

Uncertainties Associated with Small Field Proton Dosimetry



Imad Ali*, Nesreen Alsbou+

Department of Radiation Oncology, University of Oklahoma Health Sciences Center, Oklahoma City
+Department of Engineering and Physics, University of Central Oklahoma, Edmond, OK

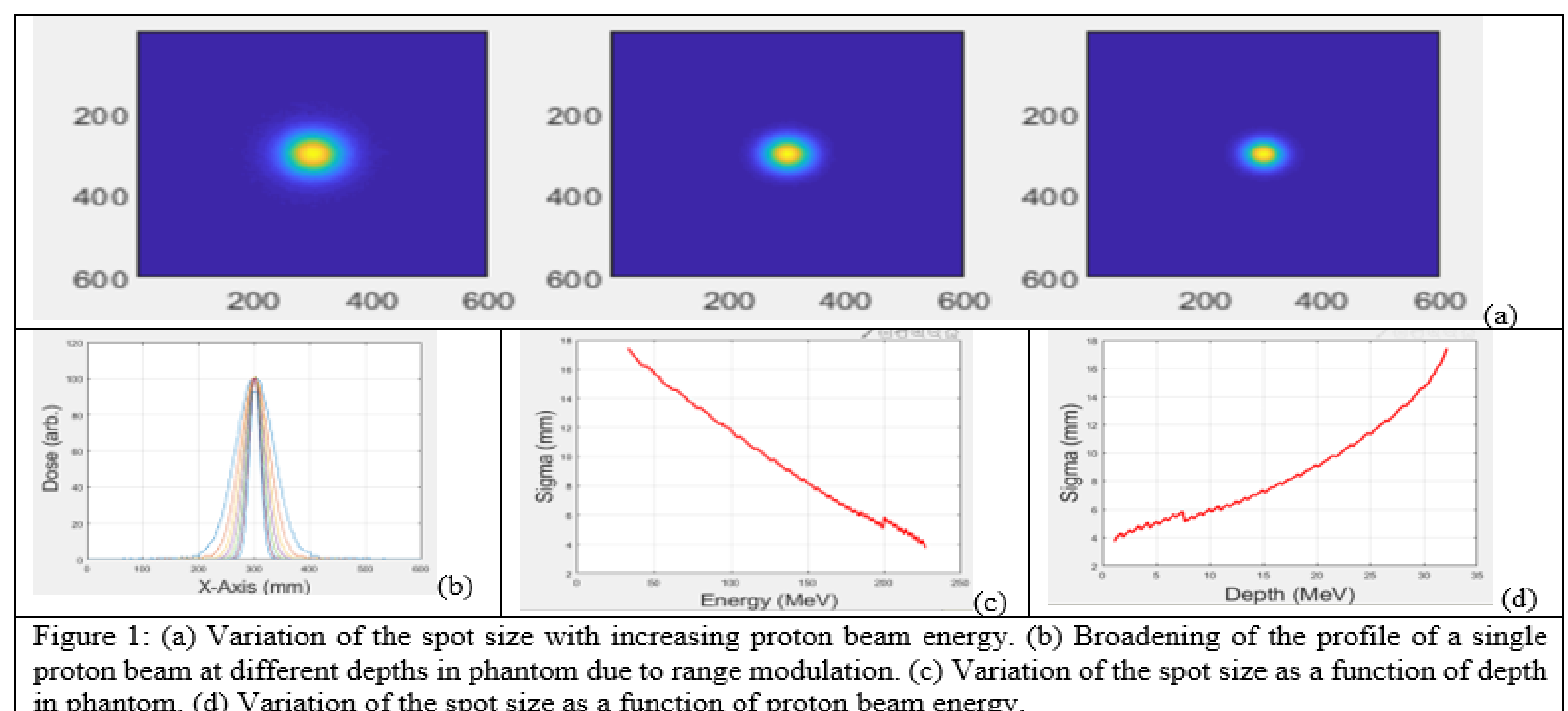


Introduction: Proton therapy enables highly conformal tumor irradiation while sparing surrounding healthy tissue, owing to the sharp distal dose fall-off at the Bragg peak and the absence of exit dose beyond the target. In addition, protons exhibit increased radiobiological effectiveness compared with conventional photon and electron therapies. Despite these advantages, the application of proton therapy to small-field treatments presents significant challenges. In particular, uncertainties in both dose calculation and experimental measurement arise when using narrow pencil beams generated by spot-scanning proton therapy systems. As proton beams traverse greater depths or undergo substantial range modulation, the Bragg peak becomes less pronounced and lateral dose spread increases, limiting the applicability of proton therapy for stereotactic treatments involving very small targets.

Motivation: The purpose of this study to evaluate dosimetric uncertainties associated with the small proton fields using spot-scanning beams used in intensity-modulated proton therapy (IMPT).

Methods: Intensity-modulated proton therapy plans were generated using the RayStation treatment planning system to treat tumors smaller than 2cm. The proton beams were generated using a MEVION-S250i spot-scanning proton therapy system. The proton fields employed densely spaced spot-scanning beams with 0.25 mm lateral spacing and 0.8 mm energy layer separation and defined with a dynamic adaptive adapter to create a conformal dose distribution. The dose distributions were measured using a high-resolution two-dimensional thin-film transistor detector (Phoenix) and compared with the corresponding calculated dose distributions from a Monte-Carlo dose calculation algorithm.

Results: Substantial discrepancies were observed between the calculated and measured dose distributions which depended on both target size and the degree of intensity-modulation. The dose differences increased as field size decreased, reaching maximum deviations of up to 15% for the smallest targets (Fig.1a). Furthermore, increased intensity modulation which was obtained by reduced spot spacing and increased energy layering to improve dose conformity, resulted in larger dose discrepancies (Fig.1b). The dose discrepancies were primarily attributed to limitations in the dose calculation algorithm ability to accurately model Bragg peak degradation, lateral dose spread, and penumbra shaping in highly modulated, small proton fields (Fig.1c). The second constraint is due to the physical spread-out of the dose distribution generated from a single spot beam with increasing depth in tissue (Fig.1d).



Conclusion: This study demonstrated clinically significant discrepancies between measured and calculated dose distributions for small-field IMPT using a Monte-Carlo dose calculation algorithm. These discrepancies resulted largely from the limitation of the dose calculation algorithm and physical spread-out of the dose distribution from a single spot beam. These findings highlight the need for improved dose modeling and validation methods to ensure accurate dose delivery in small-field proton therapy.