SIMSEB: Unlocking the Dosimetric Potential of Sequential Boost Plans in VMAT Through Simultaneous Optimization

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PURPOSE/OBJECTIVE(S)

Radiotherapy often uses a secondary dose escalation (boost) to a smaller volume containing the gross tumor volume. Sequential boost (SEB) and simultaneously integrated boost (SIB) approaches differ in that in SEB the boosts are optimized and delivered sequentially (fraction-variant delivery), while in SIB they are optimized and delivered jointly.

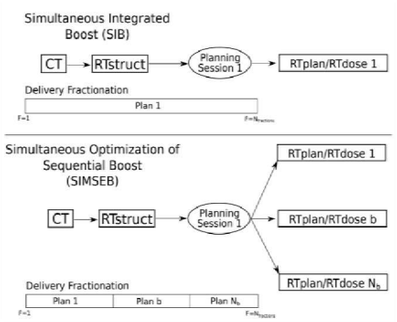
Studies point out the benefits of using SIB over SEB based on retrospective planning [1], but in this study we argue that it is SEB's separate optimization process that is blunting its dosimetric potential - not the planning approach itself [2]. To overcome this limitation, we introduce SIMSEB: a novel optimization framework for the simultaneous optimization of sequential boost plans in VMAT.

MATERIAL & METHODS

Materials:
We retrospectively plan 20 prostate cases (CT + RTstruct) using SIB and SIMSEB VMAT optimization. RTstruct segmentations include 50Gy prescription PTV2 to the prostate bed and 30Gy boost PTV1 to the prostate, along with Organs at Risk (OARs) L/R femoral head, rectum and bladder. Standard OAR planning goals were used (see table), and PTV-ring structures were used to improve dose conformity.

Methods:
Single-arc SIB-VMAT is optimized with OARs and both PTVs (PTV50 and PTV80) in the same dose volume. Single-arc SIMSEB-VMAT optimizes the two sequential boost PTVs (PTV50 & PTV30boost) at the same time, with OARs cumulatively receiving dose from both dose volumes.

Notice the right schematic, both SIB & SIMSEB have a single planning session, but SIB delivers the same plan over all fractions, while SIMSEB can do independent plans per fractionation (boost) section.



RESULTS

We compare the dosimetry of both approaches based on PTV homogeneity and conformity index (HI and CI) and OAR Dose Volume Histogram (DVH) values.

The hypothesis is that by taking advantage of the larger optimization space of SEB treatment, SIMSEB can outperform SIB by simultaneously optimizing multiple plans, each targeting a single PTV, instead of targeting all PTVs at once.

For the Conformity and Homogeneity Indices we use the standard definitions according to RTOG guidelines.

$$\mathrm{CI_{RTOG}} = \mathrm{V_{RI}}/\mathrm{TV}$$

VRI: Patient volume having at least 95% of PTV prescription.
TV: Total volume of the PTV.
Optimal value = 1

$$\mathrm{HI} = (D_{02} - D_{98})/\mathrm{D_{prescribed}}$$

D02, D98: DVH values of PTV structure dose.
Dprescribed: prescribed dose value for PTV.
Optimal value = 0.

Figure 1: Qualitative dose profile comparison between SIB and SIMSEB. Notice that for SIB we optimize 2 PTVs within the same plan, while for SIMSEB we have 2 separate dose volumes, each planning for PTV1 or PTV2.

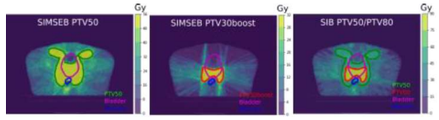


Figure 2: DVH comparison between SIB and SIMSEB. Notice the typical "chair" shape for the PTV50-PTV80_sib, showing the transition dose between PTV80 and PTV50. For SIMSEB, PTV50 and PTV30boost are independent so such transition does not exist.

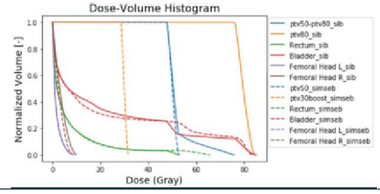


Table 1: Statistical Comparison of DVH metrics for the OARs and CI & HI values between SIB and SIMSEB planning approaches.

Structure	Quantity	SIB	SIMSEB
Bladder	V60<50	6.2±4.7	7.1±5.1
	V70<25	2.7±2.3	2.8±2.3
Femoral Head L	V50<10	0.07±0.27	0.03±0.05
Femoral Head R	V50<10	0.01±0.03	0.02±0.06
Rectum	V60<50	8.0±5.6	7.2±4.8
	V70<25	3.0±3.0	2.8±2.4
	V74<05	1.8±2.1	1.2±1.4
PTV1 (80Gy / 30Gy boost)	HI	0.23±0.08	**0.14±0.01**
	CI	1.39±0.54	**1.05 ± 0.20**
PTV2 (50Gy)	HI	0.16±0.08	**0.12±0.01**
	CI	1.05±0.06	**1.03±0.1**

- Differences between OAR DVH are small, with SIB dose being slightly lower in the Bladder and SIMSEB dose slightly lower in the Rectum.
- SIMSEB outperforms SIB in terms of HI & CI for both PTV structures.
- In particular the CI for PTV1 (base prescription) is much closer to 1 for SIMSEB compared to SIB.

SUMMARY/CONCLUSION

In this work, we introduced a novel optimization framework for the **Simultaneous optimization of Sequential Boost plans (SIMSEB)**. SIMSEB can utilize the thus-far underused potential of SEB plans by optimizing multiple treatment plans in a single planning session, rather than sequentially in multiple sessions.

SIMSEB improves dosimetric potential of SEB plans over SIB
- The results show that SIMSEB shows promise to obtain better PTV dose conformity and homogeneity compared to SIB.
- SIMSEB can exploit SEB's larger optimization space compared to SIB.
- SIMSEB allows for the optimization of fractionation-variant, partially overlapping planning objectives and structures.

SIMSEB simplifies the time-consuming SEB planning workflow
- Normal SEB planning involves a separate planning process for each boost, after which the cumulative dose for the OARs can be calculated and adjustment to individual boost plans can be done.
- SIMSEB allows to optimize any number of boosts at the same time, avoiding trial-and-error corrections to individual boost plans.

SIMSEB Extensions & Future Work:
SIMSEB can be extended to optimize any fraction-variant planning approach:
- Using multiple isocenters for different boosts.
- SIMSEB can allow mixing of e.g. IMRT & VMAT for each sequential boost.
- This even allows full-adaptive fraction-wise treatment planning to account for tumor growth or other radiobiological tumor properties over time.

REFERENCES/ACKNOWLEDGEMENTS

References:
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[2] Popple, Richard A., et al. "Simultaneous optimization of sequential IMRT plans." *Medical physics* 32.11 (2005): 3257-3266.

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