Dosimetric robustness of VMAT craniospinal irradiation (CSI) to rotational setup errors on a ring-based linear accelerator

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Purpose

To evaluate and quantify the rotational robustness of VMAT CSI delivered using translation-only couch corrections, for both nominal and vertebral-body-sparing (VBS[1-2]) CSI techniques.

Significance

- VMAT CSI requires highly precise geometric alignment due to long fields and field junctions to match cranial and spinal fields.
- Recent studies have shown Halcyon to provide superior dosimetry for CSI.[3-4]
- Ring-based gantry systems offer efficient treatment workflows, making them desirable for time-intensive treatment techniques like VMAT CSI. **However, ring-based gantry systems often lack the ability to make rotational setup corrections.**[5-6]

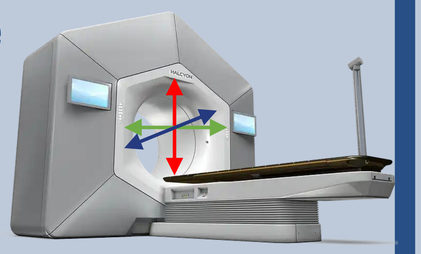

Figure 1. Varian Halcyon (Palo Alto, CA) treatment delivery platform with translation-only based treatment couch.

Specific Aims

Aim 1: Quantify changes in CSI target coverage for un-corrected roll, pitch, and yaw rotation alignment errors for one adult and one pediatric patient.

Aim 2: Develop rotational alignment tolerances using the results in Aim 1 for VMAT CSI on translation-only based couch.

Aim 3: Evaluate the impact of vertebral body dose for VBS-CSI.

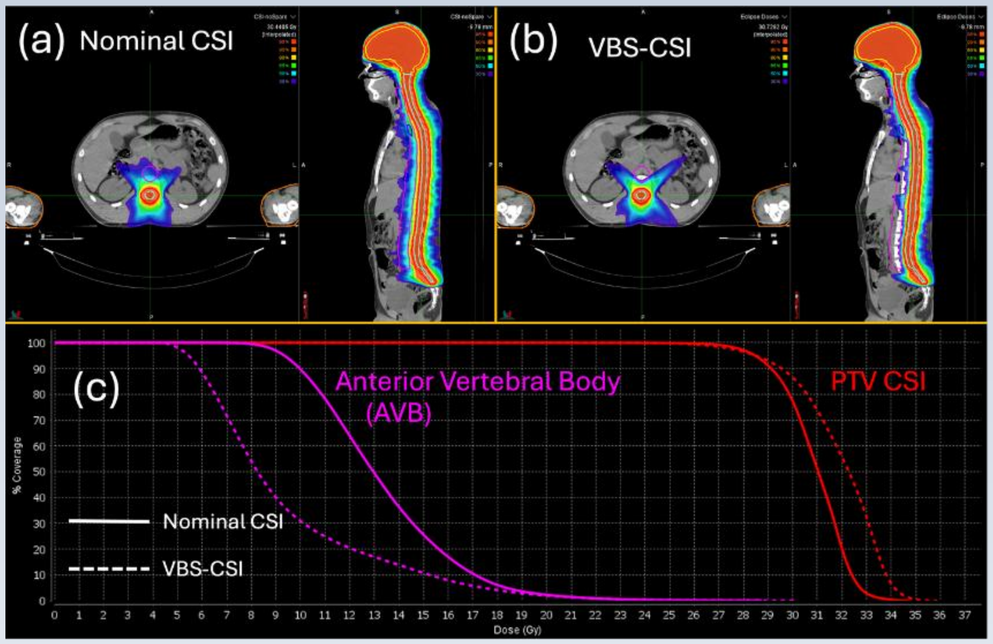

Figure 2. Dose distributions comparisons for the (a) nominal CSI and (b) VBS-CSI plans. (c) DVH comparisons of nominal (solid lines) and VBS-CSI (dashed lines) for the anterior vertebral bodies (AVB, magenta) and PTV (red) structures.

Approach

- **Patient selection:** One adult (PTV length = 76.5 cm) and one pediatric patient (PTV length = 50.2 cm).
- **Plans evaluated:** Nominal CSI and vertebral body sparing CSI (VBS-CSI)
- **VMAT field design:** 4 isocenters with 8 cm field overlap (adult); 3 isocenters with 14 cm field overlap (pediatric).
- **Rotations evaluated:** Setup errors of $\pm 1°$-$5°$ in roll, pitch, and yaw. Generated using MIM.
- **Dosimetric evaluation:** For each rotated dataset, nominal and VBS-CSI plans were calculated and DVH metrics (D90% for target) were tabulated as a function of rotation.

