Efficient Method for Daily Quality Assurance of an MR-Linac Using Time-Gated Scintillation Imaging

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Purpose: The arrival of magnetic resonance guided radiation therapy (MRgRT) has posed a challenge for many current quality assurance (QA) protocols, as MRgRT systems do not include onboard x-ray imagers often used to make regular measurements, and many detector arrays for routine QA are not MR-compatible. Optical imaging of radioluminescence signals has been shown to be a reliable and efficient method for QA and in vivo dosimetry[1,2], and can provide a rapid, MR-compatible solution for performing daily QA tasks. In this study, a method is proposed for measuring output, symmetry, field centering and multileaf-collimator (MLC) position of a MR-linac using a time-gated, intensified camera and a scintillation screen, with the sensitivity of this system to possible variations in beam parameters characterized.

Materials and Methods: This study was performed using a 0.35 T MR-linac (MRIdian, ViewRay, Cleveland, OH). In order to image optical signals generated by the 6 MV flattening filter free (FFF) beam, an intensified CMOS camera (C-Dose Research, DoseOptics LLC, Lebanon, NH) was mounted on the wall facing into the bore, at a distance of 5.5 m to isocenter and an angle of 13 degrees. The camera was remotely triggered to the rep rate of the linac using an internal stray x-ray detector, and the

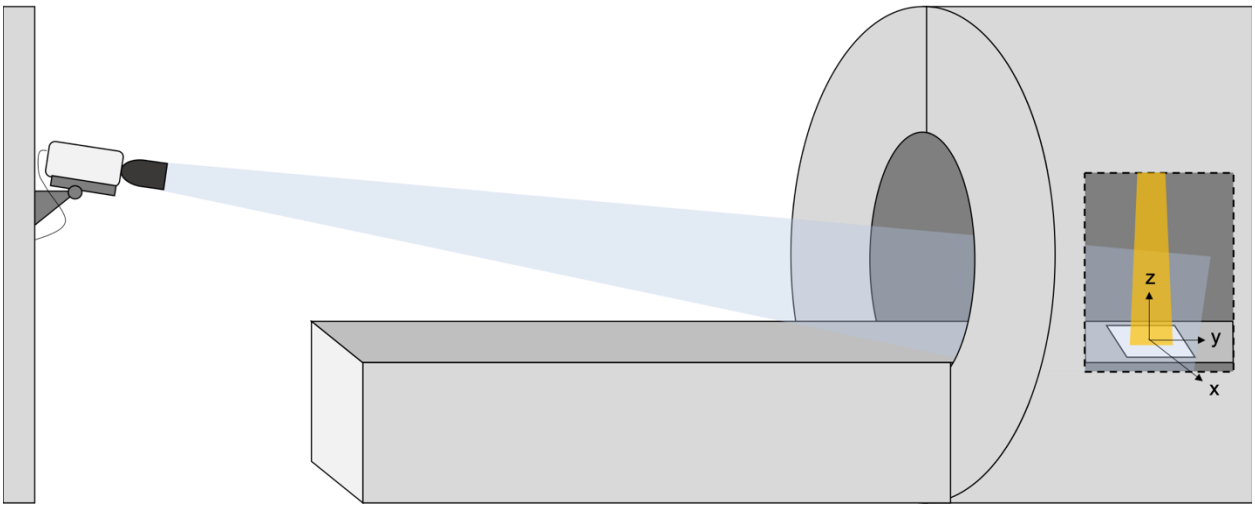
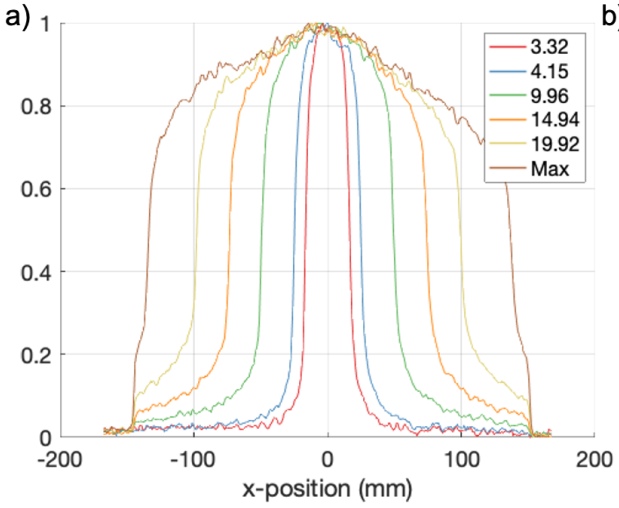


