Experimental Evaluation of Proton Therapy Transmission Spots Using Hybrid Gamma Imaging

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Innovation: This work introduces the application of spatially resolved hybrid gamma imaging to experimentally evaluate proton therapy shielding assumptions in the presence of proton transmission (“shoot-through”) spots. While robust optimization methods can intentionally generate high-energy spots that exit the patient, their shielding implications are not well characterized and are often difficult to identify using conventional survey instrumentation. By combining independent downstream dosimetry with gamma imaging that localizes

INTRODUCTION

Proton therapy shielding design typically assumes that protons stop within the patient. However, modern treatment planning optimization strategies may introduce high-energy proton transmission (“shoot-through”) spots that exit the patient and deposit energy in treatment room structures. This work experimentally evaluates the downstream dose and room-level radiation associated with proton transmission spots.

METHODS AND MATERIALS

- A head-and-neck phantom was planned in RayStation 2023B using two otherwise identical proton plans:
  - One permitting transmission ("shoot-through") spots
  - One with transmission spots removed
- Treatment deliveries were performed on an IBA Proteus®PLUS proton therapy system
- Downstream dose was measured beneath the phantom using an IBA MatriXX ion chamber array
- Treatment room radiation was evaluated using the RAVIN CAM hybrid gamma imaging system (M3D, Inc.)
- The RAVIN system combines coded-aperture and Compton imaging to localize radiation sources and activated structures
- Gamma images and energy spectra were acquired during phantom irradiations and after clinical patient treatments.

RESULTS

- Downstream dosimetry showed substantially greater dose beyond the phantom when transmission spots were permitted (Figure 1). Maximum downstream dose increased from 18.5 cGy to 50.9 cGy, with shifts in peak dose location indicating differences in proton penetration and range
- Hybrid gamma imaging localized elevated radiation to downstream treatment room structures during delivery of the transmission-spot plan (Figure 2). Radiation levels were markedly lower for the control plan
- Energy spectra were dominated by a 511 keV photopeak, consistent with positron-annihilation activity. Ambient radiation increased from 6–7 µR/hr to 55–80 µR/hr during beam delivery, while floor measurements increased from 16 µR/hr to 36 µR/hr when transmission spots were present
- Post-treatment gamma imaging demonstrated activation patterns similar to those observed in the phantom study (Figure 3), with localized activity along expected beam-exit pathways, indicating that transmission-related activation may occur during routine clinical treatments

