Scintillator-Based Optical Imaging for Use in Remote Surface Dosimetry

Irwin Tendler[1], Petr Bruza[1], Michael Jermyn[1], Benjamin Williams[2,3], Lesley Jarvis[2,3], Brian Pogue[1,3], David Gladstone[1,2,3]

1. *Thayer School of Engineering, Dartmouth College, Hanover, NH 03755*
2. *Department of Medicine, Geisel School of Medicine, Dartmouth College, Hanover, NH*
3. *Norris Cotton Cancer Center, Dartmouth-Hitchcock Medical Center, Lebanon, NH*

Objective:

In radiotherapy, verifying surface dose is essential to both minimizing negative skin reaction and ensuring treatment prescription is executed correctly.[1] Current methods for measuring surface dose either rely on application of wired probes or wireless devices requiring post-exposure processing. The time and resources required for these processes place a burden on radiation oncology staff, thereby minimizing the use surface dosimeters in the clinic.[2,3] Thus, there exists a need for a technology capable of reporting surface dose rapidly, remotely, and with limited human input. This research focuses on the development of an imaging system that captures scintillation emission from plastic discs, attached directly to the patient skin surface, and converts their corresponding pixel intensities to surface dose.

Materials and Methods:

Following preliminary design tests[4], custom-machined discs (15 Ø x 1 mm thick) composed of EJ-212 scintillating plastic (Elijen Technologies, Sweetwater, TX) were selected as candidate samples for this study. An intensified camera (CDose; DoseOptics, Lebanon, NH) was time-gated to linear accelerator pulses and positioned to the side of the gantry head of a linear accelerator (linac). Acquired images were online background subtracted, spatial and temporal median filtered, darkfield subtracted, and flat-field corrected. A MATLAB (MathWorks, Natick, MA) image-processing algorithm was created to convert detected scintillator light output to dose. After fitting a Gaussian-convolved-ellipse function to each scintillator region of interest (ROI) per frame, the maximum amplitude of the fit was summed across all frames producing a single value for each dosimeter. This result was converted to dose using an empirically derived calibration factor.[5] An overview of the imaging setup is shown in Figure 1.

Scintillators were attached to a flat-faced phantom and irradiated using photon and electron beams from a medical linear accelerator (linac) (Varian Medical Systems, Palo Alto, CA). Tests were conducted to evaluate scintillator: dose linearity, radiation damage resistance, emission spectra, as well as energy, temperature, dose rate, angle, and distance dependence. Furthermore, in a human pilot study, the ability of scintillator dosimeters to report surface dose for patients undergoing Total Skin Electron Therapy (TSET) was assessed and compared to standard Optically Stimulated Luminescence Detectors (OSLDs).

