

# A High-Throughput Collimator for Murine Subcutaneous Tumor Model Irradiation with Electron FLASH Radiotherapy

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## INTRODUCTION

- Compared to conventional (CONV) dose rate, ultra-high dose rate radiation has been shown to advantageously spare normal tissue without compromising tumor control efficacy (i.e., the FLASH effect).
- However, the dependence of the FLASH effect on beam parameters and the synergistic effects of other cancer therapy approaches (immunotherapy and hyperthermia etc.) with FLASH radiotherapy needs to be investigated.
- Murine subcutaneous tumor models offer an efficient and cost-effective choice for these studies, which typically involve tens or even hundreds of animals.
- Therefore, there is a dire need to develop a high throughput collimator for murine subcutaneous tumor model irradiation with FLASH radiotherapy.

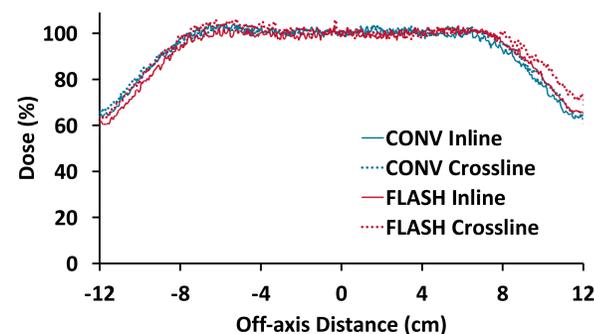
## AIMS

- To develop a high-throughput collimator for murine subcutaneous tumor model irradiation with electron FLASH radiotherapy
- To characterize the dosimetric characteristics of the proposed platform at CONV and ultra-high dose rates (UHDR)

## METHODS AND RESULTS

### Electron FLASH-enabled Linac

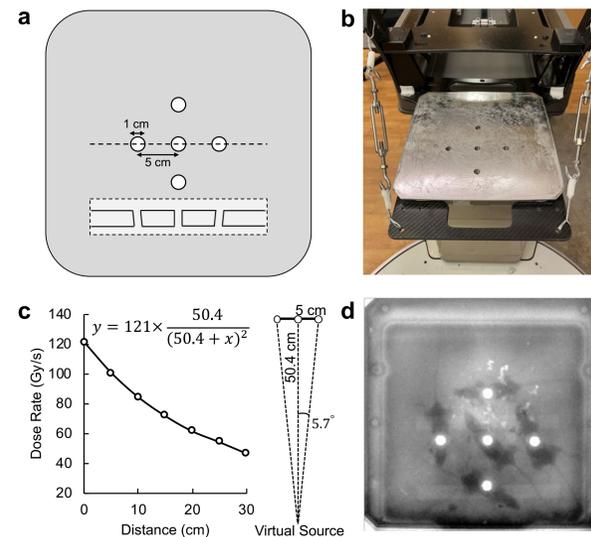
- Varian 21EX CLINAC
- CONV beam:** clinical 16MeV electron
- FLASH beam:** 20MeV converted to 16MeV UHDR beam
- Flat electron fields for both CONV and UHDR beams per film dosimetry
  - A flat field of approximately 15 cm achieved at gantry faceplate



**Figure 1. Open field profiles for CONV and UHDR beams at the gantry faceplate.** Gantry was placed at 180 degree and a 5 mm solid water slab was placed on the faceplate, after which a Gafchromic EBT-XD film was placed on top of the solid water slab with additional 1.5 cm solid water slabs placed above the film to introduce backscatter. Then CONV and UHDR beams were delivered for beam profile measurements.

