Inter-fractional Spatial and Dosimetric Variations of Target Volumes and OARs in Rectal Cancer Patients Undergoing Radiotherapy on the CT-Linac

Zerun Cai[2],Qianxi Ni[1]

[1]The Affiliated Cancer Hospital of Xiangya School of Medicine, Central South University/Hunan Cancer Hospital,[2]School of Nuclear Science and Technology,University of South China

2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Background and Objectives:
Inter-fraction changes in bowel and bladder filling may alter target geometry and organ-at-risk (OAR) dose during rectal cancer radiotherapy. This study evaluated spatial consistency and dosimetric variation of target volumes and OARs using fan-beam CT (FBCT) acquired on an integrated CT-Linac system, aiming to identify potential time points for adaptive intervention.

Methods and Materials:
Twenty rectal cancer patients treated with IMRT to 50 Gy in 25 fractions were retrospectively analyzed. FBCT images were acquired at fractions 1, 5, 10, 15, 20, and 25 on an integrated CT-Linac system. Images were deformably registered to the planning CT. CTV and PTV contours were propagated, while bladder and small bowel structures were segmented for each fraction. Spatial consistency was evaluated using Dice similarity coefficient and Hausdorff distance. Absolute volume and dosimetric parameters, including maximum dose and mean dose, were compared across treatment fractions.

Results:
CTV and PTV showed relatively stable spatial reproducibility during the first 10 fractions, with DSC values of 0.898 ± 0.028 and 0.928 ± 0.024, respectively. After approximately fraction 15, target consistency decreased, with DSC declining to 0.813 ± 0.061 for CTV and 0.859 ± 0.046 for PTV, while HD increased by fraction 20. The bladder showed substantial volume fluctuation, decreasing from 211.19 ± 153.12 cm³ at fraction 1 to 65.08 ± 22.59 cm³ at fraction 10. Bladder mean dose ranged from 2881.15 ± 686.21 cGy to 3259.51 ± 551.67 cGy. The small bowel also showed marked inter-fraction variability, with mean dose increasing to approximately 2140 cGy during later fractions.

Conclusions:
Inter-fraction variations in rectal cancer radiotherapy affected both target volumes and OARs. Target reproducibility declined after approximately fraction 15, while bladder and small bowel volume and dose parameters fluctuated across treatment. FBCT-guided CT-Linac monitoring may support individualized adaptive radiotherapy, particularly in patients with persistent OAR displacement or target-volume change.

CONTACT

Qianxi Ni
The Affiliated Cancer Hospital of Xiangya School of Medicine, Central South University/Hunan Cancer Hospital
Changsha, China
niqianxi2014@163.com

INTRODUCTION

Radiotherapy is a standard component of multidisciplinary treatment for locally advanced rectal cancer, and highly conformal techniques such as intensity-modulated radiotherapy have improved target coverage while reducing unnecessary irradiation to surrounding normal tissues. However, treatment accuracy remains challenged by inter-fraction anatomical variations, particularly changes in bladder filling, bowel gas, small bowel displacement, and progressive target-volume regression during a multi-week treatment course. These variations may alter the spatial relationship between the clinical target volume, planning target volume, and organs at risk, potentially leading to deviations between planned and delivered dose distributions. Conventional planning based on a single simulation CT may therefore be insufficient to fully characterize anatomical changes occurring throughout treatment.

The integration of fan-beam CT imaging with linear accelerator systems enables repeated high-quality volumetric imaging during radiotherapy and provides an opportunity to evaluate both geometric and dosimetric variations across treatment fractions. Quantifying contour consistency, organ-volume changes, and dose-volume parameter fluctuations may help identify critical time points when adaptive radiotherapy is most clinically relevant. In this study, we investigated inter-fraction spatial and dosimetric variations of target volumes and major organs at risk in rectal cancer patients treated on a CT-Linac platform, with the goal of informing individualized adaptive intervention strategies.

