Optimizing Ion Chamber-Based Dose Modulation of an Electron FLASH-enabled Linac

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Purpose: Radiobiological studies are often conducted at the steepest portion of dose-response curves, where small changes in delivered dose can significantly impact outcomes. The aim of this study was to optimize an ion chamber-based dose modulation system to overcome chamber recombination and machine output instability, enabling precise delivery of ultra-high dose rate (UHDR) electron beams for FLASH effect investigations in rodent models.

Methods: Our irradiation platform consists of a Cerrobend collimator supported by a Tilt-Pro™ Tilting Base affixed to the treatment couch of a FLASH-enabled linac which provides a flat UHDR beam (Figure 1A). The dose rate is modulated by varying the faceplate-to-collimator distance (FCD) (Figure 1B). An Advanced Markus® Electron Chamber seated in a 3D-printed holder is attached to a lead block positioned off-axis to measure highly-penetrating bremsstrahlung X-rays. Using a high-speed (500 Hz) scintillator-based dosimeter (HYPERSCINT RP100), the collected charge was calibrated against UHDR dose and FCD. Film dosimetry was also conducted to further validate the resulting calibration curve.

Results: After a 6-8% ramp-up, the UHDR beam repeatability is ±1% within the same day. Reproducibility measurements revealed a ±3% day-to-day variation. P_{ion} was highest at the minimum FCD and remained below 1.003 for all irradiations using the lead block setup. However, significant signal contribution from the stem effect observed. A linear relationship ($R^2 = 1$) was established between charge and HYPERSCINT dose at target FLASH dose rates, supporting real-time dose monitoring. The collected charge and FCD followed a polynomial function. Accurate doses delivered in the presence of a few percent variation in output were confirmed by film dosimetry.

Conclusions: The proposed setup prevents unwanted ion recombination during UHDR electron beam dose measurements with an ion chamber. The established polynomial function between charge and FCD allows for modulation of the dose rate and consequent dose through informed adjustment of the FCD to account for UHDR beam output variation. The ion chamber-based system enables real-time monitoring of the delivered UHDR dose, which can be accurately matched by any conventional dose rate group(s).

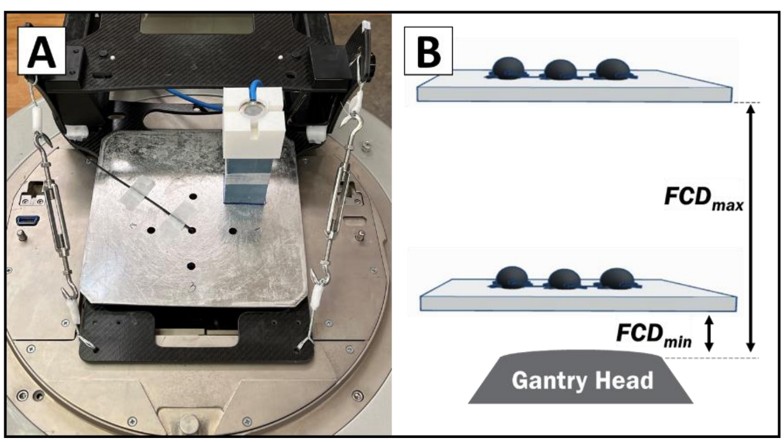

Figure 1A. Lead block-chamber setup with flank tumor collimator. **Figure 1B.** Platform schematic illustrating dose rate control.