Dosimetric comparison of biologically-guided radiotherapy and X-ray-guided stereotactic ablative radiotherapy for oligometastatic prostate cancer

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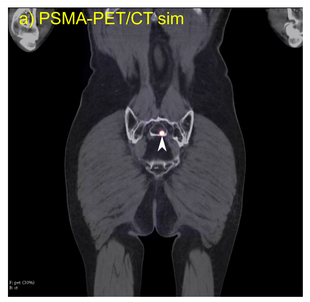
Purpose

Stereotactic ablative radiotherapy (SABR) of oligometastatic (OM) prostate cancer can improve clinical outcomes [1], but tracking small soft-tissue lesions during treatment is challenging with current techniques.

PSMA-PET/CT currently provides unparalleled sensitivity and specificity to metastatic prostate cancer [2], with an example in Fig. 1a).

A linear accelerator capable of **biologically-guided radiotherapy (BgRT)** is being developed to make use of PET emissions for tumor tracking during treatment, shown in Fig. 1b).



b) BgRT Linear Accelerator Design

Figure 1a) ^{18}F-DCFPyL PSMA-PET fused with a CT sim. **b)** BgRT linear accelerator design for PET-guided radiotherapy (reproduced from RefleXion Medical Inc.).

The purpose of this study is to produce ^{18}F-DCFPyL PSMA-PET-based BgRT plans in a cohort of OM prostate cancer patients using a novel plan optimizer, and compare resultant plans to clinical SABR plans.

Methods

15 OM prostate cancer patients imaged with ^{18}F-DCFPyL PSMA-PET/CT and treated with SABR as part of our phase II randomized trial of SABR for hormone-sensitive OM prostate cancer [3] were re-planned using a research treatment planning system (TPS) designed for the BgRT tumor tracking approach outlined in Fig. 2.

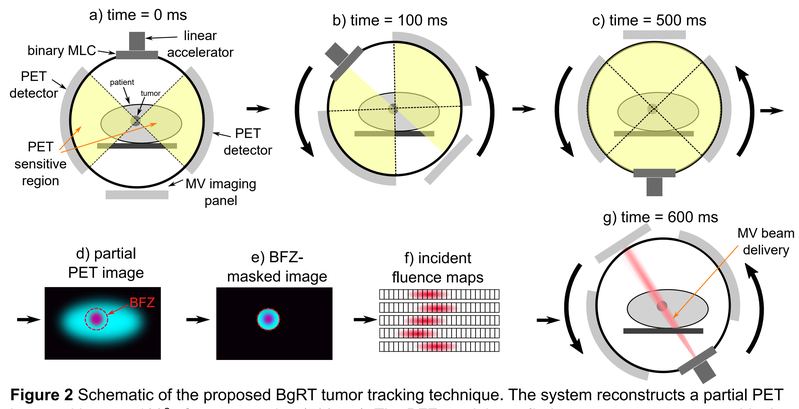


Figure 2 Schematic of the proposed BgRT tumor tracking technique. The system reconstructs a partial PET image with every 180° of gantry rotation (500 ms). The BFZ mask is applied to prevent treatment outside the target, the PET signal is converted to fluence, and the beam is delivered with an average of 400 ms latency.

A **biological firing zone (BFZ)** structure was added to each CT to prevent the treatment of non-specific PET uptake outside of the target, as shown in Fig. 3. The re-planning workflow is shown in Fig. 4.

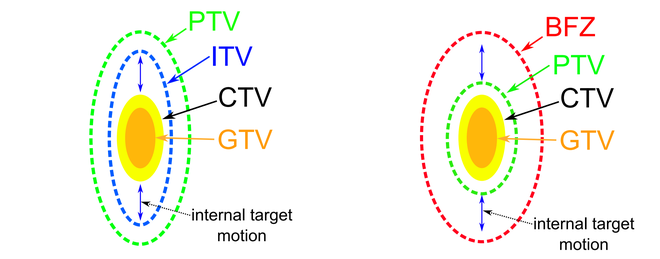


Figure 3 BgRT uses PET emissions to track internal tumor motion, eliminating the need for an internal target volume (ITV). BgRT requires a biological firing zone (BFZ), which acts as a mask to prevent the treatment of non-specific uptake outside of the target. In this study, the clinical PTV was also used for BgRT planning and the BFZ was produced by expanding the clinical PTV by 4 mm isotropically.

