Evaluation of an Integrated Radiochromic Film *In Vivo* Dosimetry System for Proton Therapy

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ABSTRACT

Purpose: *In vivo* dosimetry is essential for treatment verification and patient safety. Although commercial radiochromic film systems are established for photons, proton therapy adds complexity because film response is energy dependent and clinical beams are typically polyenergetic. The purpose of this study was to evaluate the feasibility and performance of an *in vivo* film-based dosimetry system for clinical proton therapy, with emphasis on energy-dependent calibration strategies and validation under clinically relevant proton beam geometries.

Methods: Calibration curves (0-300 cGy) were acquired using monoenergetic proton beams at clinical energies (70, 110, 160, 200 MeV). The post-irradiation film response was sampled every 5 minutes during the first hour, and then hourly up to 24 hours. Validation measurements of 125 and 175 cGy were performed with the same geometry as the calibration irradiations. An anthropomorphic breast phantom was then used to simulate *in vivo* clinical irradiation conditions for four representative proton treatment plans. Doses at five points on the phantom were measured using the film dosimeters and compared with expected doses from TPS. The impact of calibration-curve selection (energy mismatch) on the derived dose was quantified.

Results: Calibration validation yielded ~10% maximum difference and 3.76% median absolute percent difference. Simulated clinical measurements with the anthropomorphic phantom were also accurate, as the median absolute percent difference was 3.52%. Measured doses differed by up to 12% from the TPS dose, depending on which calibration curve was used for readout.

Conclusions: Commercial radiochromic film–based *in vivo* dosimetry is feasible for proton therapy when energy-dependent calibration strategies are employed. The observed dependence of measured dose on calibration curve energy underscores the need for energy-specific commissioning and appropriate calibration selection to ensure accurate *in vivo* dose verification. This work opens opportunities for potential application of this system for dose monitoring in proton therapy.

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INTRODUCTION

- Radiochromic film sees widespread use in *in vivo* photon dosimetry because of its excellent spatial resolution and near-tissue equivalence
- Conventional film workflows are slow and complicated, so commercial radiochromic film systems have been designed to streamline readout and data processing
- These systems have not been established for proton therapy, and the energy dependence and LET dependence of any film must be investigated before being used clinically[1]
- In particular, energy dependence can be a major barrier to clinical implementation, as all proton fields use multiple energies to deliver dose to different depths within the patient
- The purpose of this study was to evaluate the feasibility and performance of an in vivo film-based dosimetry system for clinical proton therapy, with emphasis on energy-dependent calibration strategies and validation under clinically relevant proton beam geometries

METHODS AND MATERIALS

- The radiochromic film system that was investigated in this study was acquired from Ashland Inc. (Wilmington, DE)
- Calibration curves were measured for four clinical proton energies (70, 110, 160, and 200 MeV) using eight dose levels between 25 and 300 cGy, as well as a reference, unexposed film. A parallel-plate chamber placed beneath the films was used as a reference for the delivered dose. The irradiation geometry is shown in Figure 1.
- The films were calibrated at 1.9 cm water-equivalent depth in solid water. This was within the plateau region of all energies in order to avoid LET-dependent quenching effects.[1]
- It is well known that the optical density of irradiated film takes time to stabilize.[2] The analysis software for the film system was used to scan the film at five-minute intervals for the first hour post irradiation and then hourly until 24 hours post irradiation
- Validation measurements of 125 and 175 cGy were performed with the same geometry as the calibration irradiations
- An anthropomorphic breast phantom was then used to simulate *in vivo* clinical irradiation conditions for four representative proton treatment plans. Doses at five points on the phantom were measured using the film dosimeters and compared with expected doses from the treatment planning system. A picture of the phantom and the film positions is shown in Figure 2
- The impact of calibration-curve selection (energy mismatch) on the derived dose was quantified

