COMBINING DOSE AND DOSE RATE INFORMATION FOR A BETTER FLASH TREATMENT PLANNING

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Introduction

While FLASH clinical trials rely on the proper delivery of both dose and dose-rate [1], combining and displaying the two information in a meaningful way to a clinician is a prerequisite for a successful treatment planning. We propose here a new metric and use it for evaluating proton transmission plans [2,3].

Dose Rate DVH

The dose-rate dose is defined per fraction, as the sum of the field doses for the voxels that have a dose rate higher than a threshold value DR_{min}:

$$DRD = \sum_{i \in \text{fields}} H(DR_i > DR_{min}) \cdot D_i \,,$$

where H is the Heaviside function. The Dose Rate Dose Volume Histogram (DRDVH), illustrated in fig. 1, can then be used to evaluate the fraction of a structure that is likely to be irradiated in FLASH regime, e.g.:

"80% of the OAR receives a dose higher than 10 Gy and a dose-rate higher than 100 Gy/s".

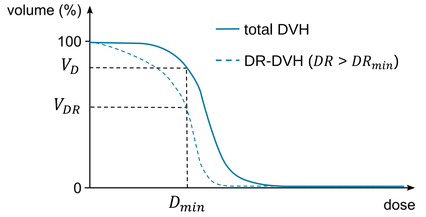

Fig. 1. Illustration of the DVH and the Dose rate DVH.

To evaluate the fraction of structure in the FLASH regime, we moreover define the following metrics:

- V_D: the volume of voxels with a dose D > D_{min},
- V_{DR}: the volume of voxels with a dose D > D_{min} and a dose rate DR > DR_{min}
- V_{DR}/V_D: ratio of the two volumes.

Methods

A set of five proton transmission fields (250 MeV, lungs tumor targeted) have been created in ECLIPSE™. The plan was optimized to deliver 34 Gy to the PTV in a single fraction while maintaining 80 % of the lungs irradiated volume above 40 Gy/s for each field. The field specifications are listed in Table 1.

	Spots	PTV dose (Gy)	Irradiation time (ms)
Field 1	67	6.0	132
Field 2	66	6.6	144
Field 3	62	7.4	149
Field 4	61	7.1	148
Field 5	65	6.9	151

Table. 1. Number of spots, PTV dose and total irradiation time for each field.

The Pencil Beam Scanning (PBS) dose rate distribution [4] was computed for each field, based on ProBeam™ machine delivery parameters [5]. The dose distribution for voxels with a dose-rate over 40 Gy/s (dose-rate dose) was calculated and superimposed to the patient CT to evaluate the plan quality.

The Dose Volume Histograms (DVHs) and DRDVHs (dose-rate over 40 Gy/s) were calculated and compared. Moreover, the DRDVH based metrics were calculated for $D_{min} = 2$ Gy and $DR_{min} = 40$ Gy/s.

Results

The DVHs and DRDVHs are shown in fig. 2. for the PTV, lungs, esophagus, tracheobronchial and great vessels.

For each structure, the difference between the DVHs and Dose Rate DVHs was smaller than 2% for doses above 2 Gy and the two curves overlap for the target volume.

The DRDVH based metrics V_D, V_{DR} and V_{DR}/V_D are listed in table 2 for the PTV and several OARs. The fraction of irradiated volume receiving at least 40 Gy/s and more than 2 Gy is 89.5 % for lungs (98 % for esophagus).

The dose rate distributions of each individual field along with the plan dose-rate dose (DR > 40 Gy/s) are shown in figure 3. For every field, most of the dose is delivered at a dose rate above 40 Gy/s. Moreover, the dose homogeneity in the PTV was within the RTOG recommendations (s-index: 1.5%) [6].

Structure	V_D (cc)	V_{DR} (cc)	V_{DR}/V_D (%)
PTV	11.6	11.6	100.0
Esophagus	6.3	6.2	98.3
Lungs	597.3	534.3	89.5
Tracheobronchial	18.5	16.9	91.4
Great Vessels	51.5	48.9	95.1

Table. 2. DRDVH based metrics for PTV and OARs.

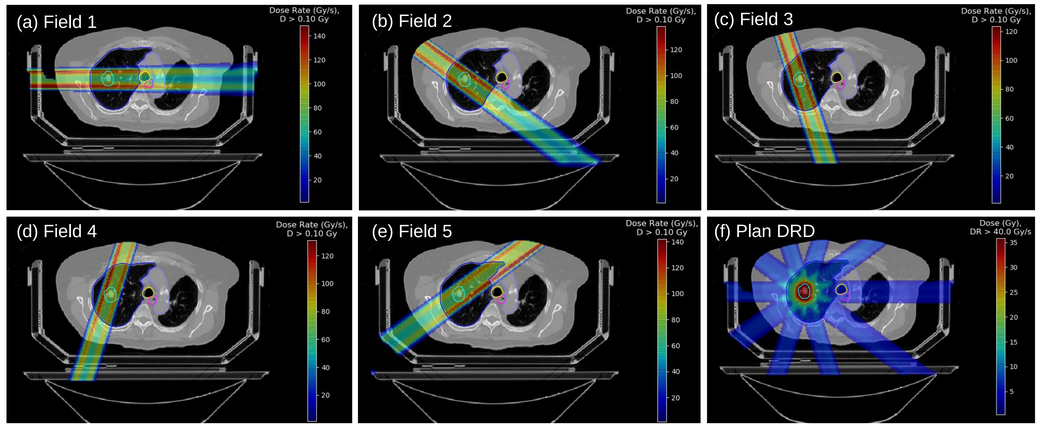

Fig. 3. (a,b,c,d, e) Dose rate distributions of each individual field. (f) Plan dose-rate dose (DR > 40 Gy/s). The target volume is shown in light blue.

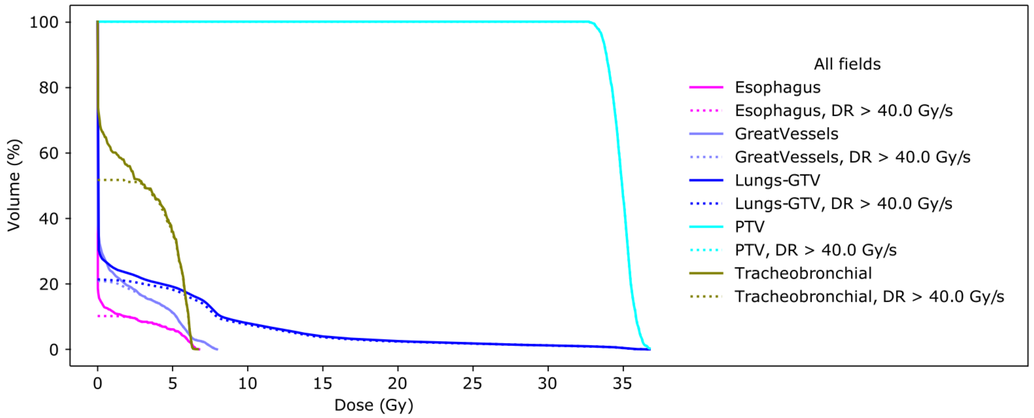

Fig. 2. DVH and DRDVH for the PTV and several OARs.

Conclusion

We have proposed a new way of combining dose and dose-rate information from multiple fields. In addition, a set of metric was proposed to assess the fraction of dose over a given dose and dose-rate thresholds. These tools will support FLASH clinical planning.

This work was designed to address a need expressed by the FlashForward™ Consortium.

References

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