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

Morphological-Dosimetric Model for Adaptive Radiotherapy Triggering in Bladder Cancer Radiotherapy

Zi Liu[1,2], Yujun Guo[3], Shiyi Xiao[1,2], Haotian Zhang[4], Liru He[1], Xin Yang[1], Sijuan Huang[1]

[1]Sun Yat-sen University Cancer Center, Guangzhou, Guangdong, 510060, China; [2]School of Biomedical Engineering, Guangzhou Xinhua College, Guangzhou 510520, China; [3]Shenzhen nanshan people's hospital, Shenzhen, Guangdong, 518000, China; [4]Southern Medical University, Guangzhou, Guangdong, 501515, China

ABSTRACT

Purpose: To explore the rules of anatomical and dosimetric changes during the radiotherapy of bladder cancer, determine the optimal trigger time and applicable patient population of adaptive radiotherapy (ART), and build a prediction model.

Methods: A retrospective analysis of 313 fractions from 29 bladder cancer patients was conducted. Anatomical parameters included relative volume change, Dice similarity coefficient (DSC), 95% Hausdorff distance (HD95), centroid shift, and bladder shape . Dosimetric triggering was defined as GTV D95% < 98%. Logistic regression and four machine learning models (LightGBM, XGBoost, AdaBoost, CatBoost) were developed. Model performance was evaluated using accuracy, precision, recall, and area under the curve (AUC).

Results: The slender-shaped bladder exhibited the highest miss rate. A relative bladder volume change of < -30% or > 50% was associated with the highest risk of anatomical miss. Dose fluctuations were mainly concentrated in the middle of treatment (fractions 3 – 6). Adaptive plans significantly improved target coverage and reduced organ-at-risk doses. Multivariate analysis identified GTV_HD95, bladder_Dice, and bladder_HD95 as independent factors for anatomical miss, while rectum_HD95, rectum_Dice, and relative small intestine volume were independent factors for dosimetric triggering. LightGBM achieved the best overall performance (AUC = 0.85, accuracy = 0.84).

Conclusions: Significant inter-fraction anatomical and dosimetric variations exist during bladder cancer radiotherapy. Patients with slender-shaped bladder or extreme volume changes may require ART. Adaptive plans offer dosimetric advantages. The LightGBM model can objectively determine ART timing and effectively assist clinical decision-making.

CONTACT

[name]Sijuan Huang
[organization]State Key Laboratory of Oncology in South China, Guangdong Key Laboratory of Nasopharyngeal Carcinoma Diagnosis and Therapy, Guangdong Provincial Clinical Research Center for Cancer, Guangdong Esophageal Cancer Institute, Sun Yat-sen University Cancer Center,Guangzhou, Guangdong 510060, China
[email]huangsijuan@sysucc.org.cn
[phone]+86-020287343089

INTRODUCTION

Bladder cancer is one of the most common malignancies of the urinary system, and radiotherapy plays a crucial role in its definitive treatment, particularly for patients who are medically inoperable or wish to preserve their bladder. However, the anatomical location and physiological function of the bladder lead to significant inter-fraction variations in volume, shape, and position. These variations pose substantial challenges to the delivery of precise radiotherapy, as target coverage may be compromised, and organs at risk (OARs) such as the rectum, small intestine, and colon may receive excessive doses.

Adaptive radiotherapy (ART) has emerged as a promising strategy to address these uncertainties by modifying the treatment plan based on up-to-date imaging feedback. Despite its potential, the optimal timing for triggering ART and the identification of suitable patient populations remain unclear. In this study, we aim to explore the patterns of inter-fraction anatomical and dosimetric variations during bladder cancer radiotherapy, clarify the optimal trigger timing and suitable patient populations for ART, and identify the influencing factors. We construct a logistic regression trigger prediction model based on dosimetric parameters, as well as four machine learning models (LightGBM, XGBoost, AdaBoost, CatBoost). Provide a scientific basis for decision-making in precision adaptive radiotherapy for bladder cancer.

METHODS AND MATERIALS

Based on a retrospective analysis of anatomical and dosimetric data from 313 fractions of 29 patients with bladder cancer, this study systematically evaluated the volumetric, morphological, positional, and dosimetric changes in the gross tumor volume (GTV) and organs at risk (bladder, rectum, small intestine, and colon). Bladder shape (slender, spherical, or oval) was defined by the BH/BW ratio on sagittal CT. Anatomical off-target was defined as GTV extending beyond the planned radiation field, while the dosimetric trigger for adaptive radiotherapy (ART) was defined as GTV D95% < 98%. Logistic regression was used to construct a prediction model for the dosimetric trigger, along with four machine learning models: LhtGBM, XGBoost, AdaBoost, and CatBoost. The predictive performance of the models was compared using receiver operating characteristic (ROC) curves.

