Clinical and Dosimetric Evaluation of CBCT-Based Adaptive Radiotherapy for Prostate SBRT

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ABSTRACT

This study investigates the clinical and dosimetric impact of advanced adaptive radiotherapy features in Varian Ethos 2.0—including High-Fidelity planning, AI-driven auto-segmentation, and HyperSight CBCT-based dose calculation—along with the feasibility of direct H-CBCT–based dose calculation for prostate SBRT.

INTRODUCTION

Prostate SBRT delivers high biologically effective doses in a few fractions while maintaining favorable tumor control and toxicity outcomes. Because SBRT requires highly conformal dose distributions and steep dose gradients, small anatomical changes can compromise target coverage and increase dose to nearby organs at risk (OARs), such as the rectum and bladder[1-5]. Online adaptive radiotherapy (ART) addresses these challenges by adapting treatment plans to daily anatomy, improving target coverage while sparing normal tissues[6-9].

The Varian Ethos platform enables online ART through integrated CBCT imaging, automated contouring, and treatment planning. Although early studies of Ethos 2.0 have shown dosimetric and workflow benefits of HF mode in other stereotactic treatments, its role in prostate SBRT remains unclear. This study evaluates the impact of HF mode on adaptive prostate SBRT. It also assesses the dosimetric accuracy of HyperSight CBCT-based dose calculation to support clinical implementation of CBCT-guided adaptive radiotherapy.

METHODS

Part 1; A retrospective dosimetric study was conducted in 20 prostate SBRT patients. For each patient, two plans were generated using identical objectives and constraints: HF mode enabled and disabled. All plans prescribed 37 Gy in 5 fractions. Plan quality was assessed using DVH metrics, target coverage (PTV D95%), conformity index, dose fall-off (D2cm), monitor units, optimization time, and dose calculation time. HF On and HF Off plans were compared using paired nonparametric tests ($p < 0.05$).

Part 2; The feasibility of direct dose calculation on H-CBCT was evaluated using phantom studies. HU-to-relative electron density (RED) calibration curves were generated with a Gammex phantom for 125 and 140 kV protocols, and dosimetric accuracy was assessed in a humanoid phantom. An in-house Monte Carlo framework further evaluated dose uncertainties associated with HU-to-density variations and CBCT imaging energies in patient anatomy.

RESULTS – PART 1: High-Fidelity planning

Total MU & Planning time with High Fidelity mode On/Off

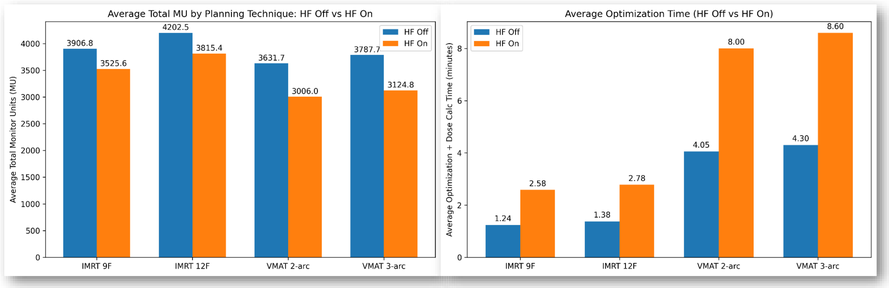

Fig. 1 Left: Average total MU for IMRT 9/12 field plans and VAMT 2,3-arcs when HF On compared to HF Off. Right: Comparison of the average optimization and dose calculation time for different planning techniques with HF Off and HF On.

OAR maximum dose and target dose comparison

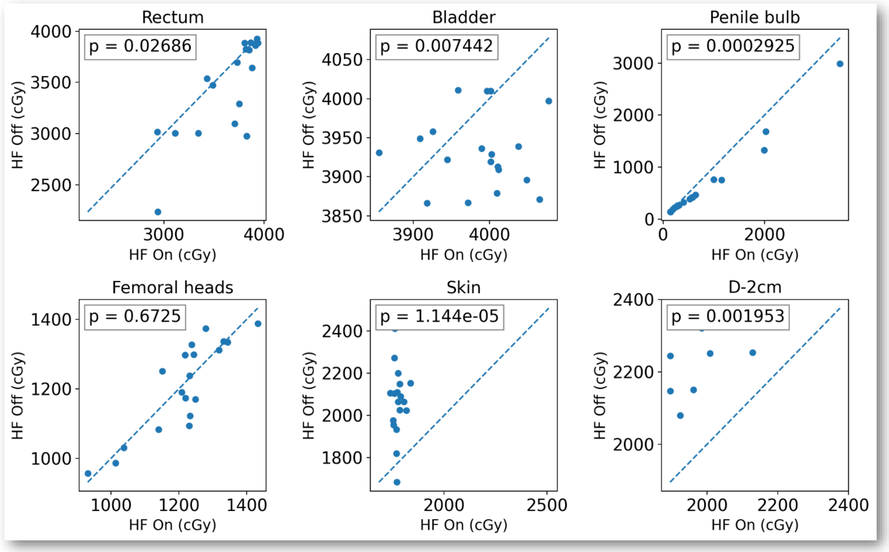

Fig. 2 Comparison of the maximum dose (D_{max}) for the OARs—the rectum, bladder, penile bulb, femoral heads, skin and D-2cm structure—between plans generated with HF On and HF Off. Each scatter point represents an individual patient, with the x-axis showing HF On D_{max} values and the y-axis showing HF Off D_{max} values. The dashed line represents the unity line (Y = X), where points located on the line indicate identical doses between the two planning approaches**.**

