



Dosimetric Feasibility of FLASH-Compatible Single-Energy Bragg Peak (SEBP) Proton Therapy for Hypofractionated Pancreatic Cancer

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Introduction

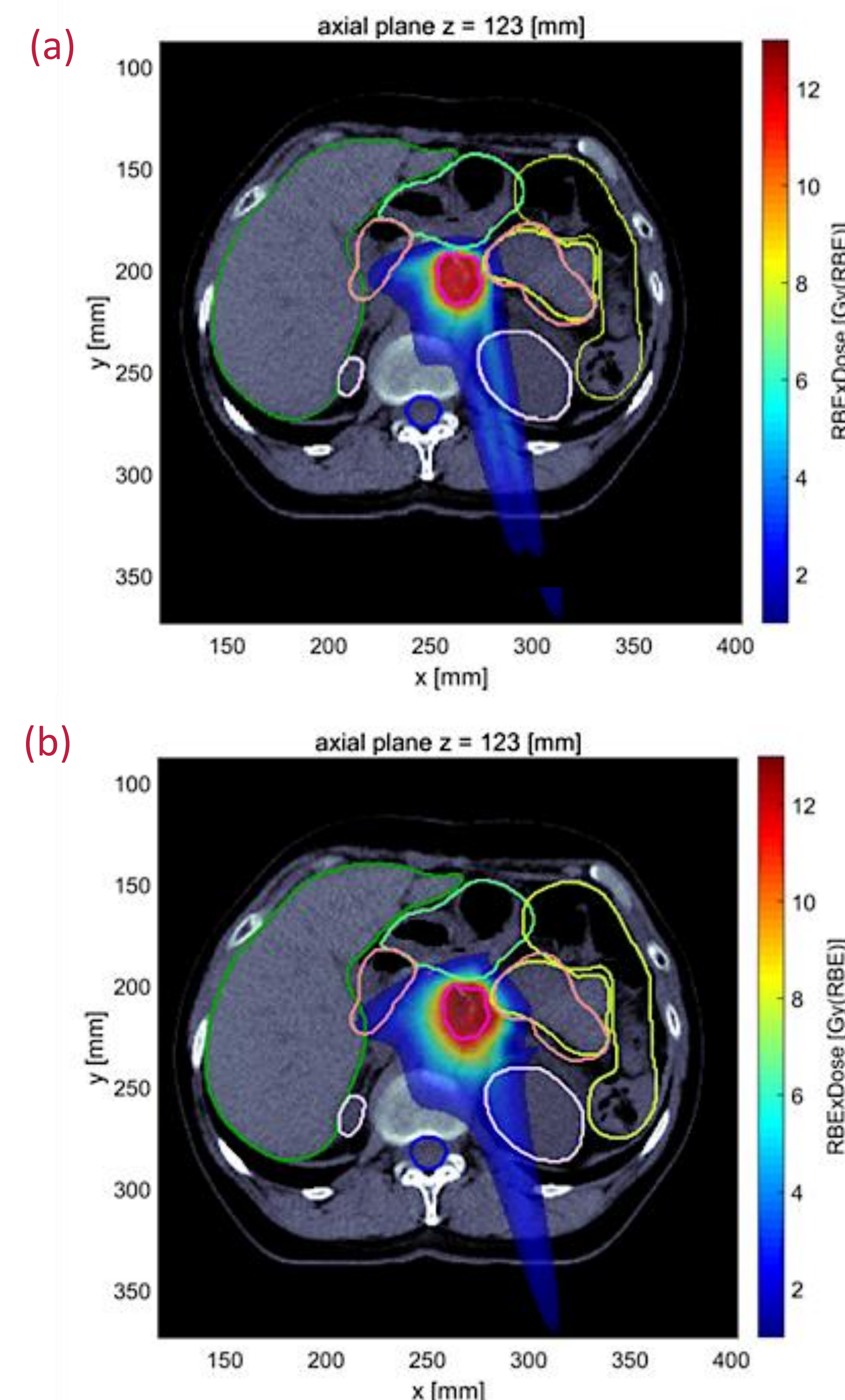
- Hypofractionated proton therapy for pancreatic cancer is limited by the close proximity of radiosensitive abdominal organs to the pancreas
- FLASH irradiation may preferentially spare these radiosensitive organs while maintaining tumor control
- Single-energy Bragg peak (SEBP) proton delivery enables ultra-high dose-rate (UHDR) irradiation while maintaining highly conformal dose distributions, making it a promising approach for clinically feasible FLASH radiotherapy
- This study evaluates the dosimetric characteristics of SEBP planning for hypofractionated pancreatic radiotherapy and compares target coverage, organ-at-risk (OAR) doses, and dose-rate characteristics with conventional intensity-modulated proton therapy (IMPT)