Figure 1 MatriXX Ion Chamber Array

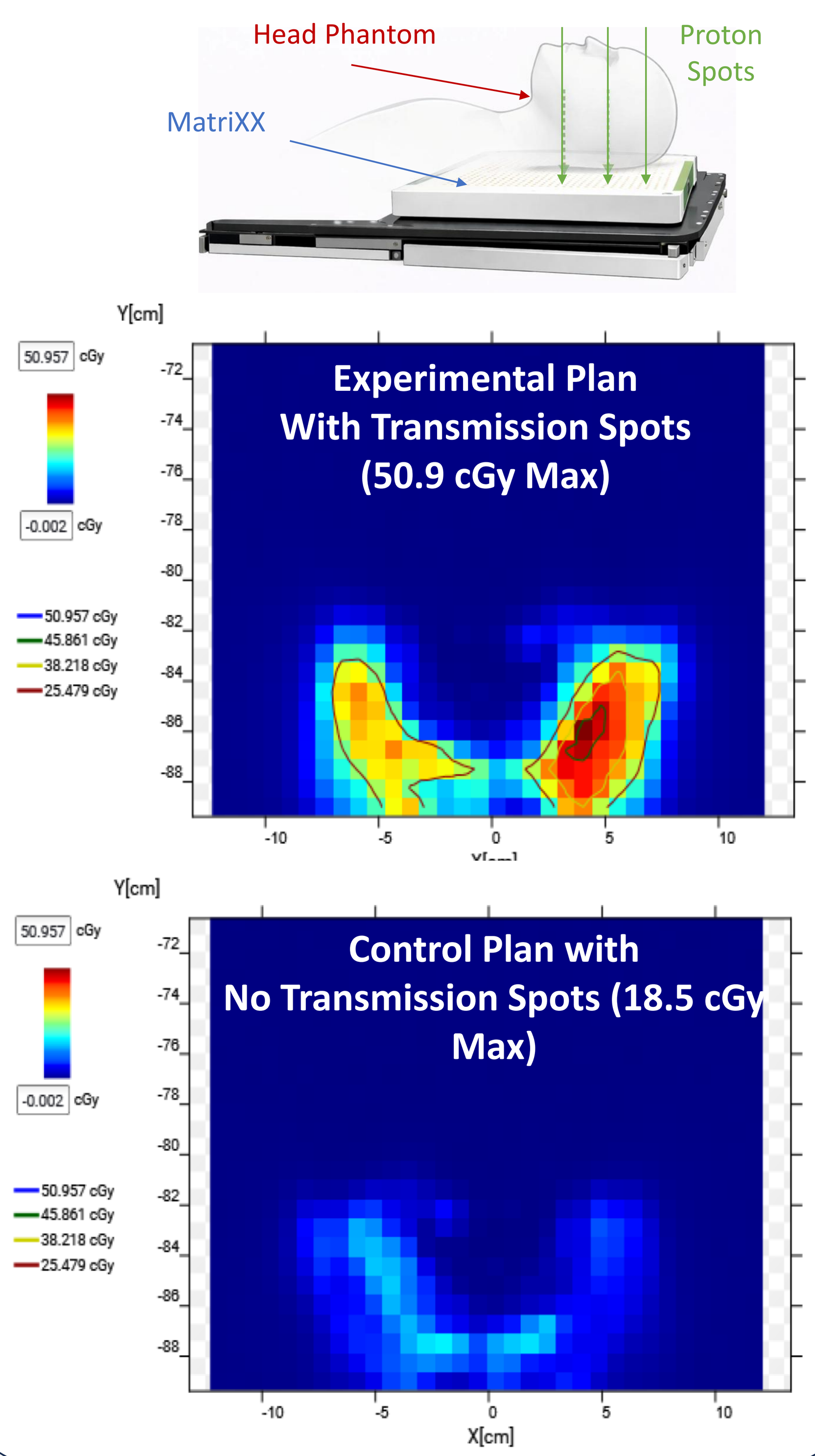


Figure 2 Ravin Hybrid Gamma Imaging

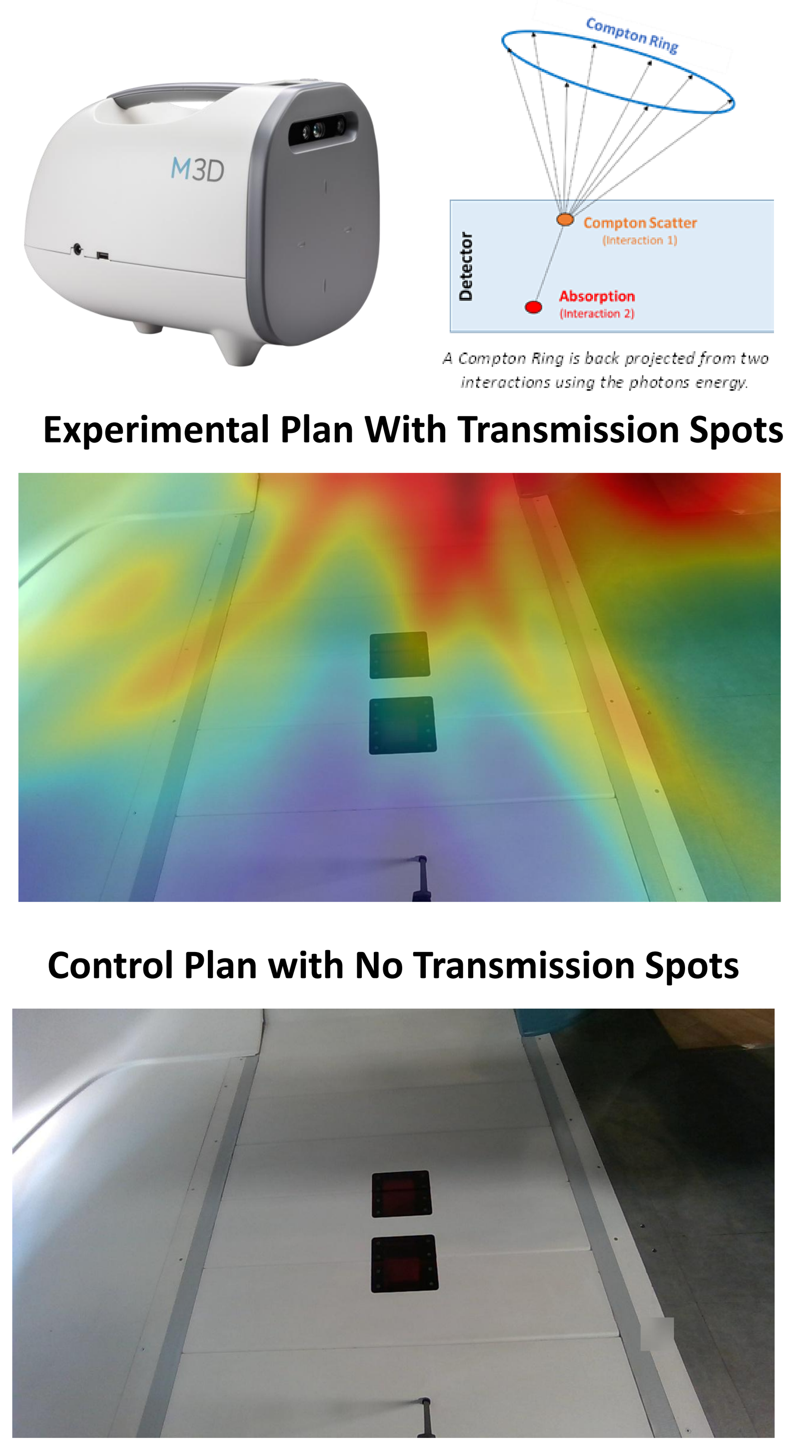
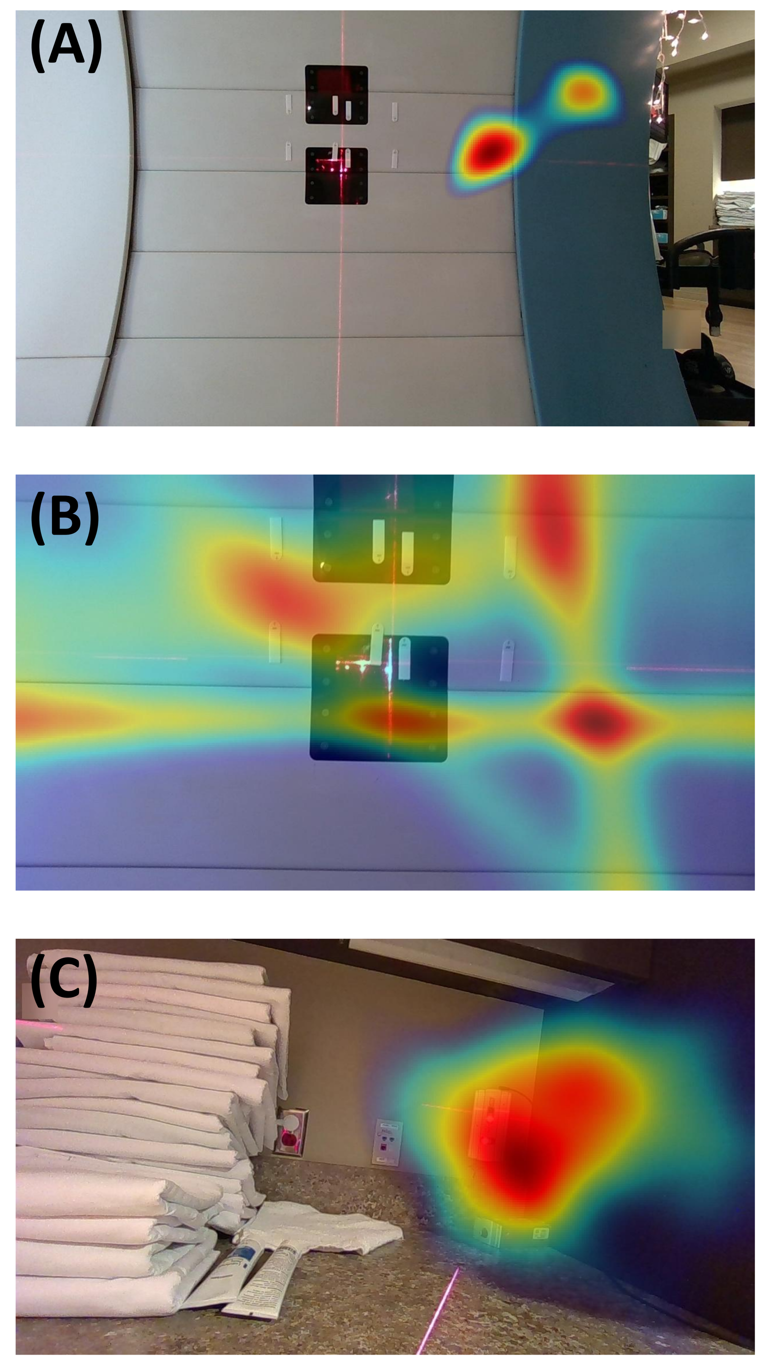


Figure 3 Examples of Activation Following Patient Treatments (A,B) and QA Delivery (C)



CONCLUSIONS

This study provides experimental evidence that proton transmission spots can produce measurable downstream dose and detectable activation in treatment room structures. Hybrid gamma imaging offers a powerful method for visualizing and characterizing these effects in situ. These findings suggest that shielding analyses should explicitly consider the potential impact of proton transmission spots, particularly for tangential beam geometries and robustly optimized plans.

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