## METHODS AND RESULTS (CONTINUED)

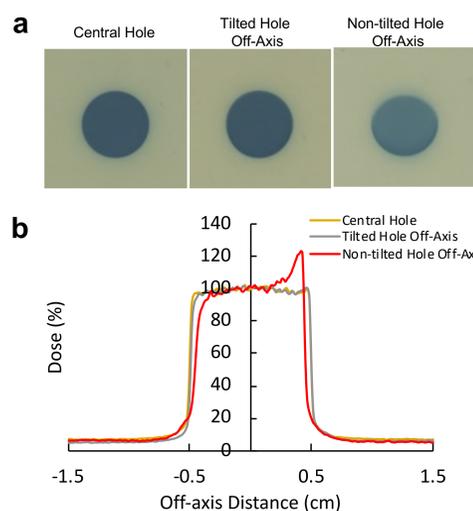
### Radiation Platform



**Figure 2. Radiation platform design.** (a) A schematic illustration of the collimator with the central hole perpendicular to the central axis and the off-axis holes with a tilt of 5.7° to follow beam divergence. (b) A prototype of the Cerrobend collimator supported by a Tilt-Pro™ Tilting base attached to the treatment couch. (c) Determination of the tilt angle for off-axis holes based on the measured virtual source position obtained from an inverse-square fitting of the HyperScint-measured FLASH dose rate and distance. Given the 5 cm off-axis distance and this virtual source distance at 50.4 cm, the tilt angle of 5.7° is derived. With the collimator positioned over the linac faceplate, the FLASH dose rate is at approximately 120Gy/s. (d) A 6-MV portal image showing the feasibility of simultaneous irradiation of 5 mice on the collimator.

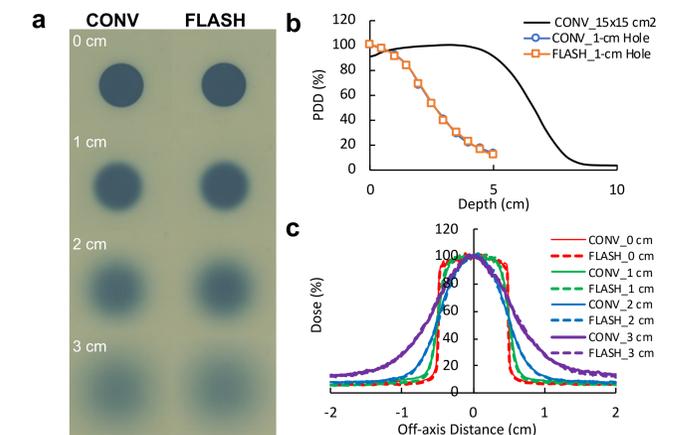
### Film Dosimetry

- Necessity of Off-axis Holes Tilted



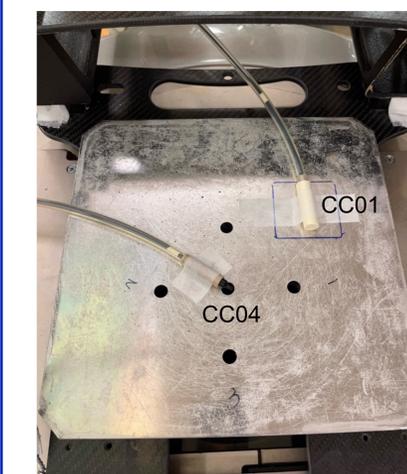
**Figure 3. Film-measured dose profiles demonstrating the necessity of off-axis holes tilted.** (a) Film measurements showing surface dose distribution for the central hole, a tilted off-axis hole with the 5.7° angle, and a non-tilted off-axis hole. (b) Extracted dose profiles from the three films. While the tilted off-axis hole has flat dose profile similar to the central hole, the off-axis hole without tilt shows a narrower, non-flat and asymmetric profile.

### PDD and Dose Profiles



**Figure 4. Percent depth dose and beam profiles along depth.** (a) Film images showing the CONV and FLASH dose distributions at 0, 1, 2, and 3 cm depths. (b) PDD curves of the 1-cm hole-collimated CONV and FLASH (120 Gy/s) fields, and the CONV beam collimated by a 15×15 cm<sup>2</sup> cone. (c) Dose profiles of the 1-cm CONV and FLASH fields at 0, 1, 2, and 3 cm depths show that this collimator is suitable in providing relatively uniform dose coverage for flank tumors a few millimeters in size.

### Dose Equivalence of Five Holes



**Figure 5. Evaluation of the dose equivalence of the five holes using ion chambers.** A reference chamber CC01 is placed on top of the collimator at a fixed location to account for instability of the UHDR beam. A field chamber CC04 is placed at the center of the holes to assess the output from them. Three beam deliveries were performed at each hole to minimize measurement uncertainty. The ratios between the charges from CC04 and CC01 for different holes show a variation at ±1.2%. Therefore, the five holes have similar output factors.

## CONCLUSIONS

- For subcutaneous tumors a few millimeters in size, this collimator is adequate in providing uniform and comparable dose coverage at CONV and FLASH dose rates
- Surface collimation provides sharp penumbrae at shallow depths
- Therefore, this high-throughput collimator offers a useful tool for murine subcutaneous tumor model irradiation with electron FLASH radiotherapy and beyond