GRAND VALLEY STATE UNIVERSITY MEDICAL DOSIMETRY

A Quantitative Evaluation of Inter-fraction Variability of Rectal Gas in Stereotactic Body Radiation Therapy Treatment of Localized Prostate Cancer

Shomanike Head, BS, RT(T)[1], Karen Snyder, MS, DABR[2], Matt Davis, RT(R)(T), CMD[3], Loree Nisley, BA, RT(T), CMD[3], Hannah Lee, PhD, DABR[3]

[1] Grand Valley State University, [2] Henry Ford Health, Department of Radiation Oncology , [3] Michigan Healthcare Professionals Radiation Oncology Institute

Introduction

Prostate cancer is the second most common malignancy in men in the United States, and Stereotactic Body Radiation Therapy (SBRT) for localized prostate cancer offers comparable biochemical control, to standard fractionation, along with patient convenience. Due to the high dose per fraction, the SBRT technique requires accuracy in patient setup to protect adjacent organs at risk (OAR), including the rectum.

GI toxicity is a concern for prostate SBRT treatments, and an issue that is continually investigated and has led to mitigation techniques such as endorectal balloons, rectal spacer hydrogels (utilized in the SABRE trial), and adaptive planning techniques. The presence of rectal gas is an inter-fractional anatomical variation that can impact GI toxicity as well as planning target volume (PTV) coverage.

The aim of the study is to quantify for a 40 Gy in 5 fraction SBRT prostate and seminal vesicles (SV) treatment, what amount of gas within the rectum makes a dosimetric difference across several metrics.

Methods

Ten male pelvis patients from a single institution were selected for this quantitative SBRT planning study to the prostate and SV. Patients with extreme anatomy and additional devices in the pelvic region were excluded from selection for this project. The PTV was expanded from the clinical target volume (CTV) contoured by the radiation oncologist: prostate and SV + 3 mm posteriorly and 5 mm in all other directions.

Patients were separated into small versus large groups based on the mean diameter of rectum measurements directly posterior to the PTV (**Figure 1**).

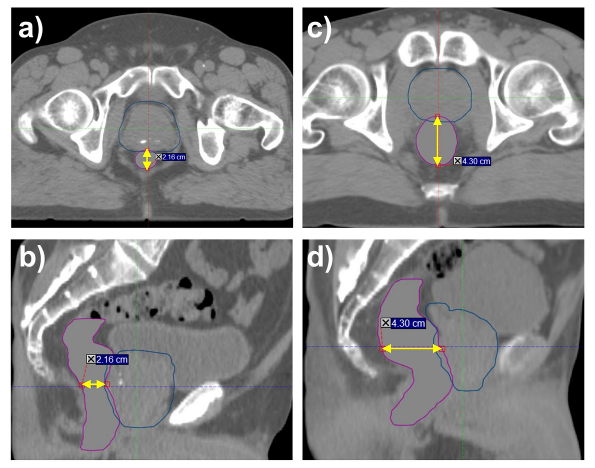


Figure 1: Samples of small (a, b) and large (c, d) group measurements based on the diameter of 5 rectal measurements directly posterior to each PTV for each patient. The average small rectum measurement size was 2.9 ± 0.4 cm; the average large rectum measurement size was 5.1 ± 0.5 cm.

Mean HU for Rectal Filling Override

	Override 1 - Purple	Override 2 - Green	Override 3 - Blue	Override 4 - Yellow	Override 5 - Orange
Feces	100%	75%	50%	25%	0%
Gas	0%	25%	50%	75%	100%
HU Override	38	-165	-368	-570	-773
Mass Density (g/cm³)	1.04	0.87	0.63	0.41	0.21