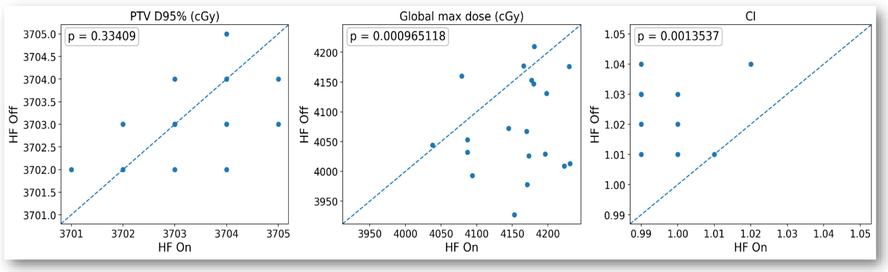

Fig. 3 Comparison of PTV D95%, Global max dose to the PTV, and CI between HF On and HF Off treatment plans. The blue markers represent individual patients, while the dashed line indicates the unity line (HF On = HF Off).

RESULTS – PART 2: HyperSight cone-beam CT study

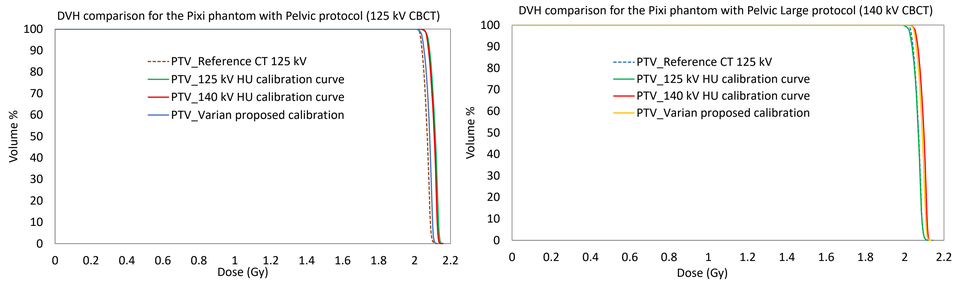

Fig. 4 DVHs for the PTV generated from H-CBCT Acuros for CBCT images acquired at 125 kV (left panel) and 140 kV (right panel) with dose calculated using the 125 kV and 140 kV HU-to-RED calibration curve. These plot also includes the result for Varian proposed HU-to-RED calibration curve.

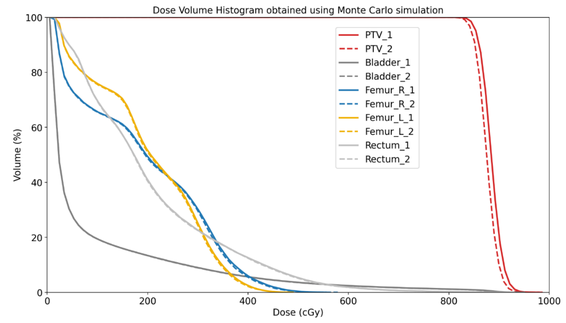

Fig. 5 DVH obtained using Monte Carlo simulation: 1- the solid lines represent the dose calculations with 125 kV imaging, 2- the dashed lines correspond to the 140 kV imaging. The agreement for the Planning Target Volume (PTV) is within 1.1%.

DISCUSSION

- Enabling HF mode consistently reduced the average number of monitor units (MU) by 17%; however, this improvement came at the expense of increased optimization time. In addition, the reduction in MU had a minimal impact on beam delivery time, reducing treatment delivery by approximately 1-2 minutes.
- HF mode maintained target coverage, improved dose fall-off and skin dose, but its statistically significant OAR dose differences were small and did not translate into meaningful adjacent OAR sparing.
- H-CBCT HU values were sensitive to acquisition and reconstruction settings, emphasizing the need for protocol-specific HU-to-RED calibration for accurate dose calculation.140 kV acquisitions showed better agreement with planning CT in high-density regions compared with 125 kV scans, while soft-tissue regions showed minimal differences between protocols.
- End-to-end validation using a humanoid phantom confirmed the feasibility of direct H-CBCT–based dose calculation within a clinically validated adaptive workflow (DVH differences <2% in the worst-case scenario).
- Monte Carlo simulations of a representative patient case indicated that dose deviations were on the order of 1.1% for the D95% when the two tube voltage settings were used interchangeably

CONCLUSION

High-Fidelity (HF) planning in Ethos 2.0 provided limited overall dosimetric benefit for prostate SBRT but may be advantageous in cases where reduction of distal dose is prioritized. Its clinical use should be balanced against increased optimization time and the potential impact on doses to nearby organs at risk within the adaptive workflow.

The Acuros iCBCT reconstruction algorithm demonstrated clinically acceptable accuracy for direct HyperSight CBCT–based dose calculation, supporting its feasibility for adaptive radiotherapy workflows. This approach may reduce dependence on synthetic CT generation; however, further studies are needed to determine whether it offers advantages over current synthetic CT–based dose calculation methods.

CONTACT

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