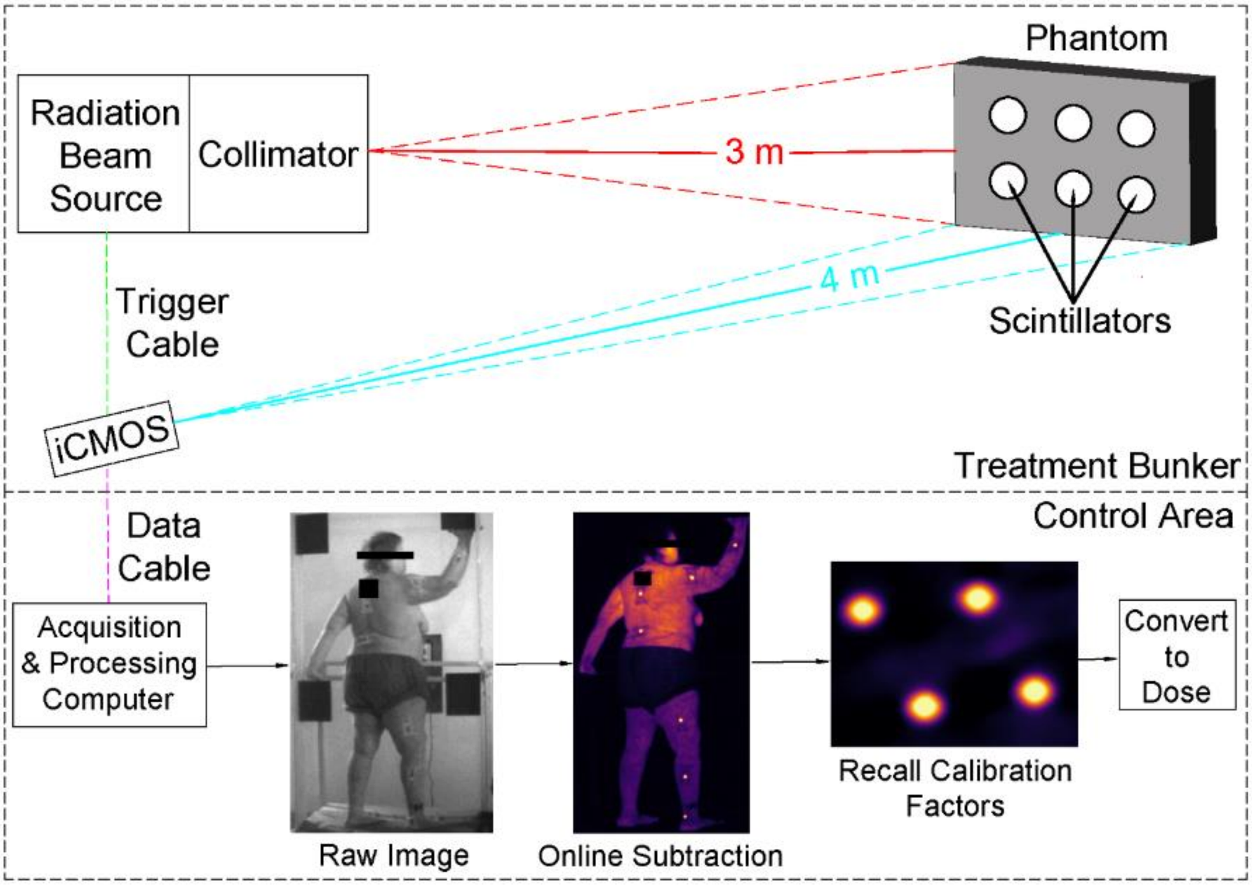

Figure 1: An illustration of the imaging setup. Linac is represented by “radiation beam source” and corresponding “collimator”. Image acquisition is time-gated to linac pulses; a trigger cable is attached between the signal panel of the linac and the camera. Image data is sent to a computer located outside of the treatment bunker via optical data cable.

Results:

It was found that scintillators have a linear response to dose; when comparing scintillator output to dose measure by OSLD, a linear relationship with $R^2 = 0.99$ (RMSE = 3.4e3) exists, Figure 2A. The scintillators function independent of: energy (linear relationship with dose for 6 – 18 MeV electrons, $R^2 = 0.99$, and 6 – 18 MV photons, $R^2 = 0.98$, Figure 2B), dose rate (data shows ≤ 0.05% change from mean across all dose rates tested, Figure 2C), temperature (0.69 ± 0.02% increase in signal for 10^o C – 40^o C, Figure 2D), angle (camera-scintillator or incident radiation-scintillator $\angle = 0^o – 55^o$)[5], and distance (change in camera-scintillator distance ≤ 1.5 m)[5]. Scintillators were found to have a maximum wavelength of emission of 422 nm, Figure 2D, and are resistant to radiation damage up to 15,000 Gy (0.2% decrease from mean), Figure 2F.