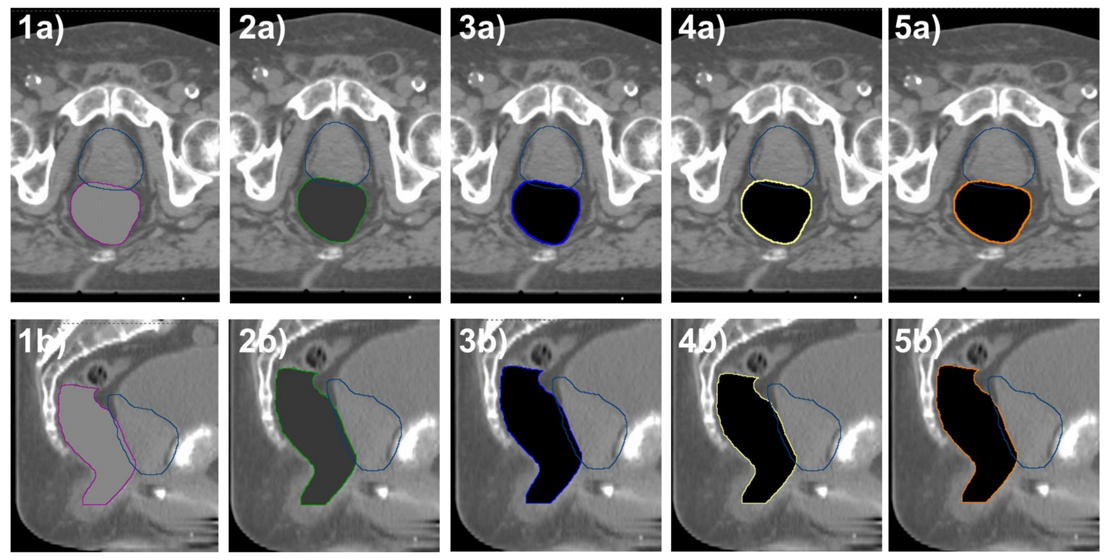
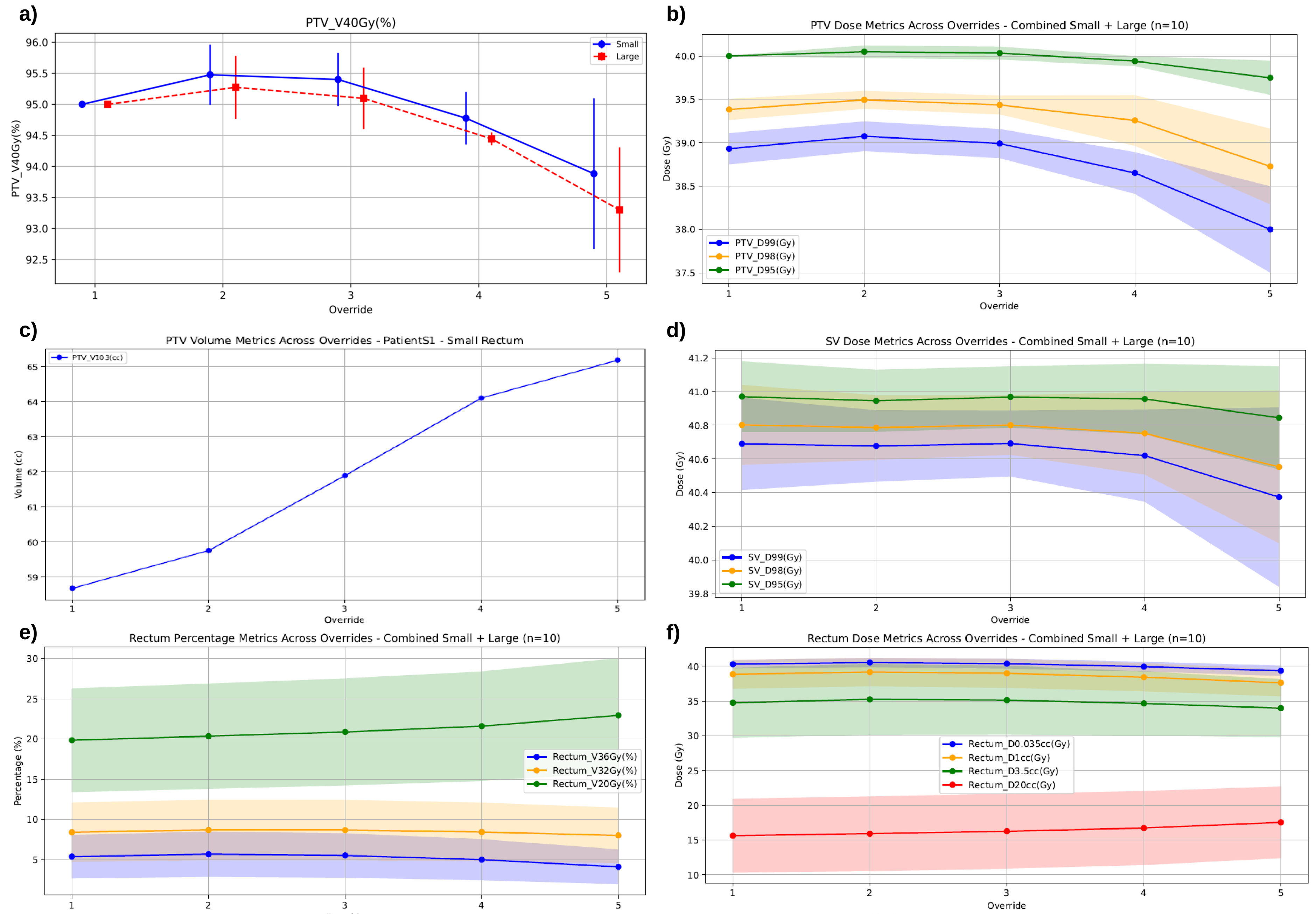


Figure 2 and Table 1: Simulated rectal filing in 5 incremental mean Hounsfield units (HU) overrides ranging from 100%-0% feces and corresponding 0%-100% gas contributions. The visual representation of these HU overrides are shown in this figure corresponding to the table (1a-1b through 5a-5b).