Re-planning Workflow

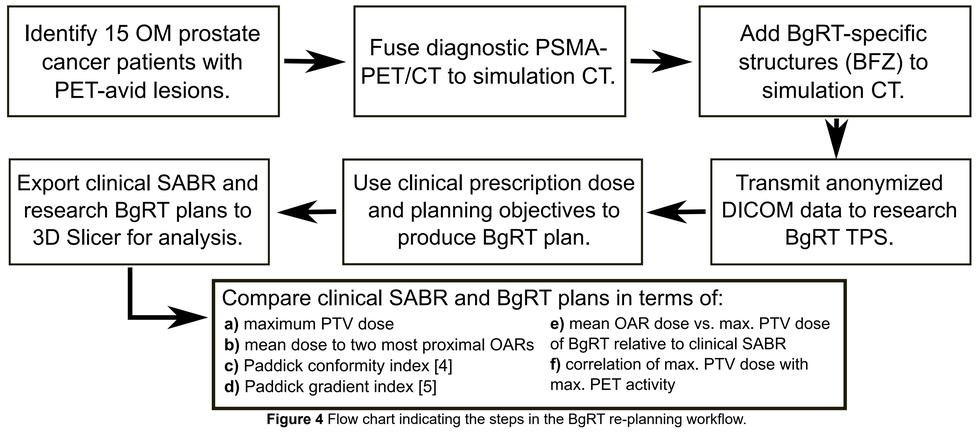


Figure 4 Flow chart indicating the steps in the BgRT re-planning workflow.

