Evaluation of eGFR's Relation to Intra-Fractional Bladder Filling and the Dosimetric Impact during Online Adaptive Radiotherapy for Pelvic Lymph Node Cases

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ABSTRACT

Purpose: To quantify the relationship between estimated glomerular filtration rate (eGFR) and intra-fractional bladder filling during online adaptive radiotherapy (oART) and to evaluate the dosimetric effect on surrounding organs at risk (OARs).

Methods: A retrospective study was conducted on 53 patients with adaptive prostate cancer. For each fraction, the initial CBCT images acquired were compared with verification CBCTs to assess intra-fractional bladder filling. Bladder volumes were delineated, and bladder inflow rates (mL/min) were calculated. Inflow rates were compared with patients' eGFR values. Additionally, 9 patients with pelvic lymph node (LN) disease were used to validate the previous findings and analyze the dosimetric impact of bladder filling on targets and OARs.

Results: The mean interval between scans was 15.5 min ± 4.3 min. The cohort's average eGFR was 79.8 ± 20.1 mL/min/1.73m², with an overall inflow rate of 2.9 ± 2.1 mL/min. Patients with an eGFR above the cohort average had a higher bladder inflow rate than those with an eGFR below the cohort average. In pelvic lymph node patients, we observed increases of 12.5% and 66.3% in the mean and maximum bladder doses, respectively, while the mean doses to the large bowel and small bowel decreased by 17.1% and 27.1%, respectively. The absolute percent difference in the mean dose increased with time, reaching 3% for the PTV and 2% for the GTV after 20 minutes.

Conclusion: Results suggest a positive correlation between eGFR and intra-fractional bladder filling rate. Patients with eGFR above the cohort average exhibit higher bladder inflow rates, resulting in greater volume changes and intra-fractional uncertainty. Limiting the time interval between CBCTs might help reduce potential dosimetric effects on the PTV and GTV.

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INTRODUCTION

Intrafractional anatomical variations, particularly organ motion, have challenged the effectiveness of radiation therapy (RT). As a consequence, radiation doses delivered to clinical target volumes (CTVs), planning target volumes (PTVs), and organs at risk (OARs) may deviate from the prescribed dosage. Online adaptive radiotherapy (oART) addresses these challenges by enabling real-time modification of treatment plans during the patient's on-couch time.

With cone beam computed tomography (CBCT)-based adaptive RT, an initial CBCT (CBCT1) is acquired to allow for contouring based on current anatomy. The plan is then reoptimized in real time, and the physician can choose between the scheduled plan and the newly created adaptive plan. Once a plan is selected, a verification CBCT (CBCT2) is captured to verify the patient's position on the couch. However, even with the adaptive workflow, there is a delay between initial image acquisition and treatment delivery. During this delay, growth and changes in the bladder's position can lead to unanticipated anatomical variations, displacing targets and OARs adjacent to it. Since treatments are based on CBCT1 alignment with the PTV, these displacements can result in potential overdosing or underdosing, not reflected in the treatment plan.

Specific physiological predictors of such changes have not been linked to intra-fractional filling during oART. The estimated glomerular filtration rate (eGFR) is a measure of kidney function, defined as the volume of fluid filtered by the glomeruli per minute (mL/min). The primary function of the kidney is to remove excess waste and water, producing urine. Given that higher eGFR values reflect better renal function, we propose that higher eGFR values may indicate greater bladder filling.

Geometric variation in OAR positions due to bladder filling can lead to unintended treatment outcomes. This study aims to quantify the relationship between eGFR values and intrafractional bladder filling during oART and to evaluate the dosimetric effects of bladder filling on surrounding OARs.

METHODS AND MATERIALS

A retrospective study was conducted on 53 adaptive prostate patients (538 CBCTs). For each fraction, the initial cone-beam CTs (CBCTs) acquired were compared with verification CBCTs to assess intra-fractional bladder filling. Bladder volumes were delineated, and bladder inflow rates (mL/min) were calculated as the change in volume divided by the time between scans. Inflow rates were compared with patients' eGFR values. Additionally, 9 pelvic lymph node (LN) patients were used to validate the previous findings and analyze the dosimetric impact of bladder filling. Dose distributions were rigidly aligned with the PTV to shift the dose cloud to the second CBCT. The minimum, mean, and maximum doses to targets and OARs were then compared.

RESULTS

The average elapsed time between CBCT1 and CBCT2 for the patients was 15.5 ± 4.3 minutes. The average bladder inflow rate across the patient cohort was 2.9 ± 2.1 mL/min, and the average eGFR value was 79.8 ± 20.1 mL/min/1.73 m². When patients were categorized by eGFR, those with higher-than-average eGFR had an average bladder filling rate of 3.56 mL/min, compared with those with lower eGFR (2.00 mL/min). A linear regression analysis of the plot in Figure 1 showed a positive correlation between eGFR and bladder filling rate ($p < 0.00001$; $R^2 = 0.265$). These results suggest that patients with better kidney function will exhibit a higher rate of bladder filling during treatment.