Figure 1: Drawing of the room setup. The camera is mounted on the wall, and the scintillation screen is placed at the beam isocenter and irradiated from above.

a)

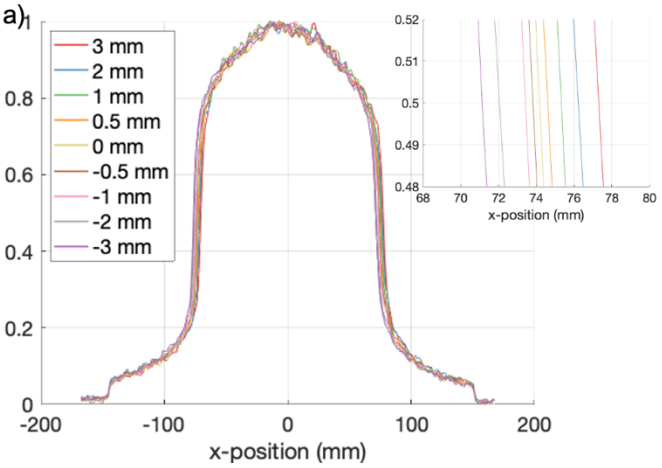


b)

Field size (x) (cm)	Optical FWHM (cm)	Discrepancy (mm)
3.32	3.29	-0.3
4.98	4.94	-0.4
9.96	9.85	-1.1
14.94	14.72	-2.2
19.92	19.70	-2.2
27.40 (max)	27.03	-3.7

Figure 2: (a) Crossplane profiles measured from the optical data at various field sizes; (b) Table displaying programmed field sizes, field width measured at half maximum of each profile, and the discrepancy between the two.

a)

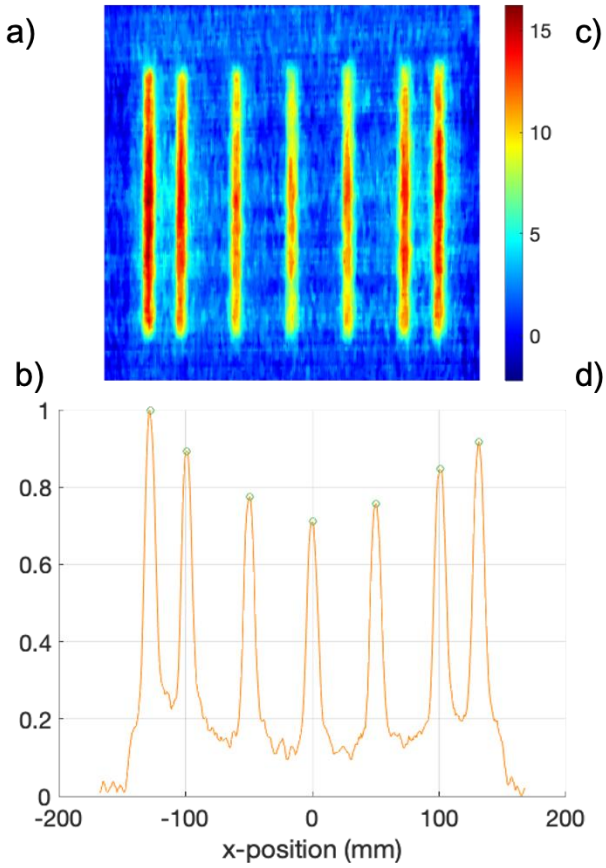


b)

MLC Shift (x) (cm)	Optical shift (cm)	Discrepancy (mm)
-3	-3.09	-0.9
-2	-2.16	-1.6
-1	-0.90	1.0
-0.5	-0.45	0.5
0.5	0.48	-0.2
1	1.03	0.3
2	1.93	-0.7
3	2.97	-0.3