Example Plans

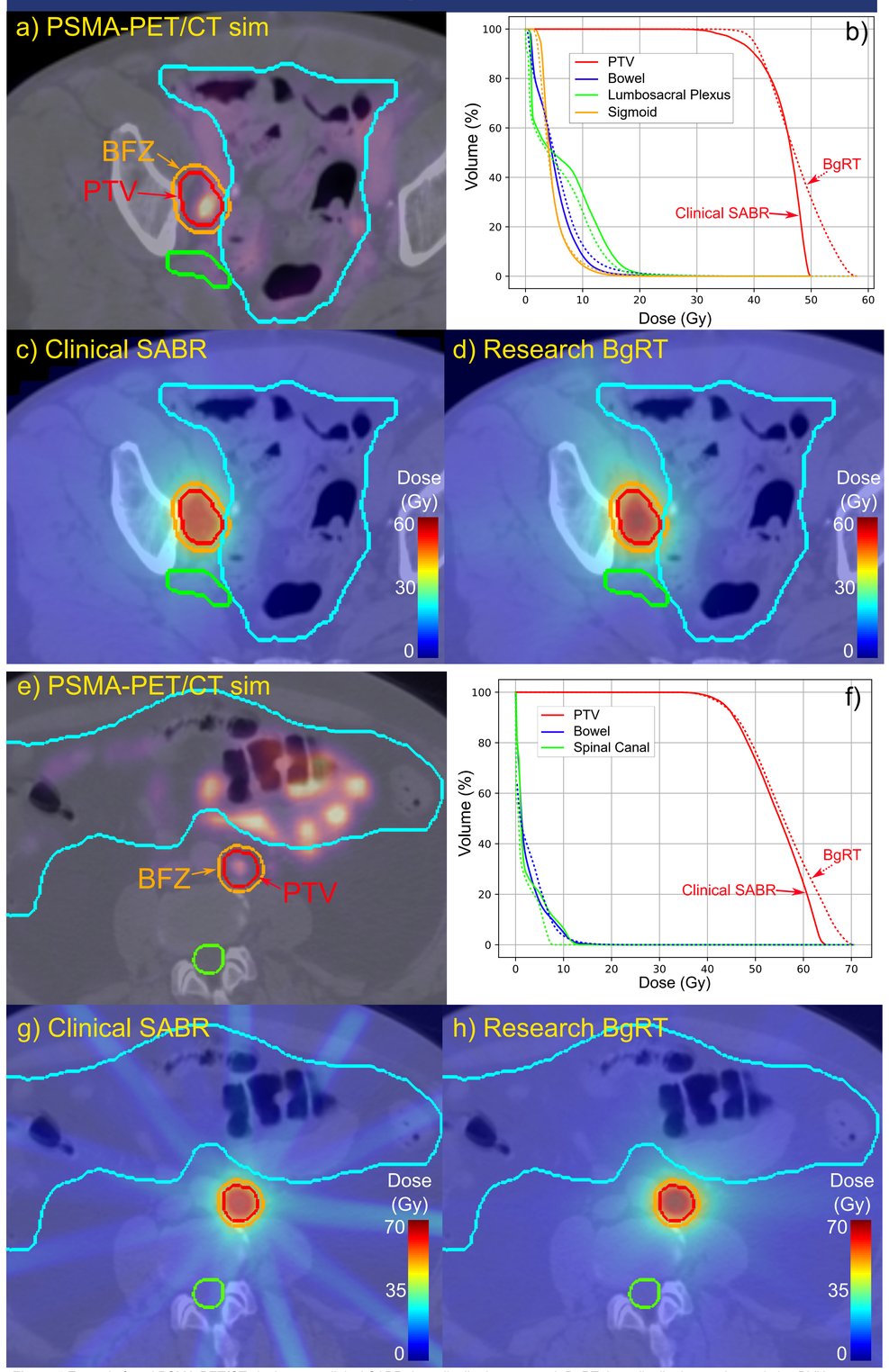


Figure 5 Example fused PSMA-PET/CT sim images, clinical SABR dose distribution, research BgRT dose distribution, and cumulative DVH curves for two patients. In the DVH curves, solid lines correspond to clinical SABR and dotted lines correspond to research BgRT. Note that the spatial distribution of the BgRT dose does not match the spatial distribution of the PET activity.

Results

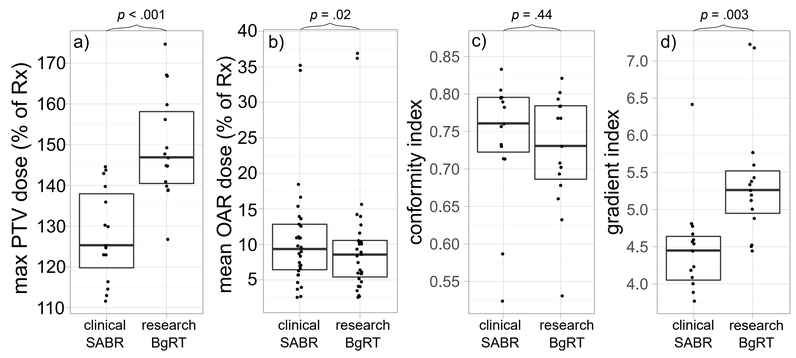
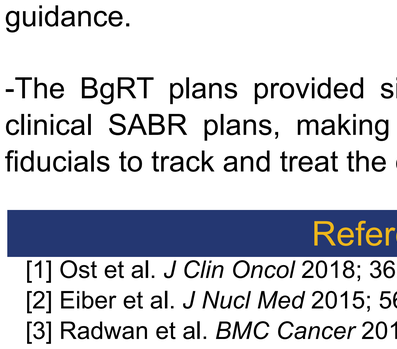


Table 1 Mean±standard deviation dose metrics for each planning approach.

	PTV D_{max} (% of Rx)	Conformity Index	Gradient Index	OAR D_{mean} (% of Rx)
Clinical SABR	128±11	0.74±0.08	4.47±0.63	11±8
Research BgRT	150±13	0.72±0.08	5.40±0.83	10±8



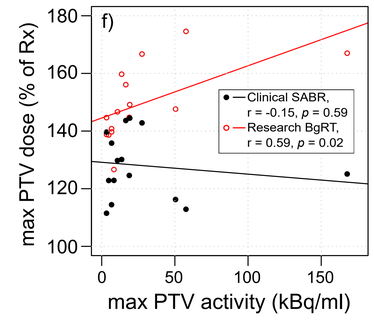


Figure 6a-d) Box plots of dose metrics. Center lines indicate median values and boxes indicate inter-quartile range. P-values are from paired t-tests. Summary statistics are provided in Table 1.

6e) Scatter plot of mean OAR dose versus maximum PTV dose for BgRT relative to clinical SABR with Pearson correlation coefficient, solid line of best fit, and dashed blue identity line (slope = 1).

6f) Scatter plot of max. PTV dose versus max. PTV activity with corresponding Pearson correlation coefficients.

Conclusions

- BgRT plans resulted in significantly higher maximum PTV doses while decreasing mean dose to OARs.

- The majority of points below the identity line (dashed, slope = 1) in Fig. 6e) indicate that BgRT improved the ratio of PTV-to-OAR dose for most patients.

- A statistically significant correlation between PTV D_{max} and maximum PSMA-PET activity indicates the dependence of the BgRT optimizer on the underlying PET data, which is necessary for PSMA-PET based biological guidance.

-The BgRT plans provided similar target coverage to the clinical SABR plans, making use of PET-avid regions as fiducials to track and treat the entire PTV.

References

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