Small Animal FLASH in vivo Dosimetry: Dose and Dose Rate Reproducibility for 200 Mice

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Objectives: Real-time dose and dose rate monitoring are crucial to ensure accurate delivery in FLASH studies. This work focuses on quality assurance (QA) techniques for in vivo dosimetry and establishes its routine uses for proton FLASH small animal experiments when the monitor chamber is saturated for FLASH delivery.

Methods: Over 200 mice were irradiated for proton transmission FLASH experiments at the New York Proton Center between November 2022 and October 2023, with the purpose of characterizing the proton FLASH effect on abdominal irradiation and examining various endpoints. All beams were delivered with 250 MeV protons and were collimated with two rectangular brass blocks to a 40mm by 25mm field. Doses prescribed were 12, 13, 14 and 15 GyRBE, and FLASH beams were requested to be >80 Gy/s. A 2D strip ionization chamber array (SICA) detector was used for in vivo dose monitoring during irradiation. The SICA detector was placed upstream of the aperture. Prior to each series of mice irradiated, a calibration curve was established by delivering the beams at FLASH and conventional (CONV) dose rates and correlating the SICA values with those of an advanced Markus chamber at the isocenter. During delivery, the SICA detector was used to monitor the dose and dose rate received by each mouse and verify the 2D dose distribution.

Results: Daily calibration curves approached a linear slope for both FLASH and CONV with a minimal R^2 value of 0.991 and 0.985, respectively, and slopes were consistent for each delivery modality. Average delivered dose did not vary from prescribed dose by more than 2.30% for FLASH or by 0.48% for CONV. Beams delivered experimentally had an average field-averaged dose rate of 78.959±0.811Gy/s, an average local dose rate of 160.6±3.0Gy/s, flatness of 11.0%±2.0 in X and 28.5%±0.4 in Y, symmetry of 0.25%±0.59 in X and 5.37%±0.36 in Y, penumbra of 6.21±0.25 in X and 5.88±0.08 in Y, as measured by the SICA detector before collimation. During calibration, these same fields were measured at the isocenter after collimation and had a penumbra of 1.05 mm in Y, flatness of 4.23±0.96% in Y, and symmetry of -0.74% in Y, and a field size of 25.3 mm in Y, the only dimension being collimated. The use of in vivo dosimetry allowed for the accurate detection of variation between the delivered dose and the prescribed dose.

Conclusion(s): In vivo dosimetry allows mice to be regrouped based on actual dose received when the delivered dose deviates from the planned dose, allowing for more accurate experimental data.