Multi-Institutional Dosimetric Commissioning of a High-Resolution CMOS 2D Detector Array for Patient-Specific QA of VMAT SIMT Stereotactic Radiosurgery

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Objectives: Volumetric modulated arc therapy (VMAT) for stereotactic radiosurgery (SRS) has increasingly become the standard of care for patients with multiple brain metastases. Using multi-leaf collimators (MLCs) in a C-arm LINAC, the single-isocenter multi-target (SIMT) technique allows simultaneous treatment of multiple lesions with a single plan delivery. Although SIMT significantly reduces treatment time and improves patient experiences, patient-specific quality assurance (PSQA) remains technically challenging. Geometrically, the gantry-defined radiation isocenter must be in tight concordance with the rotational axis of the couch, and any translational error induced by couch pitch and roll must be monitored. Dosimetrically, the targets may be very small, distant from the isocenter, with steep dose gradients. The combination of geometric and dosimetric uncertainties makes SIMT PSQA especially challenging. It is critical to have a high-resolution detector that can accurately measure the dose profiles of small brain lesions, to ensure the treatment quality of SIMT.

Here we report a multi-institution commissioning of a new high-resolution CMOS 2D detector array with sub-millimeter resolution for PSQA of VMAT SIMT stereotactic radiosurgery. The 2D CMOS array detector (12 × 14 cm2) has a spatial resolution of 0.4 mm, the highest commercially available. This study (1) investigated the basic dosimetric response characteristics of the CMOS detectors, (2) examined the dosimetric congruency in dose distribution between the CMOS 2D detector array and film dosimetry, and (3) discussed the feasibility of using the CMOS 2D array for SRS commissioning and PSQA SRS.

Methods: Dose rate, field size, energy and beam angle dependencies were characterized for the detectors. Dose rate dependency was evaluated from 40 to 2400 MU/min. It was defined as the ratio of the central axis (CAX) response to the response at a dose rate of 400 MU/min. Field size dependency was characterized by square field irradiation from 0.5 cm to 10 cm. It was defined as the response ratio of each field size to the 10 cm x 10 cm measurement. Energy dependency was evaluated for 10 cm x 10 cm square fields for 6X, 15X, 6FFF, and 10FFF beams. It was calculated as the ratio of the CAX response of each energy to the response of 6FFF. Beam angle dependency was measured at gantry rotations from 00 to 1800 and couch rotations of 00, 450, and 900. It was defined as the ratio of CAX detector readings at each gantry and couch angle permutation to the CAX reading at gantry angle 00 and couch angle 00. Detector characteristics were measured for all 6X, 15X, 6FFF and 10FFF beam energies.

For PSQA, a multi-institutional commissioning procedure was established as follows. First, standard plans were provided to each institution to standardize the procedures for joint commissioning. Second, each institution optionally provided clinical plans for the other institution to evaluate on their respective devices and machines. Dose distributions were measured by the CMOS 2D array and by the film using the same clinical setup. Dosimetric congruence was evaluated by absolute dose comparisons and by Gamma Index analysis.

Results: Signal reproducibility was within ±0.1 %, and the output calibration was stable over a 4 month period. For dose rate dependency, the detector showed saturation with dose rate (DR) (Signal = -0.00000001*(DR)2+0.00005*(DR)+0.9802, R2=0.99). Signals decreased 6% from 2000 MU/min to 40 MU/min, with no detectable change from 2000 MU/min to 2400 MU/min (h = 0, P > 0.5). For field size dependency, the output factor (OF) reproduced similar small field dosimetry characteristics: as the field size became smaller, the OF first decreased gradually, and then decreased drastically. At the smallest field size of 0.5 cm x 0.5 cm, the OFs were measured at 0.591 ± 0.005, 0.566 ± 0.002, 0.538 ± 0.015, and 0.456 ± 0.004 for 6FFF, 6X, 10FFF, and 15X, respectively. For energy dependency, the signal increases with energy. The response ratios were 1, 1.03 ± 0.00, 1.08 ± 0.02, and 1.12 ± 0.02 for 6FFF, 6X, 10FFF and 15X beam energies, respectively, for the 10 cm x 10 cm field size. The detectors showed a strong beam angle dependence with the smallest signal detected at gantry angles of 00 and 2700 (-27.5% reduction for the 6FFF beam). Angularity measurement showed reasonable agreement with the manufacture reference (average Δ = 0.83±1.55%)

For measurement of standard and clinical doses, Gamma Index pass-rate of dose distributions between the CMOS 2D array and film dosimetry was on average 99.3 ± 1.1 % (3 %/2 mm/10 %, global), 99.1 ± 0.7 % (1 %/1 mm/10%, global), 99.0 ± 1.2 % (3 %/2 mm/10 %, local), and 98.2 ± 1.7 % (1 %/1 mm/10 %, local). The average dose difference from CMOS to film measurement (ROI = 50 %) was 1.5 ± 0.7 %.

Conclusion(s): With proper calibration and angularity corrections, a sub-millimeter high-resolution CMOS 2D detector array is a viable alternative to film dosimetry for VMAT SIMT SRS commissioning and PSQA.