The Bragg peak may undermine the FLASH effect: Results from a novel plastic scintillator

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Purpose: While the FLASH effect has primarily been studied with transmission protons in the entrance plateau, this type of delivery has limited clinical applications and investigators expect to capitalize on the dose-escalation of the Bragg peak region for clinical treatments. In this study, we evaluate the feasibility of triggering the FLASH effect of ultra-high dose rate protons by measuring the fluctuation of dose rate due to pencil beam scanning at different depths.

Methods: The Hyperscint, a previously-calibrated plastic scintillator capable of rapid dose sampling at 400 Hz, was used to measure the percent depth-dose in a stack of solid water at 3–40 cm depths for a 250 MeV proton beam scanned across a small area (3.5×3.5 cm^2). The plastic scintillator measurements were corrected for energy quenching at low energies and validated within ≤1% using an Advanced Markus parallel-plate ionization chamber and were used to calculate average and maximum instantaneous dose rate as a function of depth.

Results: As the proton beam penetrates deeper in solid water, the spot size increases due to scattering and divergence. As a result, fewer spots contributed dose to the scintillator signal when it was positioned in the entrance region as compared to the Bragg peak region, where spot size is maximal. Consequently, the dose delivery time at the central axis increased by a factor of ~1.7 between the entrance and the Bragg peak regions. The average dose rate consequently varies from 52.7 Gy/s at the entrance to 29.3 Gy/s at mid-depth, to 70.4 Gy/s at the Bragg peak. While the decrease in average dose rate is mitigated by dose escalation at the Bragg peak, the maximum instantaneous dose rate decreases from 472 Gy/s near the entrance to 236 Gy/s at the Bragg peak.

Conclusions: As the FLASH effect typically occurs at average dose rates ≥40 Gy/s, this has profound implications on the ability of investigators to maintain the dose rates necessary to trigger the FLASH effect at or near the Bragg peak, where organs at risk would normally be situated.

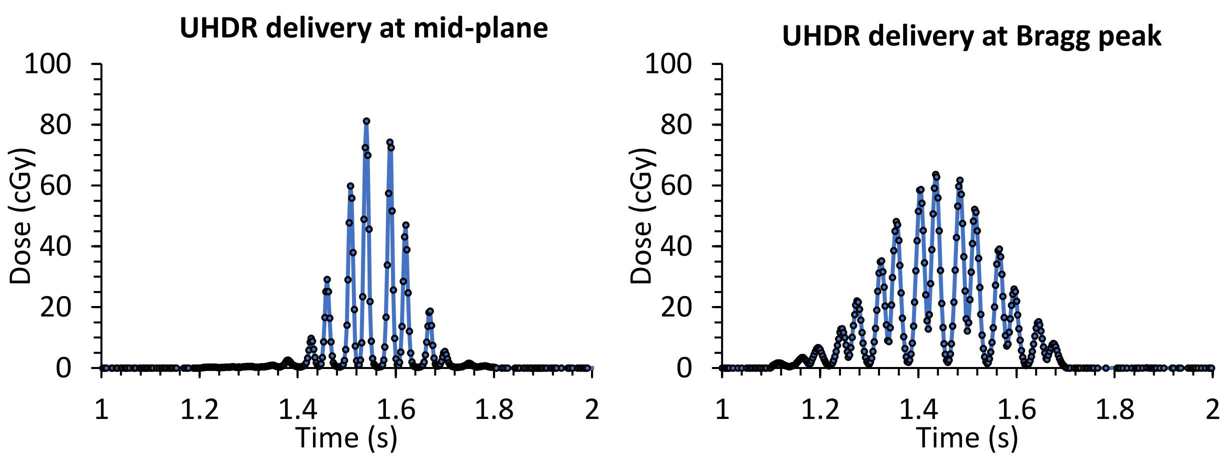

Figure 1. Difference in the time-dose profiles for the dose delivered at mid-plane (left) vs the Bragg peak (right). UHDR delivery at the Bragg peak takes nearly twice as long to execute, and the instantaneous dose rate is generally lower than that at shallower depths.