Evaluating the Impact of Rectal Gas on Treatment Dose Distribution in Prostate Tumor Therapy: A Retrospective Analysis

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ABSTRACT

Prostate cancer is the most common form of cancer, excluding skin cancer, and results in significant genitourinary toxicity. Rectal gas buildup has exacerbated this by changing simulated patient anatomy and introducing tissue inhomogeneity. We are investigating the practical effects of tissue inhomogeneity by retrospectively evaluating the dosimetric impact of rectal gas pockets on target coverage and rectal wall dose in prostate VMAT radiation therapy.

Patients treated for Volumetric Modulated Arc Therapy (VMAT) prostate cancer were retrospectively reviewed. Rectal gas buildup was visually evaluated for its volume and proximity to the Planning Target Volume (PTV). Clinically delivered plans were then recalculated using rectal gas density overrides to simulate gas-free anatomy. Density overrides were defined at <-150 HU and were overridden to soft tissue equivalent densities (0 HU). Recalculated plans primarily compared hot spots for both the rectal wall and prostate target. We then investigated how dose changes vary with the size of the rectal gas pocket.

Evaluation of the dosimetric differences showcased an association between the localized rectal gas pocket and an increased dose to the rectal wall and the PTV. A linear relationship was observed between the volume of gas proximal to the PTV, and the measured delta between each CT variant. Point dose (dose at 0.03 cc) were seen to increase by 7.7% (537.9cGy) for small volumes (12.6 cc). Larger volume metrics (2 cc) showed similar trend increases, increasing by 1.6% (113.7cGy) despite small buildup volumes (6.31 cc)

This work demonstrates clinical dose increases of up to 15% in the PTV and rectum wall for prostate VMAT radiation therapy cases even at rectal gas volume as low as 6 cm3. This increase may justify the use of rectal gas volume overrides to mitigate the effects, allowing clinics to plan conservatively and reduce the risk of overdose of targets and surrounding organs.

REFERENCES

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INTRODUCTION

Prostate cancer remains the second leading cause of cancer in men, resulting in 1,467,854 new cases worldwide in 2022. While common treatment methods such as surgery and radiotherapy have greatly reduced mortality, there remains significant quality of life implications for these patients. The introduction of advanced radiation techniques, such as IMRT and VMAT, have greatly reduced general toxicity, the proximity of key OARs such as the bladder and rectum have prevented full radiation sparing.

Increased high-dose radiation has significant correlation with late toxicity endpoints, causing significant concern for max dose metrics. While advanced treatment planning techniques can minimize these max doses, tissue inhomogeneity due to rectal gas buildup can cause significant dose deviations. This is especially true when gas is present during planning but absent during treatment delivery, with the most significant effects occurring when the gas overlaps with the PTV.

This study retrospectively evaluated the dose distribution of clinically delivered treatment plans, comparing the original plan to an identical plan with all local gas overridden to soft tissue. We evaluated the dose distribution, as well as key clinical goal metrics to investigate the toxicity impact of gas buildup.

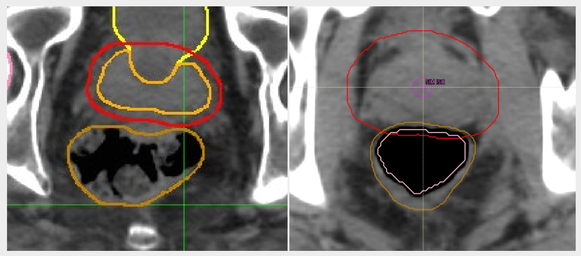

Figure 1. Axial CT Examples of partial and full gas pockets inside the rectum

METHODS AND MATERIALS

This IRB-approved retrospective study (302323-UT) included 33 patients who received radiotherapy for prostate cancer at the Dana Cancer Center between January 2020 to July 2025. 30 received moderate hypofractionation [e.g., 70 Gy in 28 fractions] , and 3 received ultra hypofractionation. [e.g., 36.25 Gy in 5 fractions]

Each plan was copied to a second CT with rectal gas (<-150 HU) overridden to soft tissue (0 HU). The delivered treatment plans were recalculated on the CT with tissue overrides. Clinical goal metrics were compared between each CT for each patient, and then sorted based on the gas volume at variable HU thresholds (-150 HU, -600 HU, and -800 HU) and for different ROIs (PTV vs Rectum Wall vs GTV etc.)