Figure 3: (a) Crossplane profiles measured from the optical data at various x-shifts for a 14.94 x 14.94 cm field, with zoomed view; (b) Table displaying programmed MLC shifts, shifts measured using the optical profiles, and the absolute discrepancy between the two.

intensifier was gated to the pulse width of the linac, allowing for substantial suppression of background light. All images were background subtracted and a flat-field correction was applied. A 14 x 17 inch scintillation screen (Blue 400, Penn Jersey X-Ray, Jacksonville, FL) was centered at isocenter using lasers in the x- and y- dimensions, with the z-position lowered completely to provide the best view from the camera (Figure 1). The screen was placed on top of a 2 cm slab of solid water to provide adequate backscatter. A 6 x 7 square checkerboard was placed at the same position as the



MLC Position (x) (cm)	Optical shift (cm)	Discrepancy (mm)
-13	-12.81	1.9
-10	-9.96	0.4
-5	-4.94	0.6
5	5.02	0.2
10	10.05	0.5
13	13.06	0.6

Figure 4: (a) Transformed cumulative optical data from the MLC picket fence test; (b) Lateral profile of optical data integrated along the y-direction; (c) TPS view of picket fence plan; (d) Table showing programmed MLC positions, measured positions, and discrepancy between the two.

screen, which was used apply a projective transformation to all optical images and convert them to a beam's eye view. Varying numbers of monitor units (MUs) were delivered by the linac at a fixed filed size of 14.94 x 14.94 cm to test output response of the scintillation screen. Subsequently, various square field sizes ranging from 3.32 x 3.32 cm to the maximum field size of 27.40 x 24.07 cm were used to irradiate the sheet, to assess crossplane (x) and inplane profiles (y) measured from the optical signal captured by the camera. Additionally, the 14.94 x 14.94 field was shifted from -3 to +3 mm in the x-direction programmatically using the MLC to characterize the system's sensitivity to small spatial deviations. Lastly, an MLC picket fence test was performed by irradiating the screen with a thin field at various x-positions, and the measured optical line profile was analyzed to reproduce and verify the preprogrammed MLC positions.

Results: The optical emission from the scintillation screen was found to be sensitive to deviations in output of 0.5%, and the signal was found to be linear with the number of MUs delivered (R^2 = 0.99). The full widths at maximum of the measured crossplane profiles were compared to the defined field sizes, with a minimum discrepancy of 0.3 mm at 3.32 cm field size, and a maximum discrepancy of 3.7 mm at 27.4 cm field size (Figure 2). Additionally, the measured shifts from the optical images matched the

programmed field shifts in the x-direction with discrepancies ranging from 0.2 mm to 1.0 mm, with an average absolute discrepancy of 0.7 mm (Figure 3). Lastly, field positions from the picket fence test were measured by finding the prominent local maxima of a line profile integrated along the y-direction in the optical image, reproducing the MLC positions with < 2 mm discrepancy (Figure 4) (tolerance 2mm).

Conclusions: This study suggests that a gated intensified camera coupled with a scintillation screen can provide valuable output and symmetry information for consistency in daily QA of an MR-linac. The system shows high sensitivity to shifts in position and output and can reproduce positional information with milliliter-level precision in many cases. Since daily QA concerns relative changes from day to day, absolute discrepancy is not a concern, as it can be included in the baseline measurement. Future work will involve making heterogeneity corrections for the screen itself, as well as combining the optical imaging technique with an MR phantom to perform MR-MV co-isocentricity measurements.

Relevance to CIRMS: This work aligns with the goals of the CIRMS medical subcommittee, specifically in how it supports development of procedures which ensure safe and accurate delivery of intensity modulated radiation therapy. Quality assurance in the radiation therapy clinic is essential to patient safety and treatment efficacy, and improvements in efficiency and accuracy of these protocols directly supports these efforts. This study is a component of the first author's doctoral work, which consists of translating Cherenkov and radioluminescence imaging to the clinic in various capacities, including patient surface dosimetry and QA.

References:

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2. Tendler I, Brůža P, Andreozzi J, et al. Rapid Multisite Remote Surface Dosimetry for Total Skin Electron Therapy: Scintillator Target Imaging. *Int J Radiat Oncol*. 2019;103(3):767-774. doi:10.1016/j.ijrobp.2018.10.030