METHODS AND MATERIALS

A retrospective analysis was performed in rectal cancer patients treated with intensity-modulated radiotherapy to 50 Gy in 25 fractions. Fan-beam CT (FBCT) images were acquired at fractions 1, 5, 10, 15, 20, and 25 on an integrated CT-Linac system. All FBCT images were deformably registered to the planning CT. CTV and PTV contours were propagated to each fraction, while bladder and small-bowel structures were segmented on fraction-specific images. Spatial consistency was evaluated using the Dice similarity coefficient (DSC) and Hausdorff distance (HD). Inter-fraction anatomical changes were assessed using absolute volume measurements. Dosimetric parameters, including D95 for target volumes and maximum and mean doses for organs at risk, were extracted from fraction-specific dose evaluations and compared across treatment fractions.

RESULTS

The study evaluated inter-fraction spatial and dosimetric variations of target volumes and organs at risk (OARs) during rectal cancer radiotherapy. CTV and PTV showed relatively stable spatial reproducibility during the first 10 fractions, with Dice similarity coefficients (DSC) of 0.898 ± 0.028 and 0.928 ± 0.024, respectively, and Hausdorff distances (HD) of 8.94 ± 1.41 mm and 8.33 ± 2.38 mm. After approximately fraction 15, target consistency decreased, with DSC declining to 0.813 ± 0.061 for CTV and 0.859 ± 0.046 for PTV, while HD increased to 13.63 ± 2.84 mm and 13.39 ± 2.48 mm by fraction 20. Target volumes showed a gradual decreasing trend, whereas D95 was relatively maintained across fractions.

OAR variability was more pronounced for the bladder and small bowel. Across 1-vs-later fraction comparisons, bladder DSC ranged from 0.460 ± 0.068 to 0.619 ± 0.068, while HD ranged from 30.92 ± 17.60 mm to 38.64 ± 21.10 mm. Bladder volume decreased from 211.19 ± 153.12 cm³ at fraction 1 to 65.08 ± 22.59 cm³ at fraction 10, and mean dose fluctuated from 2881.15 ± 686.21 cGy to 3259.51 ± 551.67 cGy. The small bowel showed lower contour consistency, with DSC ranging from 0.402 ± 0.040 to 0.463 ± 0.025 and HD ranging from 45.62 ± 12.84 mm to 53.22 ± 13.63 mm. Small bowel mean dose increased from 1875.52 ± 694.67 cGy at fraction 1 to approximately 2140 cGy at fractions 20–25. In contrast, the femoral heads remained relatively stable, with limited volume and V20Gy variation across treatment fractions.

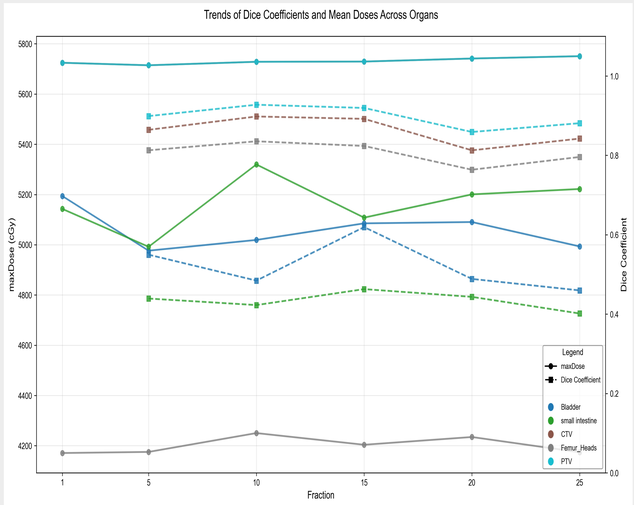

Figure 1. Longitudinal trends of segmentation consistency and dosimetric parameters across treatment fractions.

Table 1. Inter-fraction segmentation consistency, volume, and dosimetric variations of the bladder and small bowel across treatment fractions.