Methods

- Clinical proton PBS pancreatic cancer cases were retrospectively reoptimized using an in-house single-energy Bragg peak (SEBP) treatment planning platform.
- Conventional IMPT plans were reoptimized using identical beam arrangements. Both plans were prescribed to deliver 55 Gy in 5 fractions
- A spot sparsity algorithm was applied during SEBP optimization to eliminate low-monitor-unit (MU) spots and maintain ultra-high dose-rate (UHDR) delivery.
- Target coverage and standard dosimetric metrics were compared between techniques
- Dose-rate volume histograms (DRVHs) were used to quantify the fraction of OAR volume receiving ultra-high dose rates (V40 Gy/s).

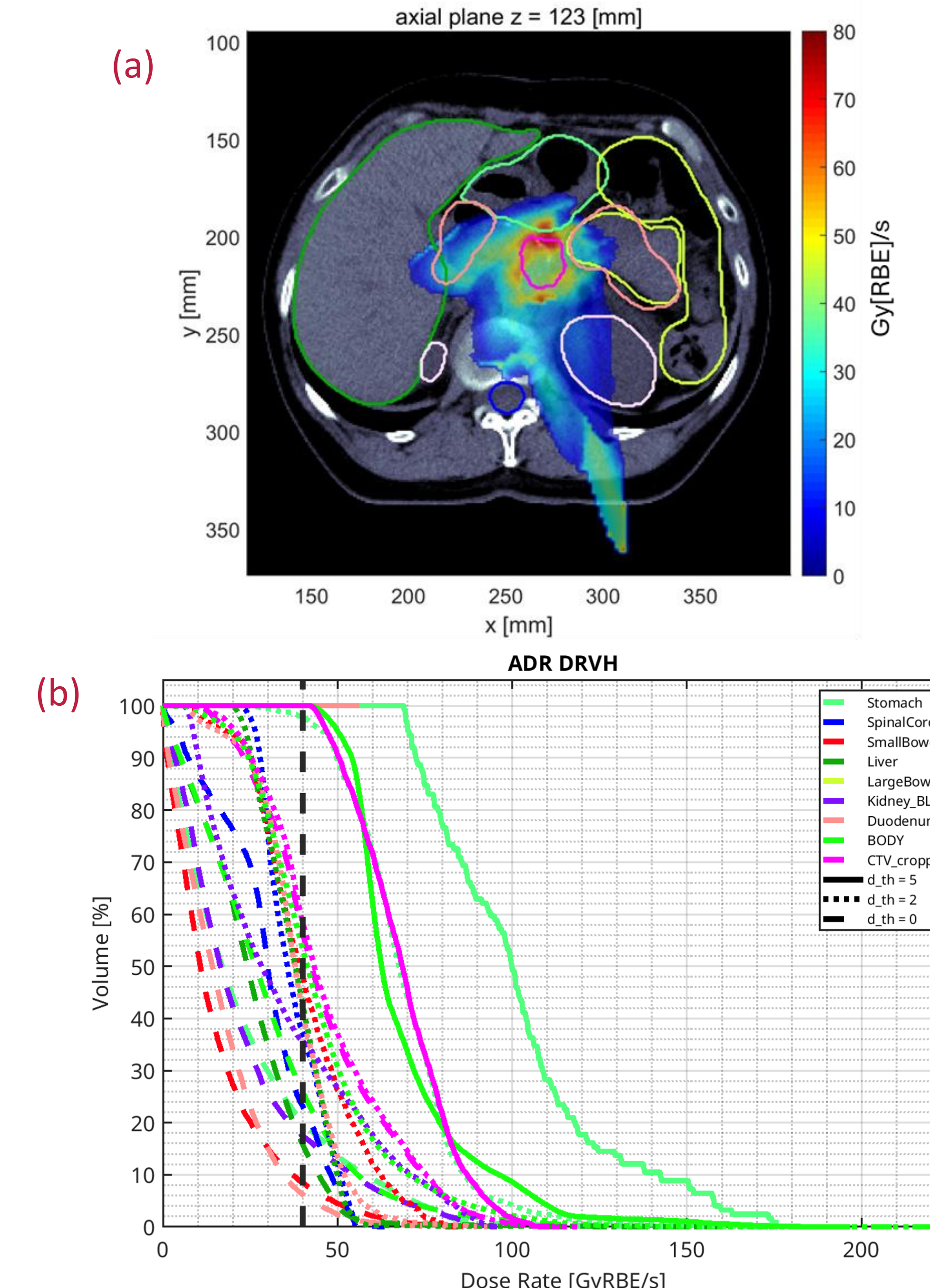
Dose Distributions

Axial dose distributions for a representative pancreatic cancer case (a) IMPT and (b) SEBP plans generated with identical three-beam arrangement (165°, 215°, 260°) and couch angles



Dose Rates

(a) Dose rate map and (b) DRVH with dose rate thresholds (d_th) of 0, 2, and 5 Gy for showcase plan demonstrating FLASH-compatible delivery with SEBP.

