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Proton beam dosimetry at ultra high dose rates: evaluation of the usability and the dose rate dependency of various radiochromic films.

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BACKGROUND

At the ARRONAX facility, the C70XP cyclotron offers the possibility to deliver proton beams from low to ultra-high dose rates (UHDR), thanks to a homemade pulsing chopper-based system [1]. Our beamline, tuned for 68 MeV, is adapted to preclinical irradiations and specifically set up to easily shift between conventional/UHDR irradiation conditions.

AIM

To evaluate the dose rate dependency of several radiochromic films commonly used for dosimetry in radiotherapy, considering various mean dose rates, linear energy transfers (LET) and beam structures.

MATERIAL & METHODS

Experimental setup

A 52- μ m tungsten foil (TF) and two Al collimators (C1 \varnothing 15 mm, C2 \varnothing 10 mm) were used to spread and homogenize the proton beam.

Doses from UHDR irradiations were calculated using electric charge readings from a photomultiplier (PM) tube. Doses from conventional (conv) irradiations were calculated using readings from a parallel-plate ionization chamber (IC). Both detectors were calibrated using a Faraday cup (FC).

The proton beam spot has a 10-mm diameter at the target position.

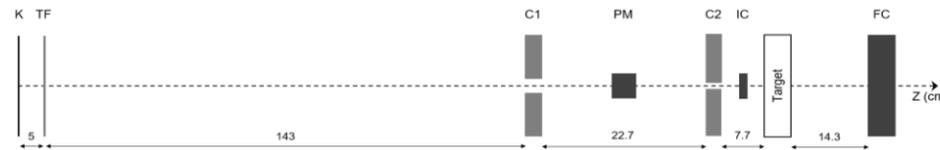


Figure 1: Proton beam experimental setup.

Radiochromic films

Three types of radiochromic films were compared: GAFchromic™ EBT3 [2] and EBT-XD [3], OrthoChromic OC-1 [4]. They were digitized between 24 and 48h after their irradiation. Their response was assessed using the net optical density (NetOD).

Experiments

Films were stacked in the same order along the beam axis: EBT3 / EBT-XD / OC-1. The positioning of each irradiation was remotely controlled using an in-house automatic XY translator. Three types of experiments were performed:

- #1 - Comparison conventional/UHDR irradiations + variation of the LET
- #2 - Variation of the mean dose rate.
- #3 - Variation of the beam structure

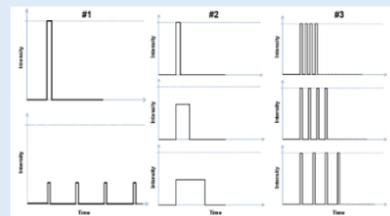


Figure 2: Beam structure variations for experiments #1, #2 and #3.

| | Mean dose rate (Gy/s) | Intra-pulse dose rate (Gy/s) | # pulses | Pulse width (ms) | Repetition frequency (Hz) |
|----|-----------------------|------------------------------|-------------|------------------|---------------------------|
| #1 | 7500 | 7500 | 1 | 0.27 – 16.67 | - |
| | 0.25 | 6.3 | 800 – 50000 | 0.4 | 100 |
| #2 | 40 | 40 | 1 | 75 – 3000 | - |
| | 7500 | 7500 | 1 | 0.27 – 16.67 | - |
| #3 | 40 | 7500 | 4 – 160 | 0.1 | 53.3 |
| | 1500 | 7500 | 4 – 160 | 0.1 | 2000 |

Table 1: Beam structures of experiments #1, #2 and #3.

RESULTS

- Significant differences of response ($NetOD_{UHDR} > NetOD_{CONV}$) between 0.25 Gy/s (conv) and 7500 Gy/s (UHDR) for EBT3 and EBT-XD films, above 10 Gy.
- No significant difference of response between 0.25 Gy/s and 7500 Gy/s for OC-1 films, except below 3 Gy.
- Similar differences of response between conventional and UHDR conditions for different LETs, for all films.
- NetOD increase with mean dose rate for EBT3 films, more especially between 1500 and 7500 Gy/s.
- Significant differences in netOD between 40 Gy/s and 7500 Gy/s for EBT-XD films above 16 Gy.
- No impact of the mean dose rate for OC-1 films between 40, 1500 and 7500 Gy/s, except below 3 Gy.
- No significant difference based on the beam structure, between a single macro-pulse and multiple macro-pulses delivery at either 40 or 1500 Gy/s, for all three types of films.

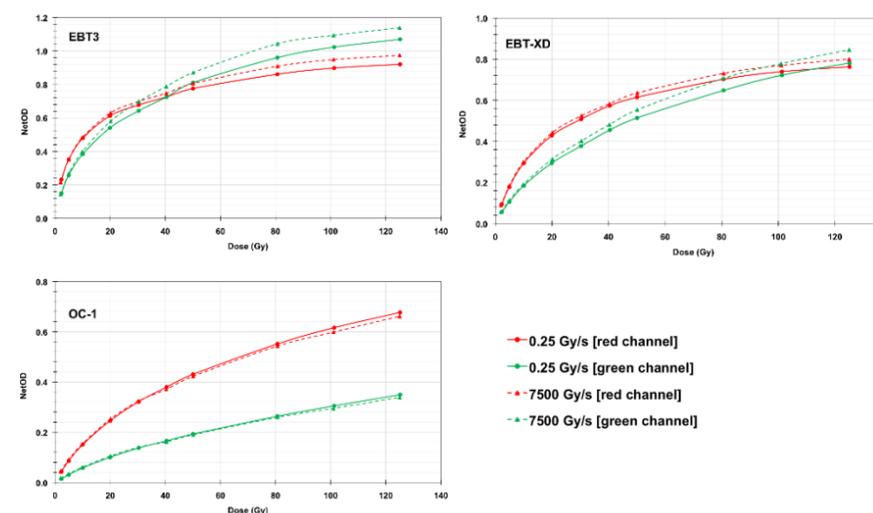


Figure 3: Difference of response between 0.25 Gy/s and 7500 Gy/s, using red and green channels of EBT3, EBT-XD and OC-1 films.

CONCLUSIONS

- EBT3 and EBT-XD films should be used with caution for the dosimetry of UHDR proton beams.
- In our future UHDR experiments, we will use EBT3 or EBT-XD films up to 10 Gy, and OC-1 films between 10 and 100 Gy.
- The dose rate dependency of OC-1 films should be evaluated at UHDR > 7500 Gy/s
- A broader investigation of the usability of OC-1 films for the dosimetry of UHDR proton beams should be conducted at other beam energies.

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