TREATMENT PLANNING TECHNOLOGY DEVELOPED FOR FAST-02 CLINICAL TRIAL

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Introduction

Following FAST-01[1], the first-ever human clinical trial of Flash therapy, the FAST-02 clinical trial [2] aims at providing critical insights into the clinical use of Flash treatment for cancer metastases.

To enable such clinical trials, Varian advanced the development of Flash therapy to become an integrated, end-to-end solution that includes innovations in treatment planning, quality assurance, and delivery technologies. We present here how Eclipse treatment planning system was modified to support the FAST-02 clinical trial.

FAST01 TRIAL	FAST02 TRIAL
Bone metastasis (-es) in extremities	Bone metastasis (-es) in thorax
Predefined library of plans	Flash transmission plan generated in Eclipse
Rectangular uniform single field	Conformal uniform single field
Gantry angle zero degrees	Full range of gantry angles

PBS dose rate calculation

A typical Pencil Beam Scanning (PBS) irradiation is depicted in fig.1. In such scheme, several pencil beams (or spots) are delivered sequentially along a scanning pattern. Each spot is delivered within a certain time and contribute to a fraction of the total dose received by a given voxel.

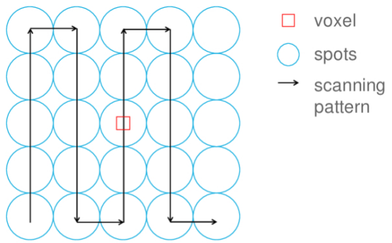

Fig.1. Schematic of a PBS irradiation.

For each field of a plan, the 3D dose rate is calculated as follows:

1) the dose distribution is calculated for each individual pencil beams of the field (influence matrix) using Eclipse dose calculation algorithm,
2) the scanning dynamics information (time spent per spot) is evaluated based on the ProBeam machine capabilities e.g., beam current, magnets speed,
3) For each voxel, the time and influence matrix are combined to compute the dose accumulated as a function of time as shown in figure 2.
4) the PBS dose rate [3] is then calculated as:

$$\dot{D}_{PBS} = \frac{D^*_{voxel}}{t^*_{voxel}}$$

where

- $D^*_{voxel} = D_{total,voxel} - 2 \cdot D_{th,voxel}$ [Gy],
- $D_{total,voxel}$ is the total dose in the voxel [Gy],
- $D_{th,voxel}$ is an arbitrary threshold dose set to 0.01 Gy,
- t^*_{voxel} is time needed for the accumulated dose to rise from $D_{th,voxel}$ to $D_{total,voxel} - D_{th,voxel}$ [s].

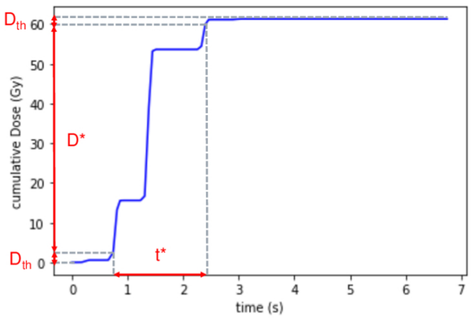

Figure 2. Example of dose accumulated in a single voxel as a function of time (blue curve). The PBS dose rate is calculated as D*/t*.

Methods

The ProBeam system's scanning dynamics were modelled in Eclipse and used to calculate the PBS dose-rate distribution [3] for a given field. To evaluate the fraction of a structure receiving Flash dose rates, the following metrics were implemented and reported in Eclipse: the volume of voxels with a dose D > Dmin (VD); the volume of voxels with both dose D > Dmin and dose-rate DR > DRmin (VDR); and the ratio of the two volumes (VDR/VD).

A QA tool (fig. 4) was also developed to verify dose rate delivery based on logfiles. To illustrate the system capability, a 250 MeV proton transmission field was created to deliver 8 Gy in one fraction to the target volume. The dose-rate-based metrics were calculated for D_min of 2 Gy and DR_min of 40 Gy/s.

