motor of the Incise 1 MLC. Total system accuracy was 0.38 ± 0.05 mm for the Incise 1 and 0.38 ± 0.16 mm for the Incise 2 platform in 9 End-to-End tests each. Picket-Fence- and AQA tests (radial offsets <=0.5 mm) displayed stable results over the test period for both systems.

Conclusions: Both MLCs showed high accuracy and adequate beam properties for SRS/SBRT applications. For Incise 1, the absence of secondary leaf monitoring demands specific quality assurance measures such as garden or picket fence tests performed after MLC exercise.