Optimizing Proton FLASH in Tangential Breast Chest Wall Radiotherapy

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Background and Aims

Post-mastectomy chest-wall (CW) irradiation is well suited for proton FLASH due to the predominance of normal tissue within the target and the feasibility of single-energy tangential transmission beam (TB) delivery. This study investigates optimization strategies to enhance FLASH activation and modeled biological sparing for large CW targets. .

Results

Clinically acceptable chest-wall coverage was achieved using a single-energy tangential TB paired with a supplemental en face clinical beam, while maintaining a simple grid-based spot layout compatible with FLASH delivery (Figure. 1a–c). Spatially, TB delivery tends to produce non-uniform FLASH activation across the chest wall, mainly towards the posterior lung region. In contrast, changing parameters such as scanning speed (V_y) and split-field TB (STB) improve the uniformity of FLASH-activated areas across both the CW-CTV and skin (Figure. 1d–k). Across the cohort, the dominant drivers of FLASH coverage were higher vertical scan speed (V_y) and STB delivery, which increased the percentage of voxels meeting FLASH criteria for both CW-CTV and skin. The highest coverage consistently occurred with the STB-ADR configuration (Figure. 2a–b). FLASH activation was model-dependent, with the ADR model achieving higher FLASH than FEM across all delivery configurations and scan speeds (Figure. 2a–b). The magnitude of sparing, evaluated by examining reductions in ΔCTV Dmean, was most pronounced in STB with ADR. GA-based sequencing produced comparable ΔCTV Dmean while improving delivery efficiency (Figure. 2c). The most promising and best outcomes of this study in terms of FLASH metrics, including maximum CW-CTV and skin FLASH activation, the most significant ΔCTV Dmean reduction, and scan-time reduction, are summarized in Table.