RESULTS

- Validation measurements of the radiochromic film calibrations yielded an approximately 10% maximum dose difference and a 3.76% median absolute dose difference
- Simulated clinical measurements with the anthropomorphic breast phantom had a median absolute dose difference of 3.52%
  - Measurements at location 1 (midline) were excluded from this analysis due to large variability between measurements
- Depending on which calibration curve was used to analyze the dose data, dose differences of up to 12% from the planned doses were observed as shown in Figure 3

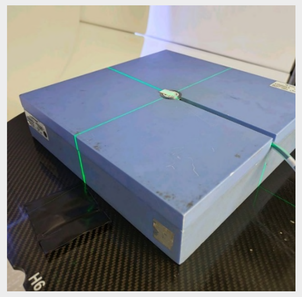

Figure 1. Film dosimeter on top of parallel-plate ion chamber for calibration measurements. Isocenter was placed at the surface of an added 1.9 cm of water-equivalent plastic

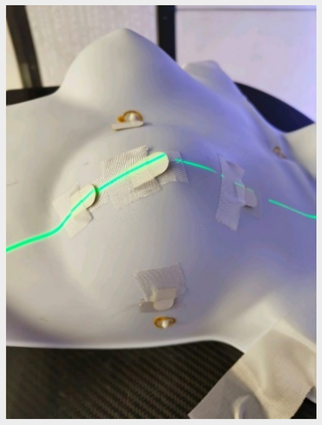

Figure 2. Anthropomorphic phantom with films placed for measurement of simulated patient plans. Location 2 was the lateral point, location 3 was central over the nipple, location 4 was superior, and location 5 was inferior

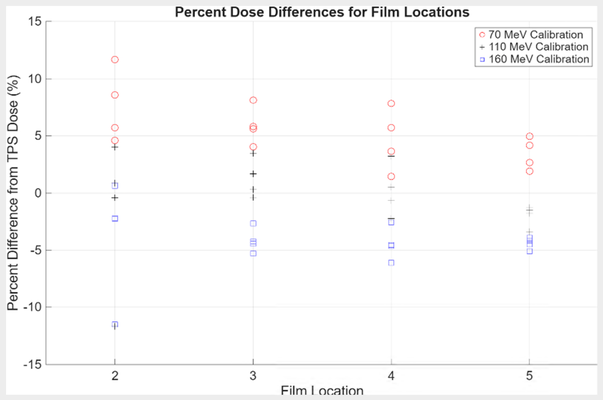

Figure 3. Scatter plot of measured percent differences from the TPS doses. The marker style corresponds to the calibration curve that was used to calculate the measured dose

DISCUSSION

- The largest differences in the calibration verification measurements were observed for the lowest energy calibration of 70 MeV
  - The dose measured by the film was compared to the dose measured by the parallel-plate chamber, which could not be placed at exactly the same water-equivalent depths. The film was at 1.9 cm depth, and the parallel-plate chamber was at 2.1 cm depth
  - The difference in dose between these two depths is negligible for higher energy protons, but may contribute to the differences observed at 70 MeV
- Overall, the phantom measurements were reproducible, with measurement standard deviations of 2% or less for most locations across all 4 plans
  - The largest variability in measurement results were observed for locations 1 and 2. We hypothesize that this is due to the difficulty of setting up the film reproducibly at those points
  - The film was planned to be placed with the minimum distance between the film and the phantom surface possible. The phantom was made of hard plastic, so it was difficult to do so on places with significant curvature, like around the midline or the lateral side of the breast
  - This issue is likely less significant for patient measurements where tissue can be deformed to sit flush with the film

CONCLUSIONS

- Commercial radiochromic film–based *in vivo* dosimetry is feasible for proton therapy when energy-dependent calibration strategies are employed
- The observed dependence of measured dose on calibration curve energy underscores the need for energy-specific commissioning and appropriate calibration selection to ensure accurate *in vivo* dose verification
- This study is the first to investigate the use of a new *in vivo* film dosimetry system in proton therapy and is an important first step in characterizing the energy dependence of the film for use in the clinic

REFERENCES

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DISCLOSURES

The authors have no disclosures.