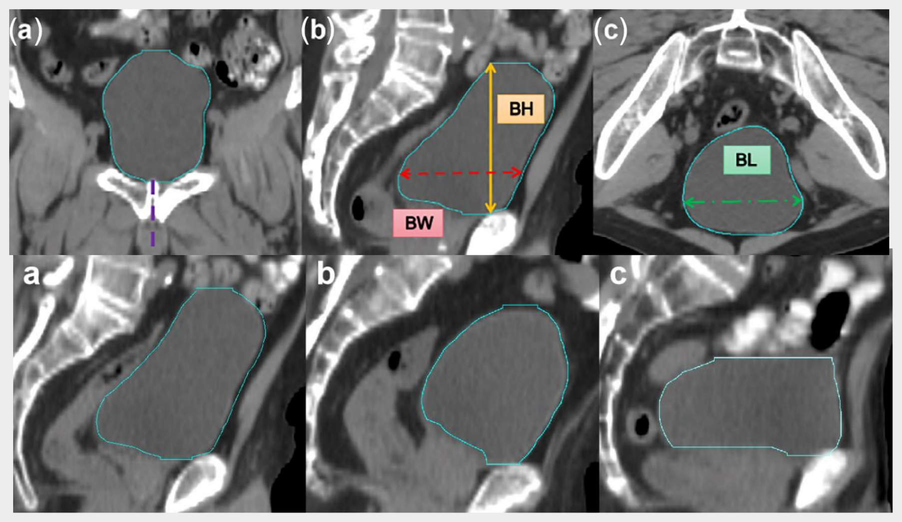

Chart 1. Diagram of BH, BW, and BL in the sagittal and transverse planes on CT images.
Diagram of BH, BW and BL in sagittal and transverse plane on CT images(a. the Elongated Bladder. b. the Spherical Bladder. c. the Oval Bladder

RESULTS

The results showed that among the 313 fractions, the spherical bladder had the lowest off target rate (27.13%), while the slender bladder had the highest off target rate (60.00%). When the relative bladder volume change is less than -30% or greater than 50%, the off target rate significantly increases, reaching 77.27% and 65.79%, respectively. In terms of dosimetry, compared with the non adaptive plan (PlanF), the adaptive plan (PlanA) significantly improved the coverage rates of target D98% and D95% (P<0.05), and reduced the doses in the rectum, bladder, and small intestine. Multivariate analysis showed that GTV_HD95, bladerylce, and bladeryHD95 were independent influencing factors for anatomical misdiagnosis; However, rectomedullium-HD95, rectomedullium-Dice, and relative small intestine volume are independent dose triggered influencing factors. In machine learning models, LightGBM achieves the best overall performance., with an AUC of 0.85 and an accuracy of 0.84.