Organ	Parameter	1	5	10	15	20	25
Bladder	Volume (cm³)	211.19 ± 153.12	115.64 ± 78.91	65.08 ± 22.59	135.18 ± 81.26	79.08 ± 30.90	71.71 ± 33.44
Bladder	Dice Coefficient	-	0.550 ± 0.068	0.484 ± 0.068	0.619 ± 0.068	0.489 ± 0.068	0.460 ± 0.068
Bladder	Maximum dose (cGy)	5193.78 ± 305.20	4976.48 ± 158.02	5019.17 ± 401.77	5085.22 ± 129.43	5090.48 ± 152.02	4993.36 ± 241.02
Bladder	Mean dose (cGy)	3252.14 ± 576.94	3049.75 ± 617.28	3171.15 ± 771.21	3161.88 ± 637.84	3259.51 ± 551.67	2881.15 ± 686.21
Small bowel	Volume (cm³)	428.91 ± 103.38	516.04 ± 109.94	539.01 ± 114.13	553.49 ± 69.71	507.29 ± 103.93	433.52 ± 51.53
Small bowel	Dice Coefficient	-	0.439 ± 0.078	0.422 ± 0.067	0.463 ± 0.025	0.444 ± 0.032	0.402 ± 0.040
Small bowel	Maximum dose (cGy)	5142.65 ± 238.49	4991.94 ± 643.59	5319.67 ± 260.16	5107.96 ± 209.75	5200.58 ± 206.98	5222.03 ± 301.33
Small bowel	Mean dose (cGy)	1875.52 ± 694.67	1908.71 ± 1058.43	2082.42 ± 811.24	1942.73 ± 796.44	2142.29 ± 887.05	2141.35 ± 1008.74

DISCUSSION

This analysis suggests that inter-fraction anatomical variation during rectal cancer radiotherapy affects both target reproducibility and OAR dosimetry. The relatively stable CTV and PTV geometry during the early treatment course indicates that conventional image-guided setup correction may be adequate initially. However, reduced spatial consistency after approximately fraction 15 suggests progressive divergence from the planning anatomy, supporting the need for longitudinal image-based assessment rather than reliance on a single simulation CT.

Bladder and small bowel variations were more pronounced than target-volume changes, reflecting the influence of organ filling, bowel mobility, and day-to-day anatomical uncertainty. The observed fluctuations in OAR volume and dose parameters indicate that delivered dose distributions may differ from those estimated at planning, even when target coverage appears relatively maintained. These findings support the potential value of FBCT-guided monitoring on a CT-Linac platform for identifying patients who may benefit from adaptive replanning. Future work should include a larger cohort, cumulative dose accumulation, and correlation with acute and late toxicity to define patient-specific thresholds for adaptive intervention.

CONCLUSIONS

Inter-fraction variations in rectal cancer radiotherapy affected both target volumes and OARs. Target reproducibility declined after approximately fraction 15, while bladder and small bowel volume and dose parameters fluctuated across treatment. FBCT-guided CT-Linac monitoring may support individualized adaptive radiotherapy, particularly in patients with persistent OAR displacement or target-volume change.

REFERENCES

1. Taylor S, Lim P, Cantwell J, et al. Image guidance and interfractional anatomical variation in paediatric abdominal radiotherapy. Br J Radiol 2023;96(1146). DOI:10.1259/bjr.20230058.3.

2. Zhou K, Wang C, Zhao J, Chen J, An X, Yin Y, Li Z. Dosimetric effects of bladder volume changes in MR-guided radiotherapy for cervical cancer. BMC Cancer. 2025 Feb 21;25(1):324. DOI: 10.1186/s12885-025-13442-3.

3. Ding S , Liu H , Wang B ,et al.Inter- and Intrafraction Bladder and Rectum Motion in Patients With Cervical Cancer Under MR-Guided Radiotherapy on a 1.5T MR-Linac[J].International Journal of Radiation Oncology, Biology, Physics, 2021(3S):111.DOI:10.1016/j.ijrobp.2021.07.1630.