Results

The fraction of irradiated volume (dose above 2 Gy) receiving at least 40 Gy/s was 71% for lungs and 81% for the body. In the region where the dose exceeded 8 Gy, the dose-rate ranged from 36.3 to 82.1 Gy/s. Most of the dose was delivered at a dose-rate above 40 Gy/s.

Structure	VD (cc)	VDR (cc)	VDR / VD (%)
PTV	290	281	97.0
Body	1048	837	81.2
Lungs	26.5	18.8	70.9
Humeral head	8.9	7.7	86.1

Table 1. The volume of voxels with a dose D > Dmin (VD); the volume of voxels with both dose D > Dmin and dose-rate DR > DRmin (VDR); and the ratio of the two volumes (VDR/VD) for the target volume and several organs-at-risk. A large fraction of each structure is irradiated at FLASH-compatible dose-rate.

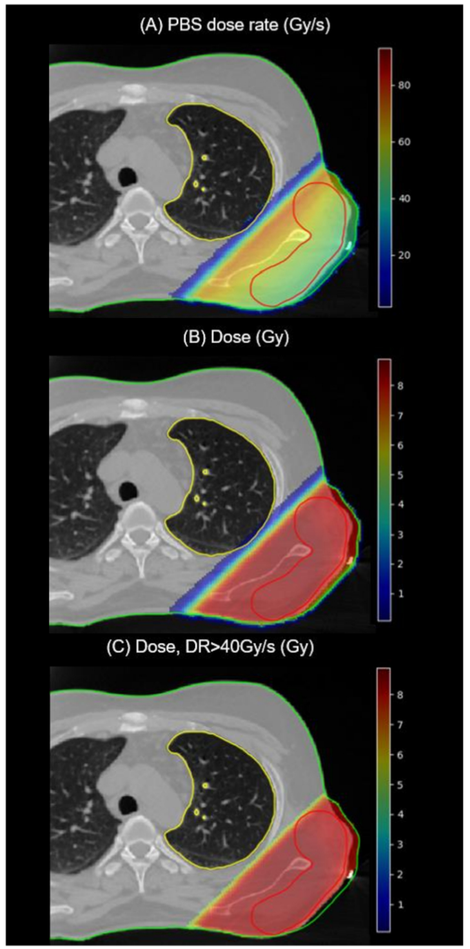

Figure 3. View of the (A) PBS dose-rate distribution, (B) dose distribution and (C) dose distribution for voxels with a dose-rate above 40 Gy/s. Except the edges of the dose distribution (dose below 5 Gy), most of the field is delivered at a dose-rate above 40 Gy/s.

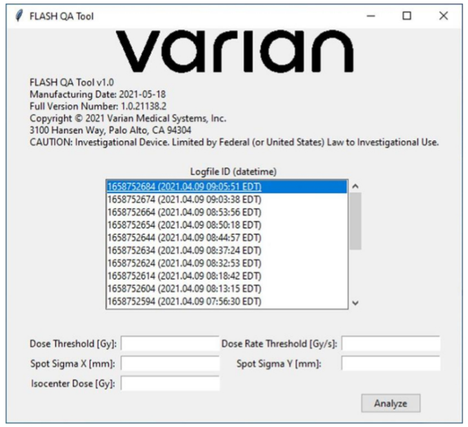

Figure 4. Screenshot of the FLASH QA tool showing a list of the most recent irradiation sessions for the user to select for analysis. Below the list are the available input parameters used to calculate the logfile-based reconstruction of delivered dose rate [3] on the isocenter plane. When the Analyze button is clicked a report is generated containing dose rate statistics within the region of interest. These delivery statistics can be compared directly with the TPS prediction of dose rate statistics calculated from a verification plan (water phantom) to assure the delivery system is performing as expected.

Conclusion

These features allow the clinician to create treatment plans delivered in a single fraction and at dose-rate compatible with Flash Radiotherapy. To optimize simultaneously the dose and dose-rate distributions, and deliver Flash irradiation in multiple fractions, new features are currently being developed.

References

[1] A. Mascia et al. JAMA oncology, 9(1), 62-69, 2023. **[2]** https://clinicaltrials.gov/ct2/show/NCT05524064 **[3]** M. Folkerts et al, *Medical Physics*, *47*(12), 6396-6404, 2020.

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