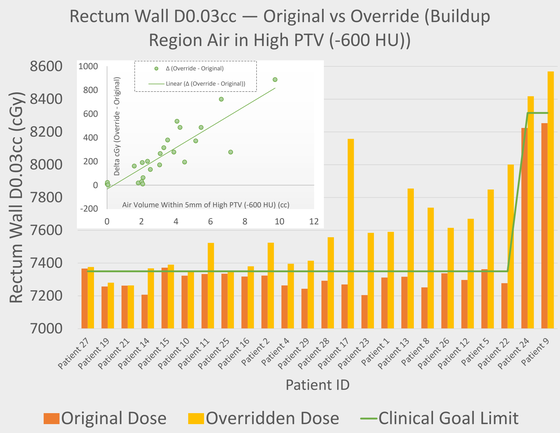

Figure 2. Rectum wall dose metrics for the original and overridden plan, showcasing Dose Delta relationships with air buildup inside the buildup region.

RESULTS

Thirty patients with moderate hypofractionation were evaluated. Dose escalation was observed throughout 2cc and 0.03cc volume metrics for volumes within 0.5cm of the PTV rectum interface. The dose escalation effects had strong correlation with air volumes within 0.5cm of the target, indicating the localized effects of tissue inhomogeneity and charged particle equilibrium were primary factors.

The study was confirmed using a Monte Carlo (MC) dose calculation algorithm, with results exceeding the equivalent CCC test by 27%. This deviation resulted from a significant underdose predication of the MC model at the tissue to gas interface.

Table 1. Dose Statistics for the PTV and Rectum Wall for deviations of the $D_{0.03cc}$

$D_{0.03cc}$	PTV Delta Evaluation (%)	Rectum Wall Delta Evaluation (%)
Min	-0.35	-.01
Q1	0.086	0.66
Median	2.04	2.71
Average	3.33	3.62
Q3	4.84	4.84
Max	15.35	12.69

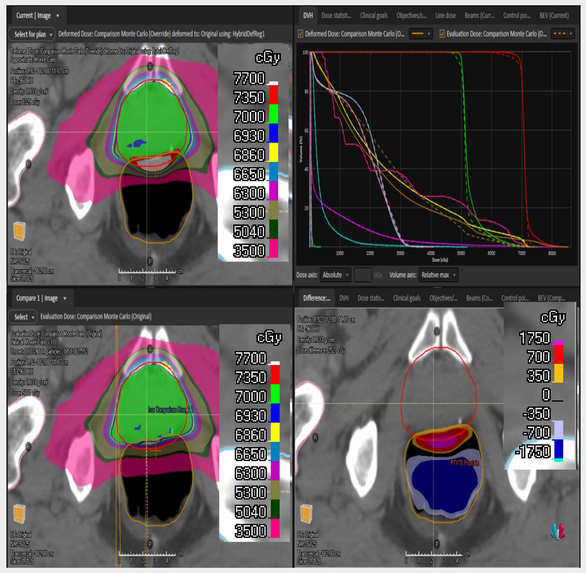

Figure 3. Axial Dose distribution of the original vs overridden plan calculated with MC.

Table 2. Dose statistics for CCC vs MC on an identical gas filled plan.