Variable rectal filling was simulated with 5 incremental Hounsfield unit (HU) overrides ranging from 100% feces to 100% gas (**Figure 2 and Table 1**). These 5 density overrides were applied to all 10 patient data sets to evaluate the dosimetric impact of rectal filling. All plans were prescribed 40 Gy in 5 fractions (following the SABRE trial) and created in Varian Eclipse v18.1 with 6MV volumetric modulated arc therapy (VMAT) fields, calculated with AcurosXB v16.1.2. Each plan was calculated for 100% feces first then copied to each structure set with the HU overrides to recalculate the doses for each sequential 4 plans per patient (total of 5 plans per patient). Across the 5 rectal overrides and between small versus large groups, the dosimetric impact was compared for PTV, SV, and rectum metrics.

Results

The PTV metrics analyzed were PTV V40Gy(%), D99%(Gy), D98%(Gy), D95%(Gy), and V103%(cc); the SV metrics analyzed were SV D99%(Gy), D98%(Gy), and D95%(Gy); and the rectum metrics analyzed were rectum V38Gy(cc), D0.035cc(Gy), D1cc(Gy), D3.5cc(Gy), D20cc(Gy), V36Gy(%), V32Gy(%), and V20Gy(%). See the figures below for trends across each metric across the rectal filling overrides, as well as comparisons between the small versus large groups.



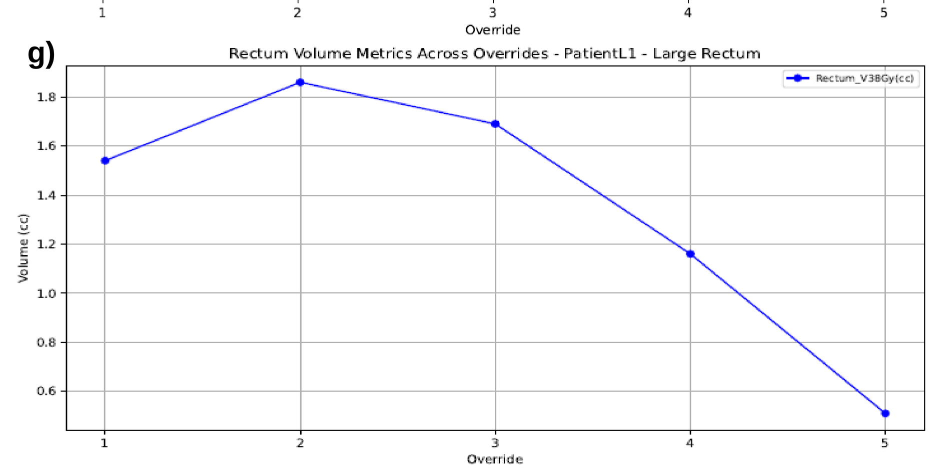


Figure 3: a) Overall for the 10 patients across the 5 rectum HU overrides, the PTV V40Gy(%) coverage decreased with increasing gas contribution. This change was steeper and more sensitive to the gas contribution for the large rectum group ($p<0.05$ for large group Override 1 versus Override 5). b) Overall for the 10 patients across the 5 overrides, the PTV D99%(Gy), D98%(Gy), and D95%(Gy) doses also decreased with increasing gas contribution ($p<0.05$ for both small and large rectum groups by at least Override 3 versus Override 5). c) Due to large differences in the volumes across all 10 patients, one representative patient demonstrating the overall trend is displayed (from the small rectum group). The overall trend for PTV V103%(cc) followed an increase in volume with increasing gas contribution.

Figure 3 continued: d) Overall for the 10 patients across the 5 overrides, the SV D99%(Gy), D98%(Gy), and D95%(Gy) doses decreased with increasing gas contribution. e) Overall for the 10 patients across the 5 overrides, the rectum V36Gy(%) and V32Gy(%) percentages generally plateaued but showed some decrease with increasing gas contribution. The rectum V20Gy(%) percentages increased with increasing gas contribution. f) Overall for the 10 patients across the 5 overrides, the rectum D0.035cc(Gy), D1cc(Gy), and D3.5cc(Gy) doses generally plateaued but showed some decrease with increasing gas contribution. The rectum D20cc(Gy) doses increased with increasing gas contribution. g) Due to large differences in the volumes across all 10 patients, one representative patient demonstrating the overall trend is displayed (from the large rectum group). The overall trend for V38Gy(cc) followed a decrease in volume with increasing gas contribution.