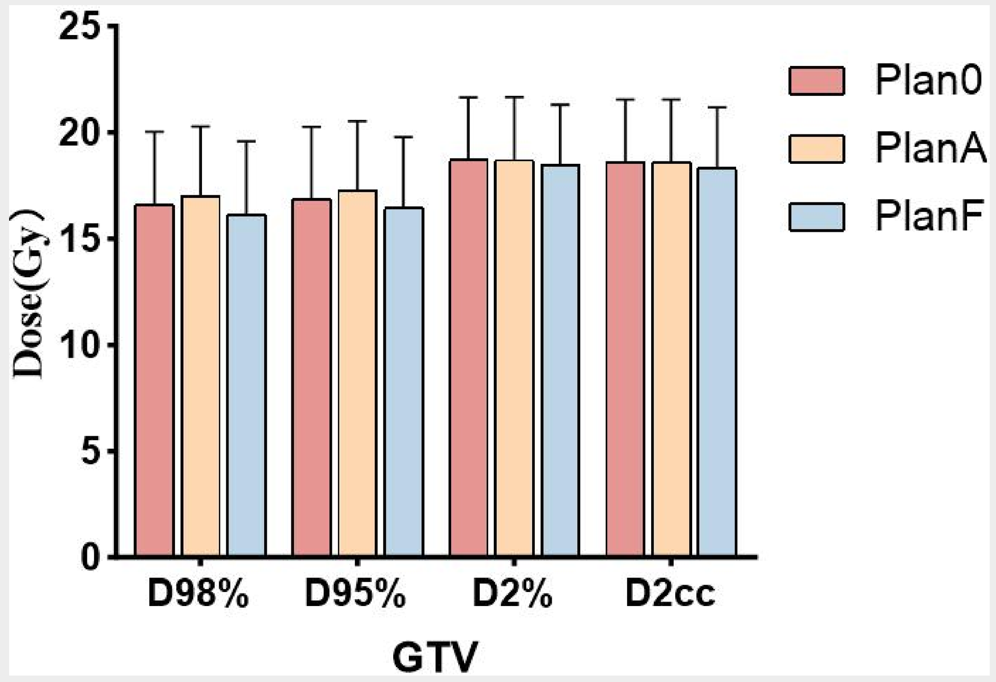

Chart 2. Comparison of Target dose distributions among the three plans

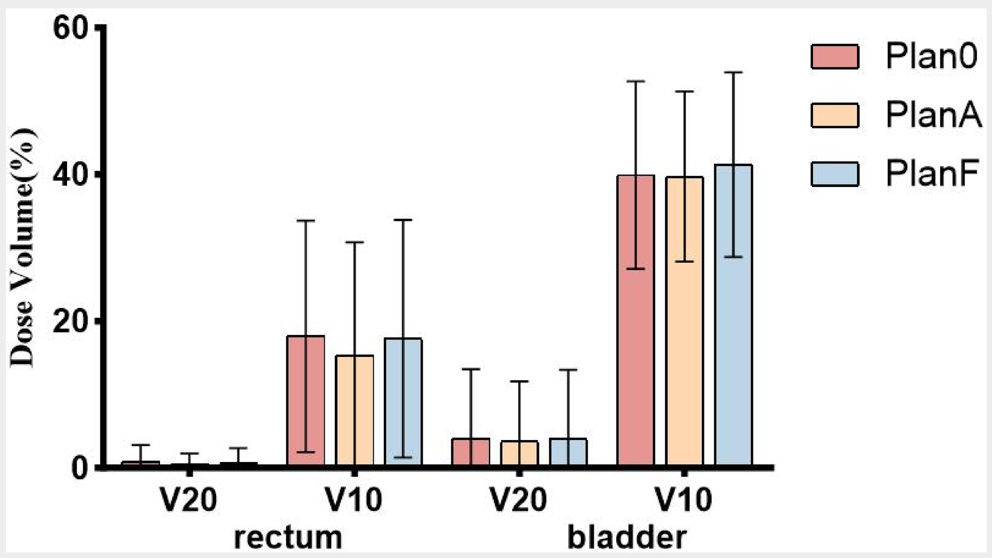

Chart 3. comparison of V20Gy and V10Gy of the rectum and bladder among the three plans.

CONCLUSIONS

The results showed that the slender-shaped bladder had the highest miss rate, and a relative bladder volume change of < − 30% or > 50% was associated with the highest risk of anatomical miss. Dose fluctuations were mainly concentrated in the middle of the treatment course (fractions 3–6). Compared with the non-adaptive plan (PlanF), the adaptive plan (PlanA) significantly improved target D98% and D95% coverage (P < 0.05) and reduced the doses to the rectum, bladder, and small intestine. Multivariate analysis revealed that GTV_HD95, bladder_Dice, and bladder_HD95 were independent influencing factors for anatomical miss; whereas rectum_HD95, rectum_Dice, and relative small intestine volume were independent influencing factors for dosimetric triggering. Among the machine learning models, LightGBM achieved the best overall performance, with an AUC of 0.85 and an accuracy of 0.84.

DISCUSSION

In this study, we systematically investigated inter-fraction anatomical and dosimetric variations in bladder cancer radiotherapy based on 313 fractions from 29 patients. Our results highlight several clinically important findings.

First, we observed that the slender-shaped bladder was associated with the highest miss rate, and relative bladder volume changes of < −30% or > 50% posed the greatest risk of anatomical off-target. These findings suggest that patients with such bladder shape or extreme volume changes should be closely monitored and considered for early ART intervention. compared with the non-adaptive plan (PlanF), the adaptive plan (PlanA) significantly improved target D98% and D95% coverage and reduced doses to OARs including the rectum, bladder, and small intestine.

Second, our multivariate analysis identified independent influencing factors for anatomical miss (GTV_HD95, bladder_Dice, bladder_HD95) and for dosimetric triggering (rectum_HD95, rectum_Dice, relative small intestine volume). These parameters reflect the spatial agreement and deformation between fractions and can serve as quantitative indicators for ART decision-making. Among the machine learning models, LightGBM achieved the best performance (AUC = 0.85, accuracy = 0.84), suggesting its potential as a clinical decision support tool to objectively determine the optimal timing for ART triggering.

Several limitations should be acknowledged. This study was retrospective and based on a single-institution dataset, which may limit generalizability. The sample size of 29 patients is modest, and external validation of the machine learning models is needed. Additionally, the dosimetric trigger definition (GTV D95% < 98%) is somewhat arbitrary and may require further refinement based on clinical outcomes.

REFERENCES

1.Bray F, Laversanne M, Sung H, et al. Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2024;74(3):229-263. doi:10.3322/caac.21834
2.Å str ö m LM, Behrens CP, Calmels L, et al. Online adaptive radiotherapy of urinary bladder cancer with full re-optimization to the anatomy of the day: Initial experience and dosimetric benefits. Radiother Oncol. 2022;171:37-42. doi:10.1016/j.radonc.2022.03.014
3.Lalondrelle S, Huddart R, Warren-Oseni K, et al. Adaptive-predictive organ localization using cone-beam computed tomography for improved accuracy in external beam radiotherapy for bladder cancer.
4.Fischer J, Fischer LA, Bensberg J, et al. CBCT-based online adaptive radiotherapy of the bladder - geometrical and dosimetrical considerations compared to conventional IGRT. Radiat Oncol. 2025;20(1):128. Published 2025 Aug 14. doi:10.1186/s13014-025-02710-y