Exploring options for proton FLASH using maximum beam energy

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See also poster #377 SIMFAME

Introduction

To achieve FLASH dose rates with cyclotron-accelerated protons, only plans with a single energy layer and max beam energy at the nozzle exit can be used. By placing hardware components between the nozzle and the patient, a broad variety of dose distributions can be achieved despite the limitations in the beam energy. Our study compares four different strategies of proton FLASH planning for a variety of patient geometries.

Methods

Four planning approaches were investigated, all utilizing a single energy layer of 250 MeV: a) standard five-field **transmission** beams, b) Spots Isolated Many Fields At Maximum Energy (**SIMFAME**) to avoid inter-and-intra-field spot-overlaps outside the target, c) distal edge tracking using **compensators**, d) IMPT-like plans using 3D range modulators (**3DRM**). The planning approaches are shown schematically in Figure 1. Such plans were optimized for a set of liver patients with varying target sizes and depth and their quality scored using a dosimetric **scorecard**. Additionally, the mean liver-GTV dose (MLD) and conformity index (CI) were extracted for all plans. The prescription was 5x10 Gy. The dose rate was calculated assuming a nozzle current of 215 nA (transmission and SIMFAME) and 430 nA (compensators and 3DRMs).

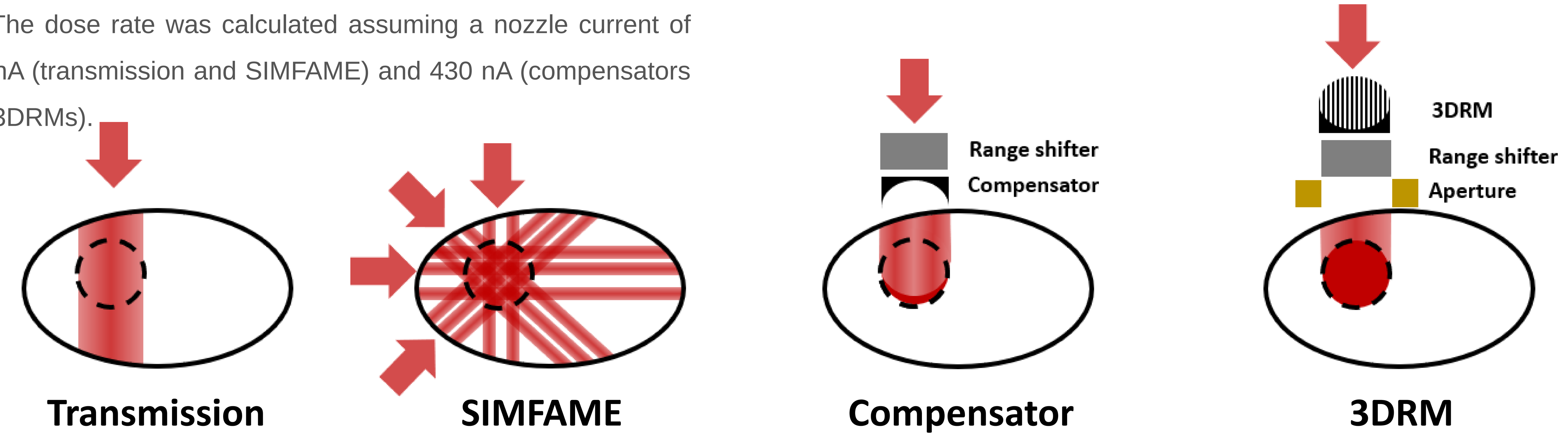

Figure 1: Schematic illustration of the four FLASH planning techniques.

Results

All plans met the protocol requirements and exhibited similar OAR doses (Table 1). Figure 2 shows a visual comparison for all planning scenarios for two extreme cases in terms of target size and position. While the different planning techniques all cover the target, they present very different dose patterns outside of the PTV. The plan quality of these plans is further described by the plan score, the conformity index and the mean dose to the liver minus GTV in Table 1. While the 3DRM scenario scored best for the large superficial tumor, the SIMFAME scenario scored best for the small deep-seated tumor. Transmission, SIMFAME and the compensator plans relied on multiple fields to cover the target homogeneously, whereas only two field were required for the 3DRM technique to cover the target.