	CCC	Monte Carlo	Delta
PTV Coverage (% Volume)	95.01	86.79	8.22
PTV $D_{0.03cc}$ (cGy)	7418	7434	-16
PTV D_{2cc} (cGy)	7249	7286	-37
PTV Volume at 110% Rx	0	0	0
PTV % Volume at 95% Rx	98.93	97.46	1.47
Rectum $D_{0.03cc}$ (cGy)	7270	7225	45
Rectum D_{2cc} (cGy)	7162	6963	199
Rectum % Volume at 40Gy	20.12	21.54	-1.42
Rectum D_{50} (cGy)	2059	2353	-294
Rectum Average Dose (cGy)	2415	2547	-132
GTV Coverage	99.91	90.5	9.41

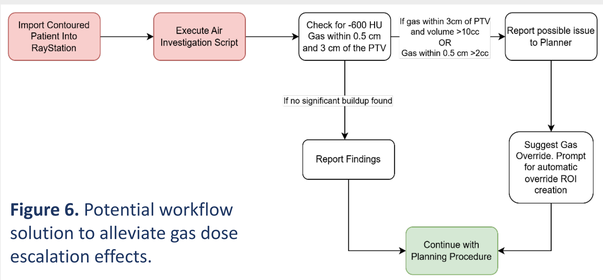

Figure 6. Potential workflow solution to alleviate gas dose escalation effects.

DISCUSSION

This study demonstrates the potential impact of gas variability on a patient's dose distribution. Gas present within 0.5cm of the PTV greatly increased dose escalation when computed on a gas free scan, resulting in plans that failed to meet clinic goals for these OARs in 87.5% of cases, while only 12.5% failed prior to gas override. Failing these goals has significant effects of rectal toxicity, reducing patient quality of life.

Monte Carlo dose evaluations were used to verify the CCC distributions. These findings found the CCC model was insufficient at properly representing dose coverage in the presence of large gas pockets, overrepresenting PTV and GTV coverage by 8-10%.

To alleviate the impact of rectal gas, we investigated preemptively overriding the gas to tissue, however we found significant underdosing occurred, potentially reducing our ability to control the tumor. We will investigate the implementation of robust evaluation between the CT sim, full gas overridden CTs, and gas free rectums ensuring full coverage and no hotspots regardless of patient anatomy.

Figure 4. MLC configuration for a high dose deviation example. PTV in red. Rectum in green, Air Pocket in white.

Robust Optimization

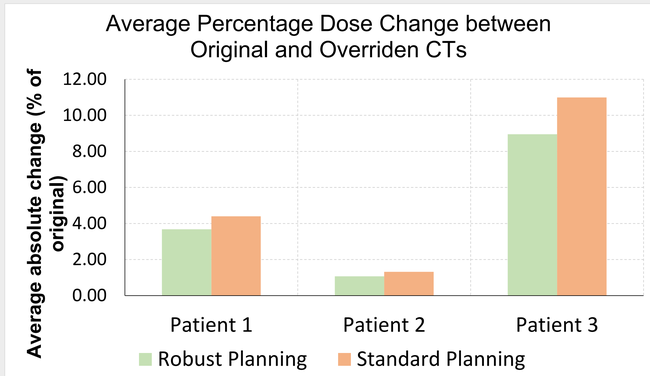

Figure 5. Average absolute dosimetric change between the original and gas-overridden CTs for robustly optimized and standard plans. Lower values indicate reduced sensitivity to rectal gas variation.

Robust optimization was investigated as a strategy to reduce dose variation cause by variable rectum gas anatomy. Plans were optimized with identical planning objectives, except for rectum max dose, which was optimized with RayStation's built in robust function. Preliminary results showed a consistent reduction in dose variation between anatomical scenarios when using robust optimization, suggesting improved plan stability.

CONCLUSIONS

This study demonstrates the dosimetric impact that gas variability has on prostate radiotherapy plans. These effects are typically localized to the interface between the rectum and PTV, allowing for intervention. We investigated the potential solution to override the gas prior to treatment and investigated the use of robustness optimization to further eliminate dose deviations. Clinics may also wish to perform gas extraction techniques for patients with a high risk of overdosing.

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