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Treatment Planning of Obese Prostate Cancer Patients on Halcyon/Ethos with 6 MV-FFF Using RayStation

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AIM

To evaluate the dosimetric impact of Halcyon/Ethos (HE) platform's single-energy 6 MV flattening filter-free (6 MV-FFF) beam for treatment planning of obese prostate cancer patients with pelvic nodal involvement.

INTRODUCTION

Unlike conventional C-arm linear accelerators such as the TrueBeam (TB), which offer 6 MV and 10 MV flattened photon beams for modulated radiation therapy, the HE platform is limited to a single 6 MV-FFF beam. This constraint raises important clinical questions regarding the capacity of a 6 MV-FFF beam to achieve target coverage, dose conformity, dose homogeneity, and organ-at-risk (OAR) sparing comparable to conventional platforms, particularly in obese patients where increased tissue separation typically favors higher photon energies. Beyond the absence of a flattening filter, the HE system incorporates distinct hardware features, including a dual-layer, jawless multileaf collimator and the absence of bending magnets, which may further influence plan dosimetry.

METHODS

Fifteen obese patients (body mass index > 30 kg/m²) previously treated to 5040 cGy in 28 fractions for prostate cancer with pelvic nodal irradiation were retrospectively replanned in RayStation v2024A. Four plans were generated for each patient: a 6 MV-FFF plan for the HE platform, and 6 MV-FFF, 6 MV, and 10 MV plans for delivery on a TB. All plans utilized identical optimization objectives and were normalized to equivalent target coverage to enable direct comparison. The TB plans were generated using jaw tracking with no field size limitation. Dose calculations for all plans were performed using the collapsed cone convolution algorithm.
Dose-volume histogram (DVH) parameters for the planning target volume (PTV) and organs-at-risk (OARs), including the rectum, bladder, bowel bag, and bilateral femoral heads, were evaluated. Mean OAR doses, dose gradient index1 (GI), PTV dose homogeneity index2 (HI), PTV dose conformity3, and monitor units (MUs) were compared among the four treatment planning approaches. Repeated measures ANOVA test was used to evaluate statistical significance.

RESULTS

Qualitative evaluation of dose distributions and dose-volume histograms (DVHs) demonstrated that HE 6 MV-FFF plans were clinically acceptable and dosimetrically comparable to all TB plans (Fig. 1, 2). HE 6 MV-FFF plans required the greatest number of monitor units (MUs) (mean: 1319), followed by TB 6 MV-FFF (1239), TB 6 MV (958), and TB 10 MV (833) (Fig. 3A). TB 10 MV plans achieved the lowest average gradient index (GI) (4.29), while HE 6 MV-FFF plans demonstrated a comparable GI (4.41) and lower GI than both TB 6 MV-FFF (4.46) and TB 6 MV (4.51) plans (Fig. 3B).
TB 10 MV plans also achieved the lowest homogeneity index (HI) (0.043). HE 6 MV-FFF plans demonstrated comparable dose homogeneity (0.045) to TB 6 MV (0.045), while TB 6 MV-FFF plans exhibited highest HI (0.046) (Fig. 3C). Among all planning techniques, HE 6 MV-FFF achieved the lowest mean bladder (2502 cGy) and rectal (1499 cGy) doses. Corresponding bladder doses for TB 6 MV-FFF, TB 6 MV, and TB 10 MV were 2576 cGy, 2609 cGy, and 2594 cGy, respectively (Fig. 3D), while mean rectal doses were 1556 cGy, 1562 cGy, and 1525 cGy, respectively (Fig. 3E). Mean skin dose was higher for HE 6 MV-FFF (764 cGy) than for TB 6 MV-FFF (716 cGy), TB 6 MV (717 cGy), and TB 10 MV (609 cGy) plans (Fig. 3I). The lowest mean right femoral head dose was observed with TB 10 MV (865 cGy), followed closely by HE 6 MV-FFF (873 cGy), whereas TB 6 MV-FFF and TB 6 MV yielded similar doses (907 cGy and 908 cGy, respectively) (Fig. 3H). Mean doses to the left femoral head followed a similar trend, with the lowest average dose observed for HE 6 MV-FFF (863 cGy), followed by TB 10 MV (867 cGy), TB 6 MV-FFF (883 cGy), and TB 6 MV (895 cGy) (Fig. 3G). Mean bowel bag dose was lowest for TB 10 MV (1405 cGy), while HE 6 MV-FFF, TB 6 MV-FFF, and TB 6 MV demonstrated nearly identical mean doses (1431 cGy, 1434 cGy, and 1438 cGy, respectively) (Fig. 3F). All reported comparisons were statistically significant ($p < 0.01$).

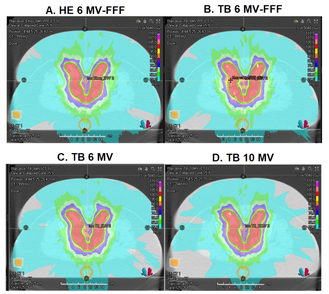

Figure 1. Sample axial dose distribution of one patient across the four different plan variations.