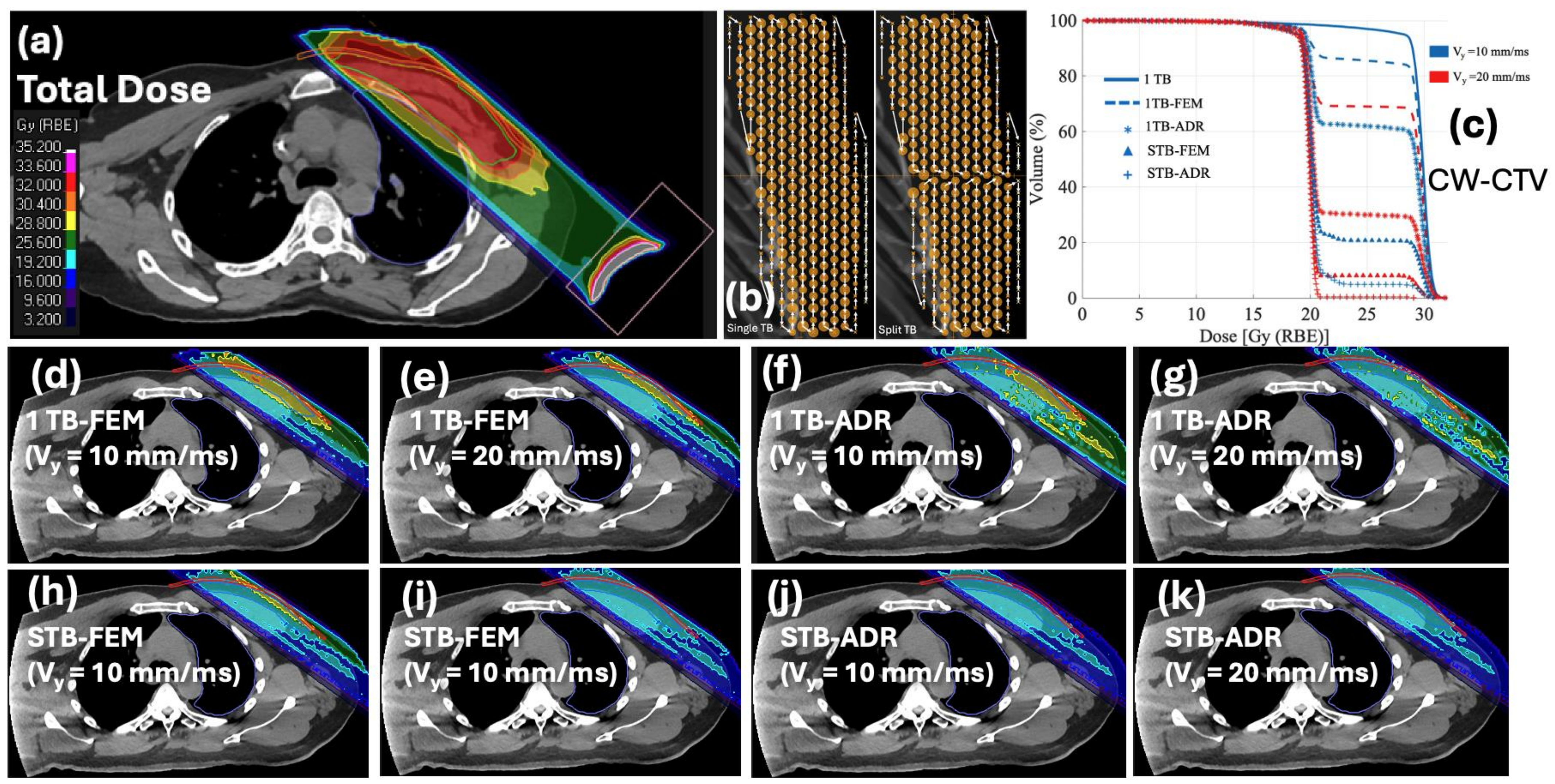

Figure 1

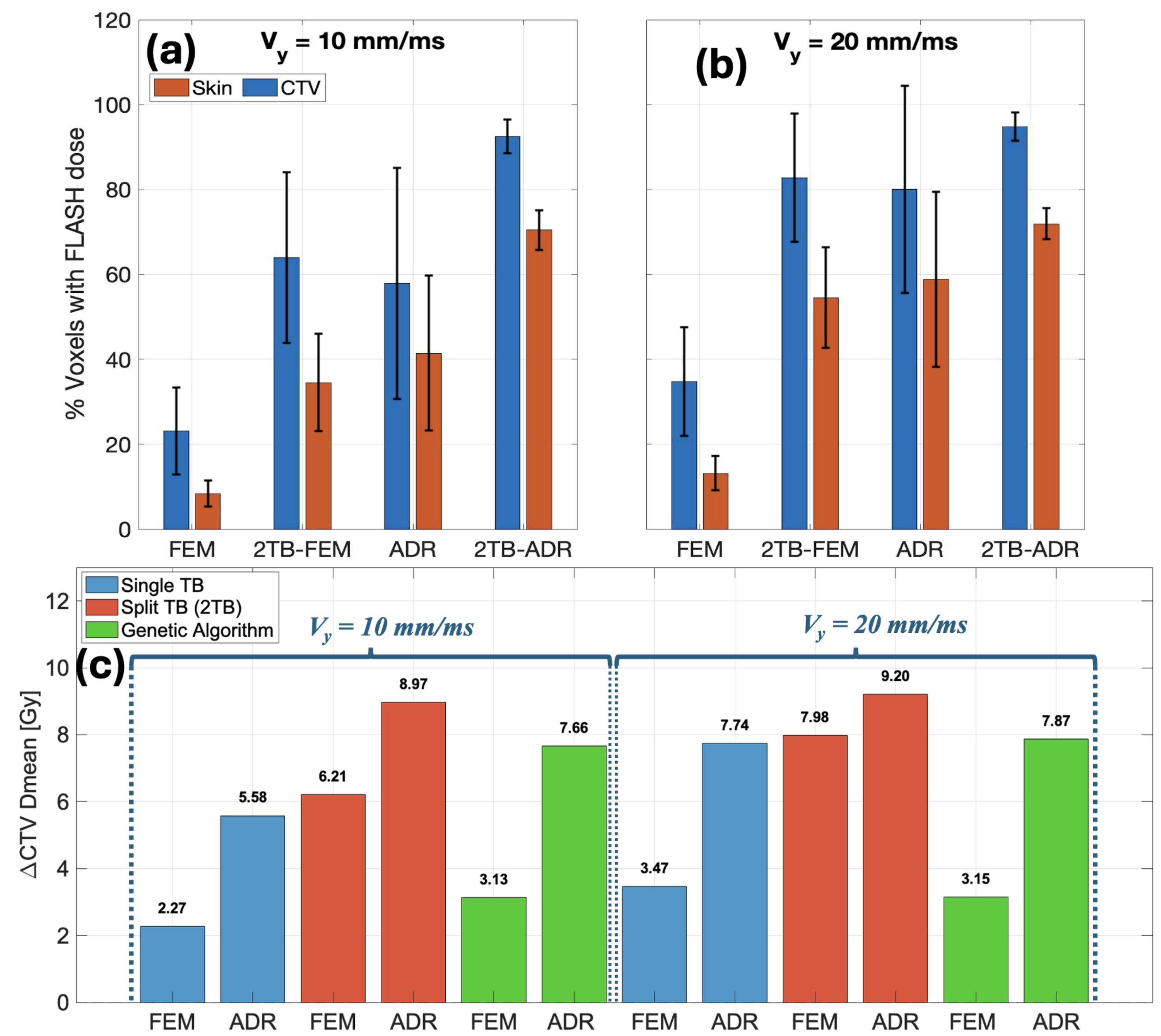

Figure 2

Conclusion

FLASH activation increased with higher scan speed (20>10 mm/ms), split-beam delivery (STB>single-TB), and ADR vs FEM, reaching 94.84% in CW-CTV and 71.96% in skin (STB, ADR at 20 mm/ms). Modeled FLASH biological sparing reduced the *effective* CW-CTV Dmean to normal tissue by 2.27 to 9.2 Gy, without compromising coverage. GA-based sequencing reduced scan time by 6.1%. Averaged across five patients, effective CW-CTV Dmean decreased from 29.20 Gy (TB) to 21.55 Gy (ADR-GA), and skin Dmean decreased from 20.94 to 17.42 Gy. Split-TB and higher scan speed produced the greatest FLASH activation. GA-based spot sequencing achieved FLASH coverage comparable to the split-beam delivery. A larger cohort study is needed for further validation.

Metric	Best Result	Condition
FLASH-activated voxels in CTV	Up to 94.84%	STB with ADR, V_y=20 mm/ms
FLASH-activated voxels in Skin	Up to 71.96%	STB with ADR, V_y=20 mm/ms
CTV Dmean reduction	Up to ~9.2 Gy (avg), 9.57 Gy (case max)	Split TB, ADR (V_y=20 mm/ms)
Scan time reduction	About 6.1%	GA-sequencing vs V_y=10 mm/ms