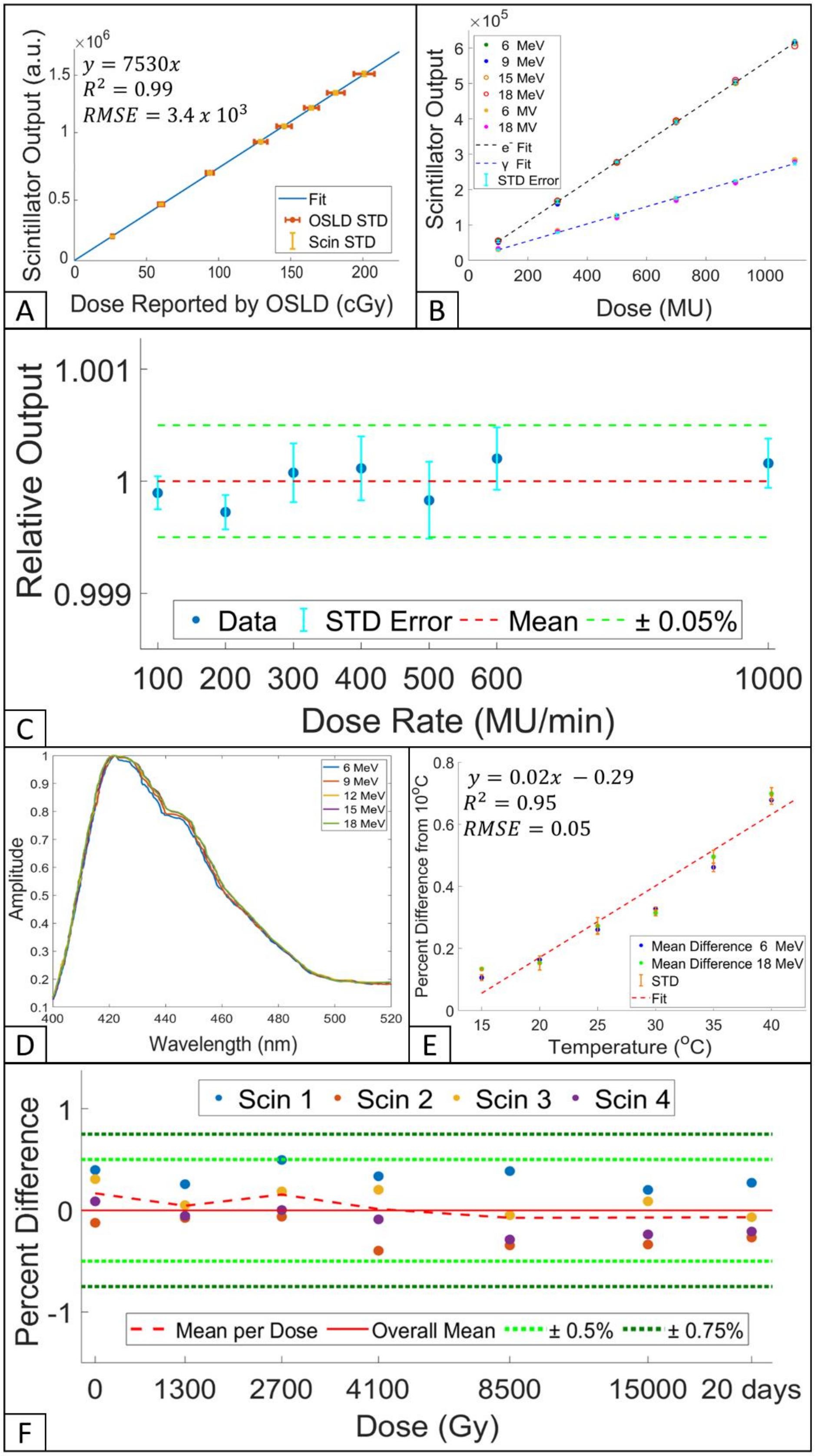

Figure 2: Results for scintillator characterization tests.

Scintillators were used to measure surface dose in 5 patients undergoing TSET. Sample cumulative images containing Cherenkov and scintillation intensity maps are shown in Figure 3. Scintillator light output is not impacted by tissue optical properties as is seen in Cherenkov emission where a distribution of Cherenkov pixel intensities is observed.