Figure 3 shows that for the compensator plan, the full dose was simulated to be delivered at 40 Gy/s or higher, whereas the SIMFAME and transmission plans showed a considerable amount of dose below 40 Gy/s. The 3DRM plan showed intermediate levels of dose above 40 Gy/s.

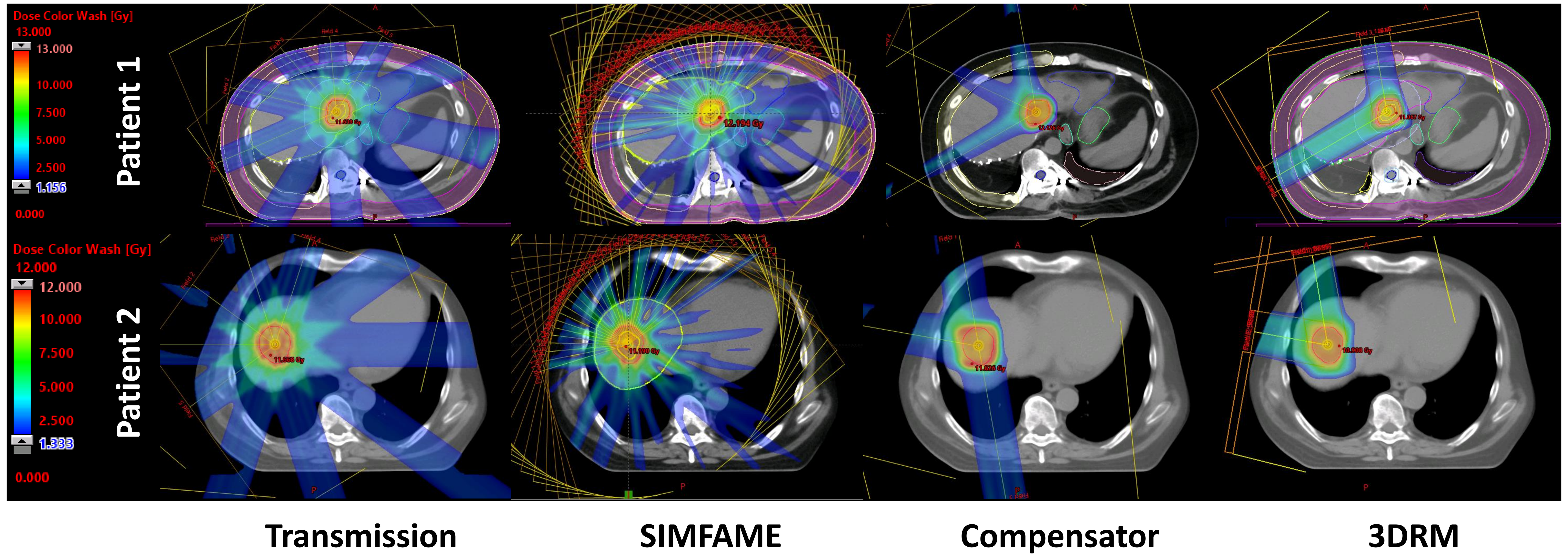

Figure 2: Resulting dose distribution for two example patient for all four planning techniques. Top: Small central target, bottom: larger more superficial target.