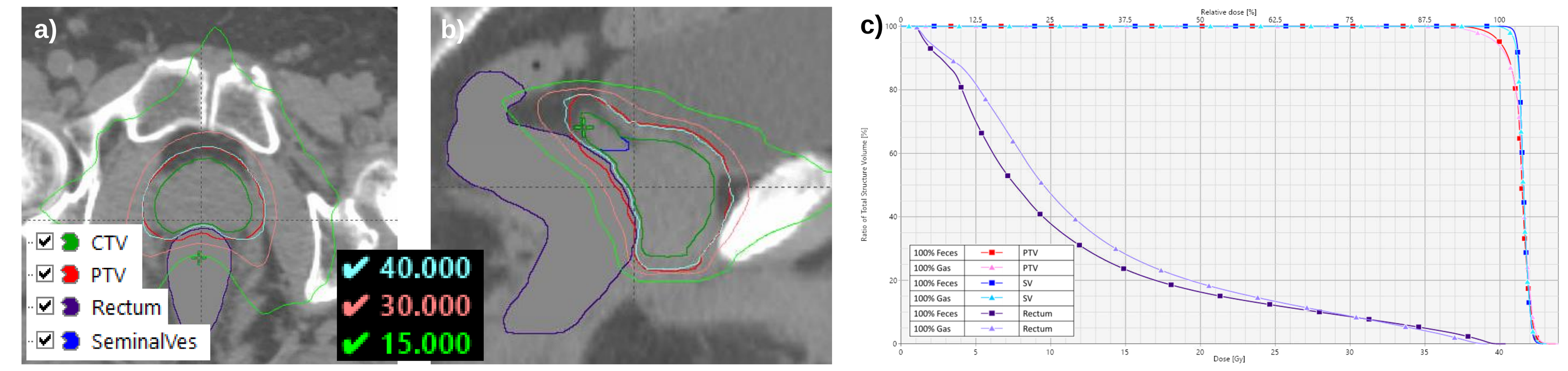


Figure 4: a) and b) A representative patient example to demonstrate the overall VMAT optimization and planning quality showing the isodose lines (IDLs) from the prescription dose of 40 Gy down to 15 Gy. c) A representative dose-volume histogram (DVH) comparison for the same patient between the overrides of 100% feces rectal filling (square symbols on plot) versus 100% gas rectal filling (triangle). The largest impact between the overrides can be seen for the rectum DVH curve.

Discussion and Conclusion

Compared to conventional intensity-modulated radiation therapy (IMRT), more recent VMAT planning techniques involve more advanced techniques to optimize the prioritization of both improved PTV coverage as well as decreased dose to OARs. An example of the prostate and SV SBRT optimization techniques to follow guidelines set by the SABRE trial is shown in **Figure 4**.

With increasing gas contribution to the rectum HU override, the impact on the PTV was more significant after at least 50% gas (Override 3) (**Figure 3a, b, c**). The impact on the PTV V40Gy(%) was more patient anatomy dependent and overall showed a steeper trend for the large rectum group. For the SV, the override dosimetric impact became more apparent after 75% gas (Override 4) (**Figure 3d**). For the rectum, a larger impact from the override could be seen for the V20Gy(%) and V38Gy(cc) for both small and large rectum groups ($p<0.05$) (**Figure 3e, f, g**). For the rectum V20Gy(%), the override dosimetric impact became more apparent after 75% gas (Override 4) (**Figure 3e**); for the V38Gy(cc), the impact became more apparent after 50% gas (Override 3) (**Figure 3g**).

This project demonstrated the importance of VMAT optimization techniques to minimize some of the potential impacts of rectal filling, feces versus gas, over the course of a high dose 5 fraction SBRT treatment. Certain metrics as described in the results and discussed above are more heavily impacted due to the increasing gas contribution, typically greater than 50-75% gas. An excessive amount of gas presence can also distend the rectal volume and push the rectal wall further into the PTV region, impacting all dosimetric metrics. Larger rectums have a greater risk for changes in rectal volume and resulting variable PTV alignment. Physicians may ask for a re-simulation from the start due to these considerations and encourage specific bowel diets. Future work includes investigating the impact of a more realistic heterogeneous filling for both small and large rectum patients utilizing pre-treatment images to delineate the feces and gas content for the HU overrides.

References

QR code:

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Dr. B. Sango Otieno, Associate Professor

Contact

Shomanike Head, BS, RT(T); headsh@mail.gvsu.edu