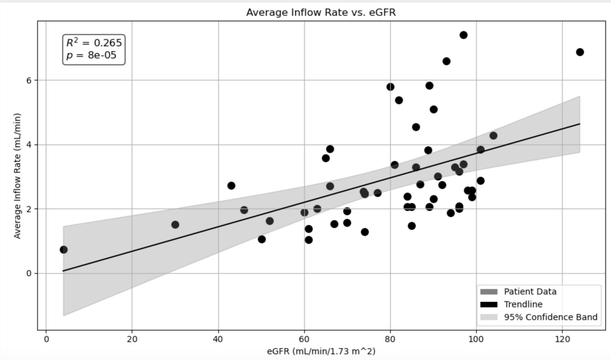

Figure 1. Correlation between eGFR and Average Inflow Rate (mL/min) for each patient.

In the cohort of pelvic LN patients, review plans were generated, and dosimetric parameters for the GTV, PTV, bladder, small bowel, and large bowel were obtained for comparison. To examine the effect of bladder growth on dosimetric inaccuracies, the mean volume difference was plotted against changes in target and OAR dosimetry, with time between CBCTs as the x-axis. As on-table time increases, the mean volume difference rises sharply beyond 20 minutes. The absolute percent difference in the mean dose increased with time, reaching 3% for the PTV and 2% for the GTV after 20 minutes. For the OARs, we observed a 12.5% increase in mean dose and a 66.3% increase in maximum dose in the bladder from CBCT1 to CBCT2. In the large bowel, we observed a 14.5% decrease in mean dose and a 9.43% decrease in maximum dose. The small bowel had a 15.0% decrease in mean dose and a 5.4% decrease in maximum dose. These results suggest that the actual dose delivered to OARs in these plans differs from the planned dose distributions.

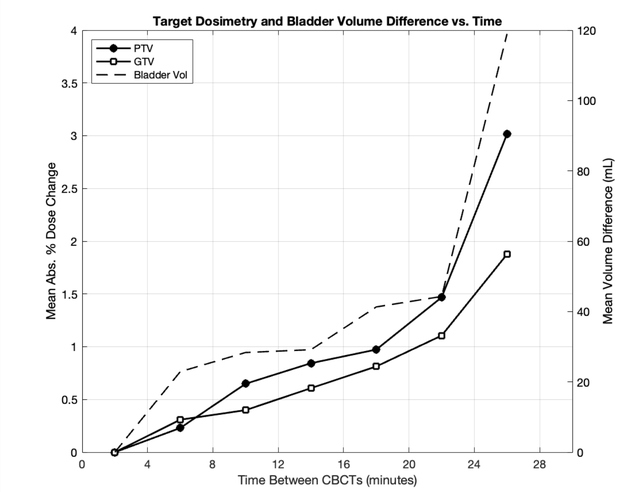

Figure 2. Time Between CBCTs vs. Mean Absolute Percent Dose Change to Target.

DISCUSSION

This study found a positive correlation between eGFR and bladder inflow rate in patients with prostate and pelvic LN. Increased bladder growth during on-couch time was associated with higher eGFR values, leading to discrepancies between the planned and delivered dose distributions. During a retrospective study of all patients' second CBCT scans, the mean and maximum bladder doses were higher than anticipated, while the doses to the small and large bowels were lower. Percent difference in doses to the target and OARs increased with increasing time spent on-table. These results suggest that renal function may influence intra-fractional bladder growth and, accordingly, impact the dose distribution to OARs. This could improve planning accuracy by accounting for bladder growth driven by patient-specific eGFR. During the study, we investigated the potential impact of other physiological factors, such as bladder size, on the bladder infill rate. Further studies measuring patients' eGFR on the day of treatment could yield more accurate results and validate these findings.

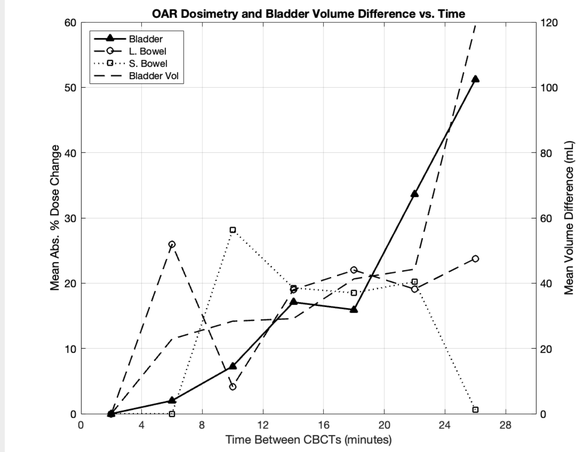

Figure 3. Time Between CBCTs vs. Mean Absolute Percent Dose Change to OARs.

CONCLUSIONS

Online adaptive radiotherapy enables dose reduction to OARs in prostate patients by tailoring plans to daily anatomical variations. However, intra-fractional bladder filling remains an uncertainty that may affect plan accuracy. This study established a correlation between eGFR and intra-fractional bladder filling during oART. These results help identify eGFR as an indicator for intrafractional volumetric differences, which can be used to predict which patients are at the most risk for dosimetric variation during on-couch time. Incorporating patient-specific eGFR into clinical workflow could enhance the accuracy of adaptive planning by minimizing on-table time for patients with higher eGFR, reducing dosimetric inaccuracies, and improving patient outcomes.

REFERENCES

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