DISCUSSION

Although HE plans required a greater number of MUs than TB plans, this is offset by several hardware advantages: the HE gantry rotates approximately four times faster than TB, MLC leaf motion is roughly twice as fast, and the dose rate is higher (800 MU/min vs. 600 MU/min for TB). Together, these features may enable comparable or faster overall treatment delivery despite the higher MU count. TB 6 MV-FFF plans were generated specifically to isolate the dosimetric impact of gantry architecture from that of beam energy, enabling a more direct comparison to HE 6 MV-FFF. The higher skin dose observed with HE 6 MV-FFF relative to TB 6 MV-FFF is likely attributable to the absence of a bending magnet on the HE platform, which on conventional linacs helps attenuate the low-energy photon component of the beam spectrum. Conversely, HE demonstrated superior OAR sparing and GI compared to TB 6 MV plans, most likely due to its stacked and staggered MLC design: HE exhibits substantially lower MLC transmission (~0.01% vs. ~2% for TB) and reduced maximum interleaf leakage (~0.8% vs. ~3% for TB). For applications where superior skin sparing, gradient index, and homogeneity are the primary priorities, TB 10 MV remains the preferred approach.

CONCLUSION

The single-energy 6 MV-FFF beam of the HE platform does not impose clinically meaningful limitations for treatment planning of obese prostate cancer patients with pelvic nodal irradiation. With appropriate optimization, HE produced clinically acceptable plans with target coverage, dose conformity, dose homogeneity, dose gradient, and OAR sparing comparable to conventional TB planning, while requiring only modest tradeoffs in skin dose. These findings support the use of the Halcyon/Ethos platform for prostate radiotherapy in patients with challenging body habitus.

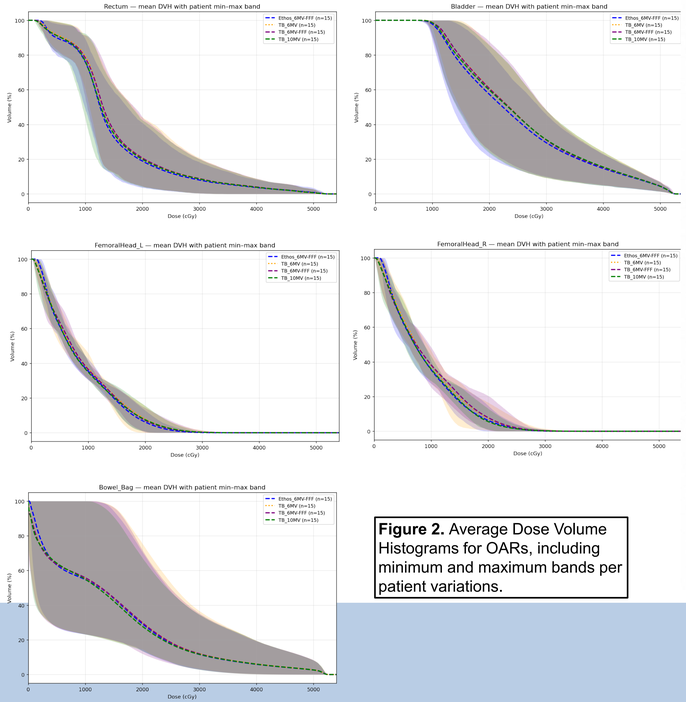

Figure 2. Average Dose Volume Histograms for OARs, including minimum and maximum bands per patient variations.

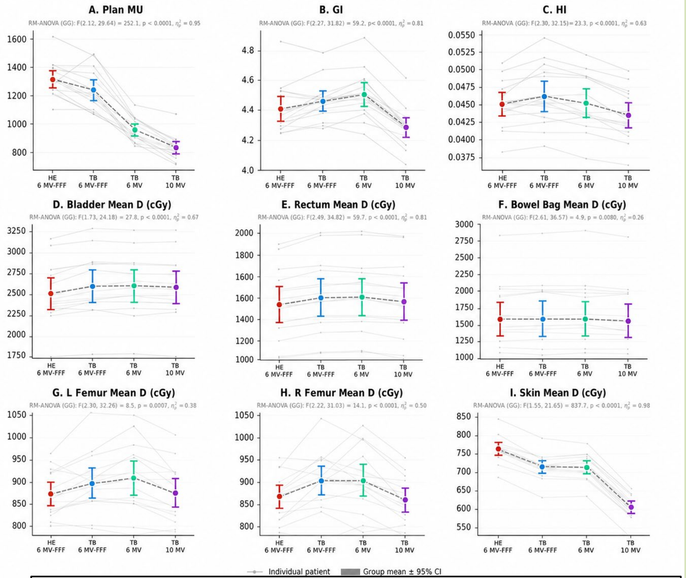

Figure 3. Dosimetric endpoints across four different plan variations for 15 patients.

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