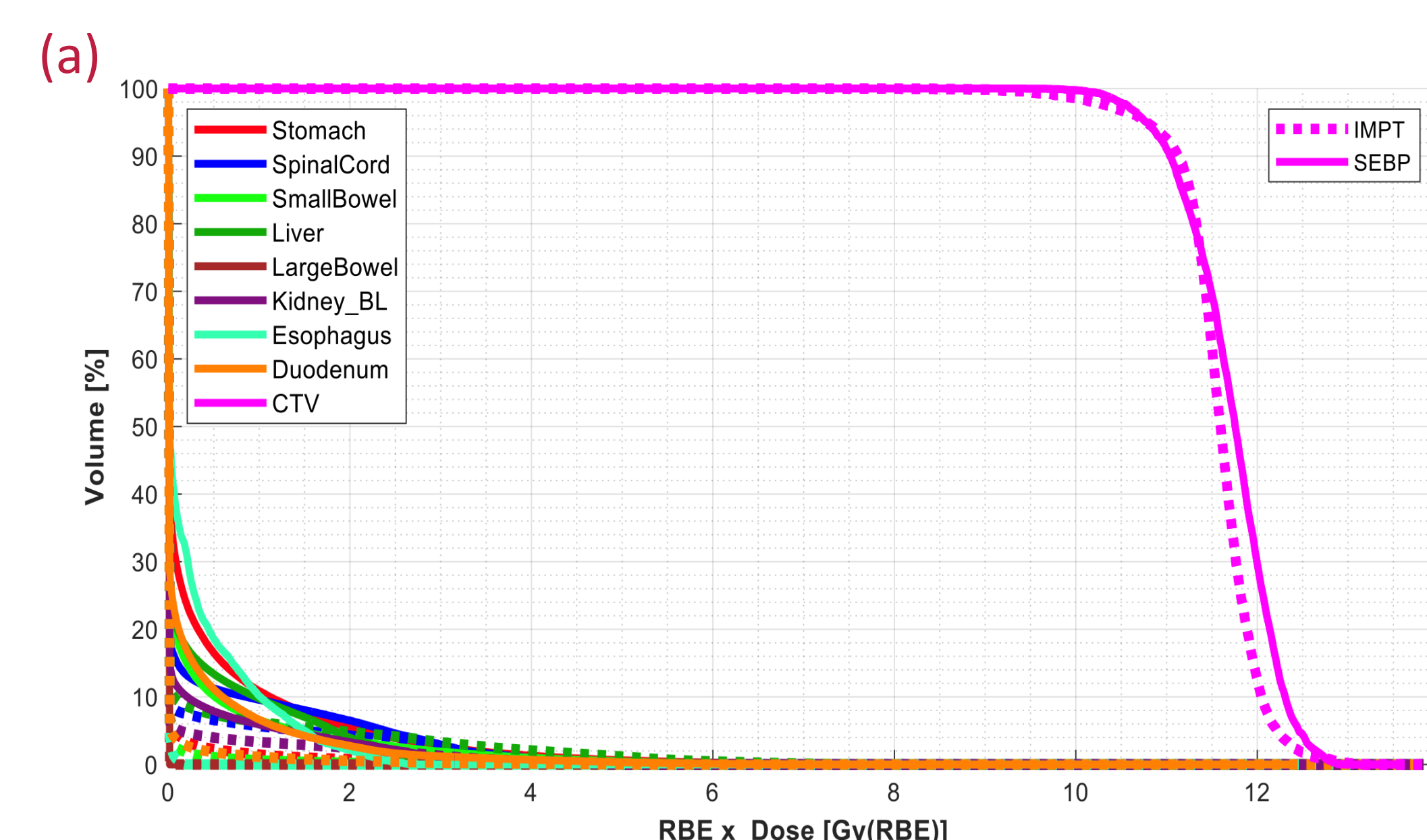


Key Results

- SEBP plans achieved target coverage comparable to IMPT, with CTV D95 of 98% for both techniques and CTV maximum dose below 120% (Dose Distributions Fig(a) and (b))
- Relative to IMPT, SEBP plans showed slightly higher doses to several abdominal OARs because of the lack of energy modulation. However, all OAR doses remained within institutional planning constraints (Dose Metrics Fig(a) and Table(b))
- Dose-rate analysis demonstrated that SEBP delivery achieved FLASH-compatible dose rates over substantial portions of abdominal OAR volumes, with high-dose regions preferentially achieving V40 Gy/s. (Dose Rate Metrics Fig(a) and (b))

Dose Metrics

(a) Corresponding DVHs for the target and abdominal organs at risk. (b) Dose metrics for IMPT and SEBP plans.



Structure	Metric	Constraint	IMPT	SEBP	ABS Difference
CTV	D95	> 98%	98%	98%	0
CTV	Dmax	< 125%	110.41%	115.72%	5.31%
Large bowel	D0.5 cc	< 35 Gy	18.42	18.69	0.27
Duodenum	D0.5 cc	< 35 Gy	25.77	39.21	13.44
Stomach	D0.5 cc	< 35 Gy	17.77	31.27	13.50
Spinal cord	D0.03 cc	< 25 Gy	21.61	23.84	2.23
Small bowel	D0.5 cc	< 30 Gy	21.36	32.07	10.71
Kidneys combined	V15 Gy	< 33%	4.72%	6.15%	1.43%
Liver	Dmean	< 15 Gy	2.84	2.61	0.23
	CI		1.02	1.13	0.11

Conclusion

- SEBP proton planning enables hypofractionated pancreatic treatments with clinically acceptable target coverage and OAR doses while achieving FLASH-compatible dose-rate characteristics.
- These results establish SEBP as a feasible planning approach for abdominal FLASH proton therapy and provide a foundation for future delivery and biological investigations.