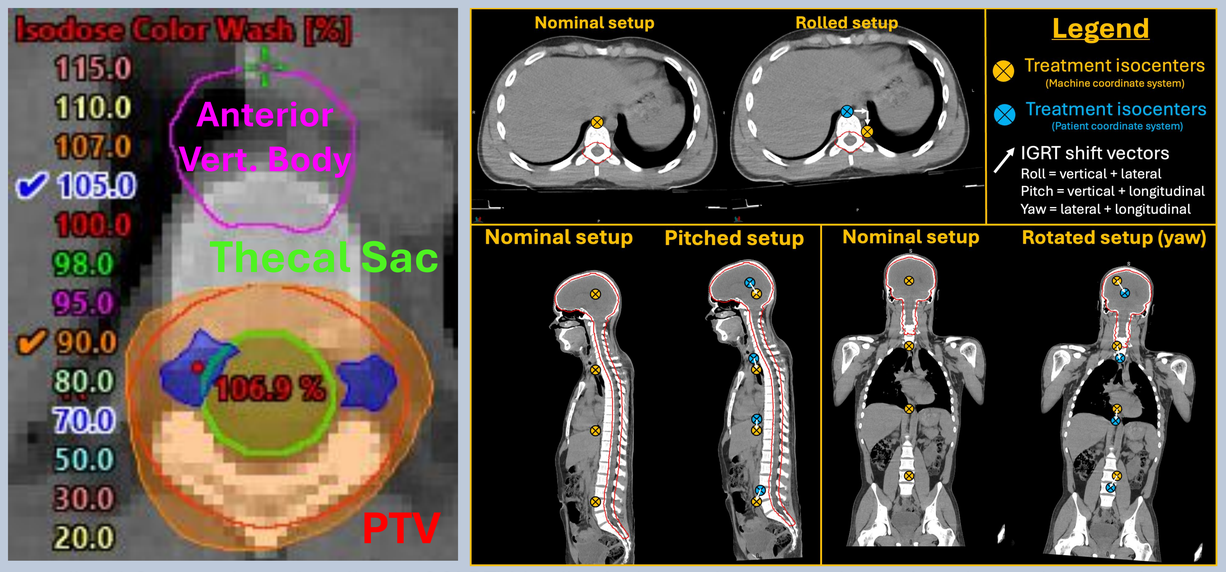

Figure 3. (Left) Screenshot of pediatric CSI PTV (red) relative to thecal sac (green) and anterior vertebral body (AVB, purple) avoidance structure with a 90% dose wash. (Right) Illustration of nominal and rotated dataset setups with corresponding treatment isocenter locations. For each rotated image, the treatment isocenters are displayed on both the patient and machine coordinate systems to illustrate the impact and direction of IGRT shifts.

Results

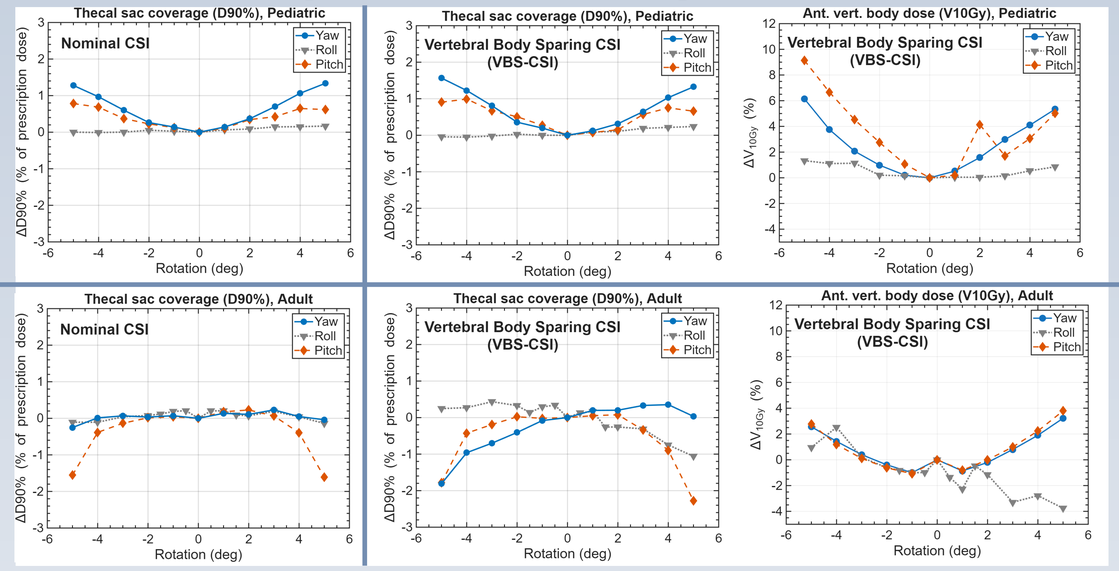

Figure 4. Summary of target coverage changes (D90% of thecal sac) relative to non-rotated scenario as a function of roll, pitch, and yaw angle for nominal CSI (left column) and VBS-CSI (middle column) for the adult bottom row) and pediatric (top row) patients. Vertebral body dose changes are shown in the right column for VBS-CSI.

Conclusion & Future Directions

- **VMAT CSI is robust to moderate rotational alignment errors (ΔD90% of thecal sac $<2.5\%$ for rotations up to $\pm 5°$) when using translation-only couch corrections.**
- **Sensitivity depends on rotation axis, treatment technique, and field arrangement.**
- **Future direction(s):** CBCT-based (HyperSight) dose verification for CSI, refining the planning/treatment workflow for Halcyon, automated treatment planning, retrospective efficiency gain evaluation (TrueBeam vs Halcyon overall treatment times)

References

[1]Perlow et. al., *Adv. Radiat Oncol.,* 2024
[2]Yang et. al., *JAMA Oncol.,* 2025
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[4]Stroubinis et. al., *Adv. Radiat Oncol.,* 2023
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Joint AAPM/COMP Annual Meeting 2026, Vancouver, BC, CA

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