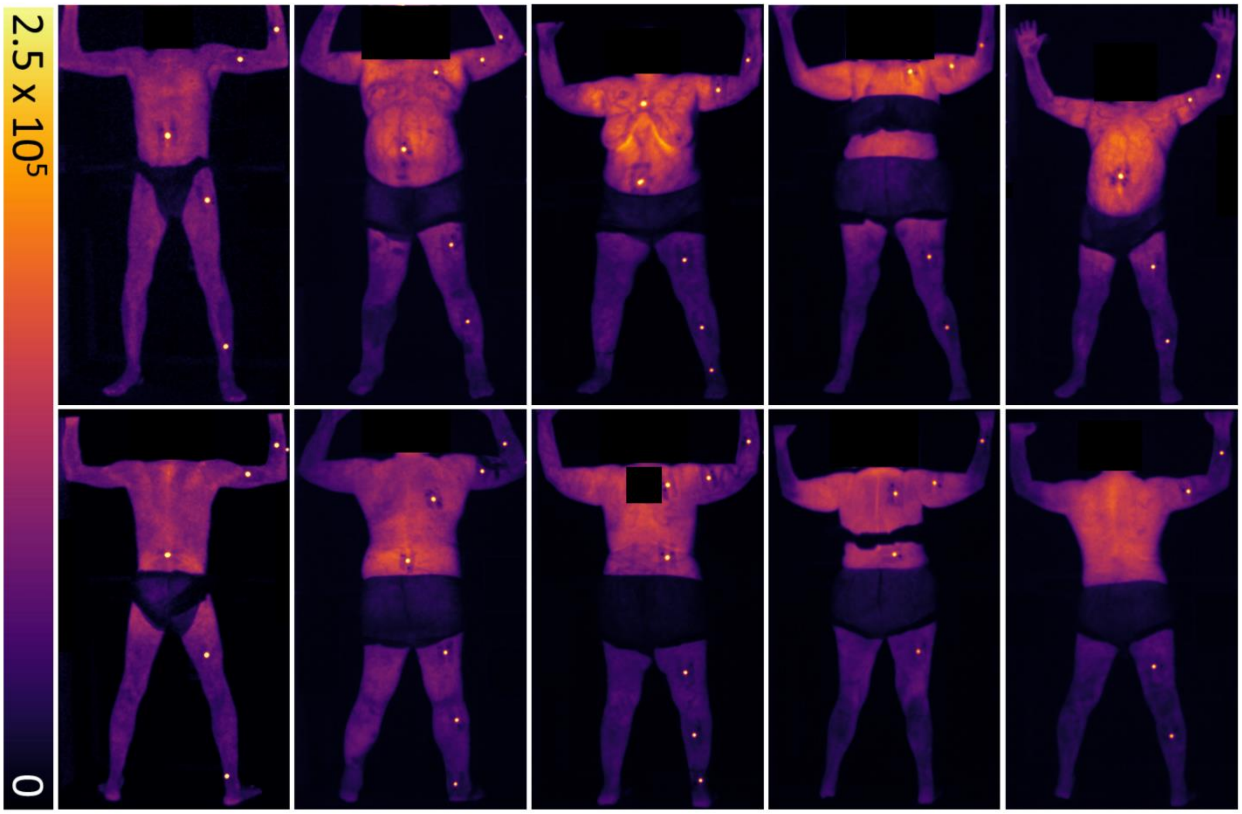

Figure 3: Cumulative, background-subtracted, Cherenkov, and scintillation-intensity maps for patients undergoing total skin electron therapy. Color-intensity scale is in digital units.

When analyzing surface dose reported per dosimetry site, it was found that there exists a linear correlation ($R^2 = 0.95$ & RMSE = 1.1 cGy) between scintillator and OSL dosimeters (Figure 4A). Compared to OSLDs, scintillators reported surface dose in TSET patients with < 5% and < 3% difference in 162/163 and 147/163 cases, respectively (Figure 4B).

Conclusions and Significance:

Scintillator dosimeters have been shown to accurately measure surface dose in both phantom and human studies. Independence of energy, dose rate, temperature, etc. of these dosimeters make them ideal for radiotherapy clinical dosimetry applications. Use of scintillators can streamline surface dosimetry-associated workflow.

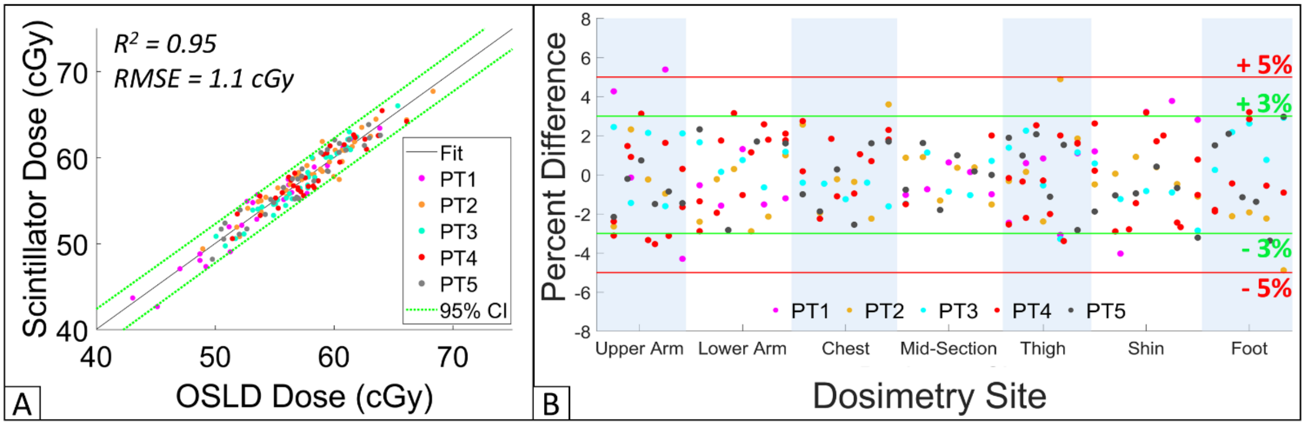

Figure 4: Comparison of surface dose measured by scintillator and OSLD for 5 patients undergoing TSET.

Relevance to CIRMS:

This body of work addresses a need in clinical surface dosimetry, it therefore aligns with one of CIRMS' primary goals: to "discuss, review and asses developments and needs" of therapeutic ionizing radiation. My professional goals are to develop a career in clinical medical physics. As I progress forward, I hope to actively engage in image-related research to improve the standard of care in radiation oncology. Given that CIRMS is a widely recognized forum for discussion of radiation measurement-related topics, I plan on actively reading reports originating from and participating in future council meetings. This project is related to the mission of CIRMS because it proposes a potential solution to a scientific and technical issue in radiation therapeutics.

References:

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