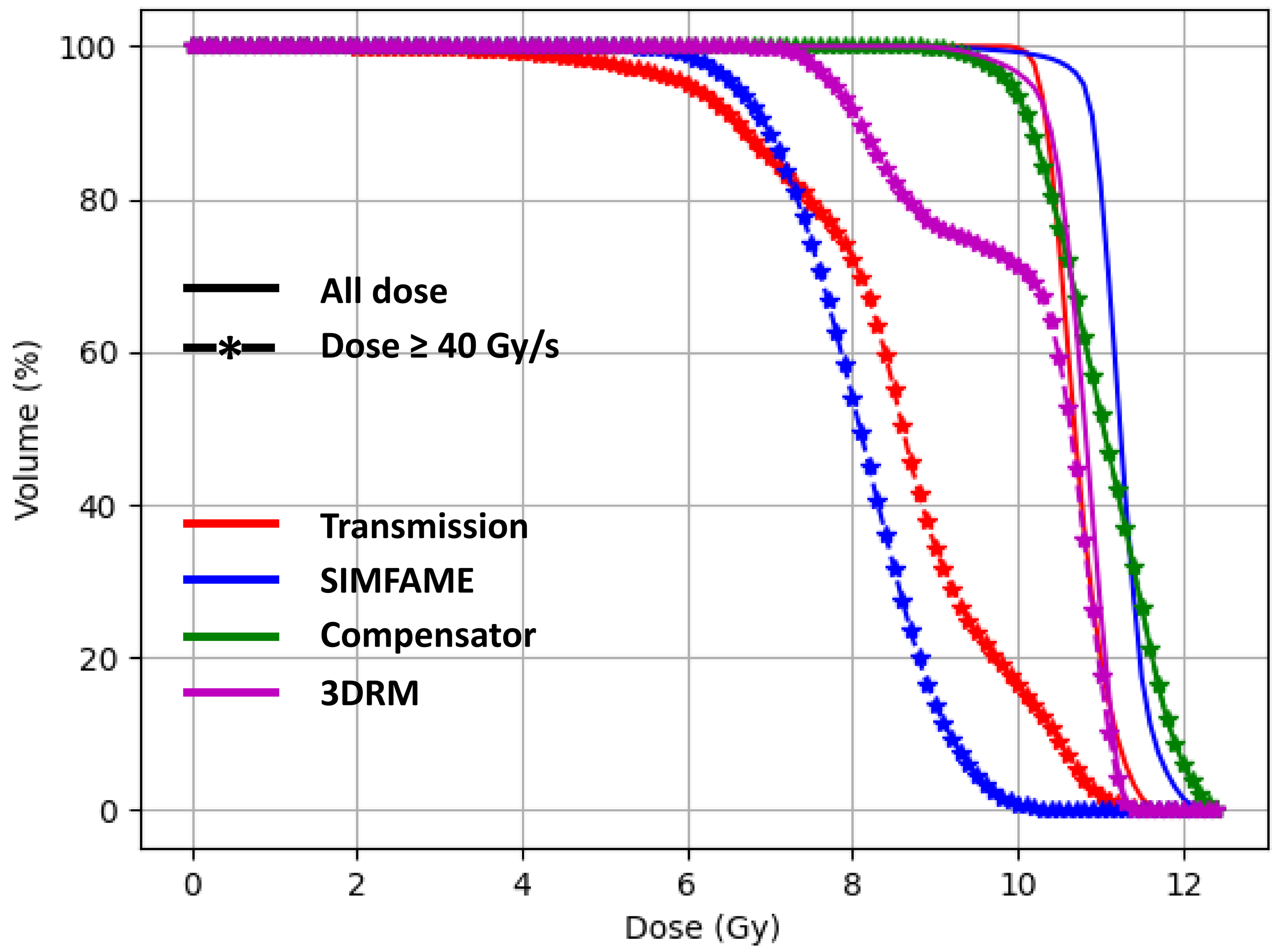

Figure 3: Dose rate DVH for all four techniques for patient 1. Solid lines: PTV DVH, dashed lines with *: PTV DVH for all dose delivered at ≥ 40 Gy/s.

Table 1: Plan quality for the two patients in Figure 2 in terms of plan score, conformity index and mean dose to liver minus GTV.

	Metric	Transmission	SIMFAME	Compensator	3DRM
Patient 1	Score /149	127	130	118	134
	Conformity index	1.53	1.28	1.30	1.15
	Mean liver dose	13.1 %	12.3 %	10.2 %	11.6 %
Patient 2	Score /149	129	134	128	137
	Conformity index	1.49	1.14	1.66	1.07
	Mean liver dose	14.3 %	13.2 %	10.7 %	9.80 %

Conclusion

The presented planning and delivery approaches for proton FLASH all met the protocol requirements by exhibiting very different dose patterns. The selection of a specific approach should be made based on patient geometry.

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