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A Complete Solution for Pediatric Upright Proton Therapy: Novel Tilting Chair for Anesthesia-Induction, Integrated Audiovisual Immersion for Awake Patients, and Child Engagement Toys

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ABSTRACT

Purpose: The significant tissue-sparing advantages of upright proton therapy (UPT) make it an appealing treatment for pediatric patients, yet its widespread use is limited by the lack of a commercially available solution for upright anesthesia-assisted treatment. Additionally, while educational preparation tools and audiovisual immersion techniques have been used as anesthesia-reducing interventions in conventional radiation therapy, these approaches have not been translated to UPT. We present a comprehensive, integrated strategy that combines multiple innovations to create a safe, effective, and patient-centered workflow for pediatric UPT.

Methods: A novel pediatric tilting chair was designed and built to enable safe anesthesia induction and treatment delivery, with complete integration into the Leo Cancer Care (Sussex, UK) upright positioning system. For cooperative patients, an audiovisual distraction system (AVATAR) is integrated with the chair to provide immersive content, biofeedback, and communication, aiming to enable anesthesia-free treatment. The clinical workflow incorporates pre-treatment educational tools, such as animated videos and custom toys, to familiarize children with the process and reduce baseline anxiety. Validation of the chair system included mechanical load testing, vertical CT imaging, and end-to-end workflow simulation.

Results: Chair prototype functionality was verified with the upright positioning system; by rotating from a supine induction to an upright treatment position, this system accommodates anesthesia protocols while maintaining optimal patient positioning and beam access. Static load testing confirmed structural integrity and CT imaging demonstrated that the chair induced no artifacts nor restricted imaging geometry. Workflow simulations validated protocols for anesthesia and awake patients.

Conclusion: We are implementing a holistic solution that addresses the multifaceted challenges of pediatric UPT. By combining a specialized anesthesia chair with advanced patient engagement and distraction technologies, this system moves beyond a single-device solution to set a new standard for compassionate, safe, and effective pediatric radiation therapy.

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INTRODUCTION

	Anesthesia Induction	Transfer to Isocenter	Immobilization	Extraction
Cooperative Child	none	Patient sits directly in upright treatment chair	*Initial patient simulation*: Straps applied to forehead/chin and Accuform pillow fit in supine position, mask fit in upright position *For each treatment*: Mask secured in upright position with support for patient head as transitioned supine to upright.	**Non-Emergency:** • Raise CT ring • lower chair to supine position • Unstrap patient **Emergency Extraction:** • Lift chair including patient from the LEO positioner onto gurney by handles at the top and base of the chair. (two or more staff required)
Semi Cooperative Child	Anesthesia administered in the vault, supine on tilting treatment chair	Chest, waist, and head straps secured. Chair raised to upright position & Locked.		
Nervous Child	Anesthesia administered with patient supine on gurney	Gurney & tilting chairs aligned, patient transferred supine. Chest, waist, and head straps secured. Chair raised to upright position & Locked.		

Figure 1. Upright pediatric anesthesia and immobilization workflows for three potential patient types: cooperative children, semi-cooperative children, and nervous children.

- **Upright proton therapy (UPT)** provides a compact alternative to gantry-based systems, enabling ultra-small footprints, proton arc therapy, and preserved physiologic orientation[1].
- **Pediatric patients** serve to benefit from highly conformal PT, but UPT imposes workflow and safety challenges, as some patients require anesthesia.
- Commercial upright chairs lack compatibility with the needs to accommodate anesthesia, as patients will be **transitioned from supine (induction) to upright (treatment) positions**.

METHODS AND MATERIALS

- A tilted pediatric chair was designed to integrate with the Leo upright CT and Mevion S250 Fit chair base. The design was **3D-printed PLA frame** optimized for pediatric dosimetry and low secondary neutrons.
- Rod-connected seat and backrest allow transition from supine anesthesia induction to a locked upright position with **carbon-fiber backrest/headrest**, providing radiopaque support for brain and CSI treatments.
- **5 cm booster seats** adjust for a range of patient sizes. Additional **air-raise positioning** with a mask enables precise immobilization to account or day-to-day variability in spinal compression and a more comfortable setup.
- **AVATAR[2]** enables awake therapy, reducing anesthesia needs and 3D-printed CT/chair/immobilization models aid patient familiarization[3]. Prototyping and testing with the UPT system was performed.

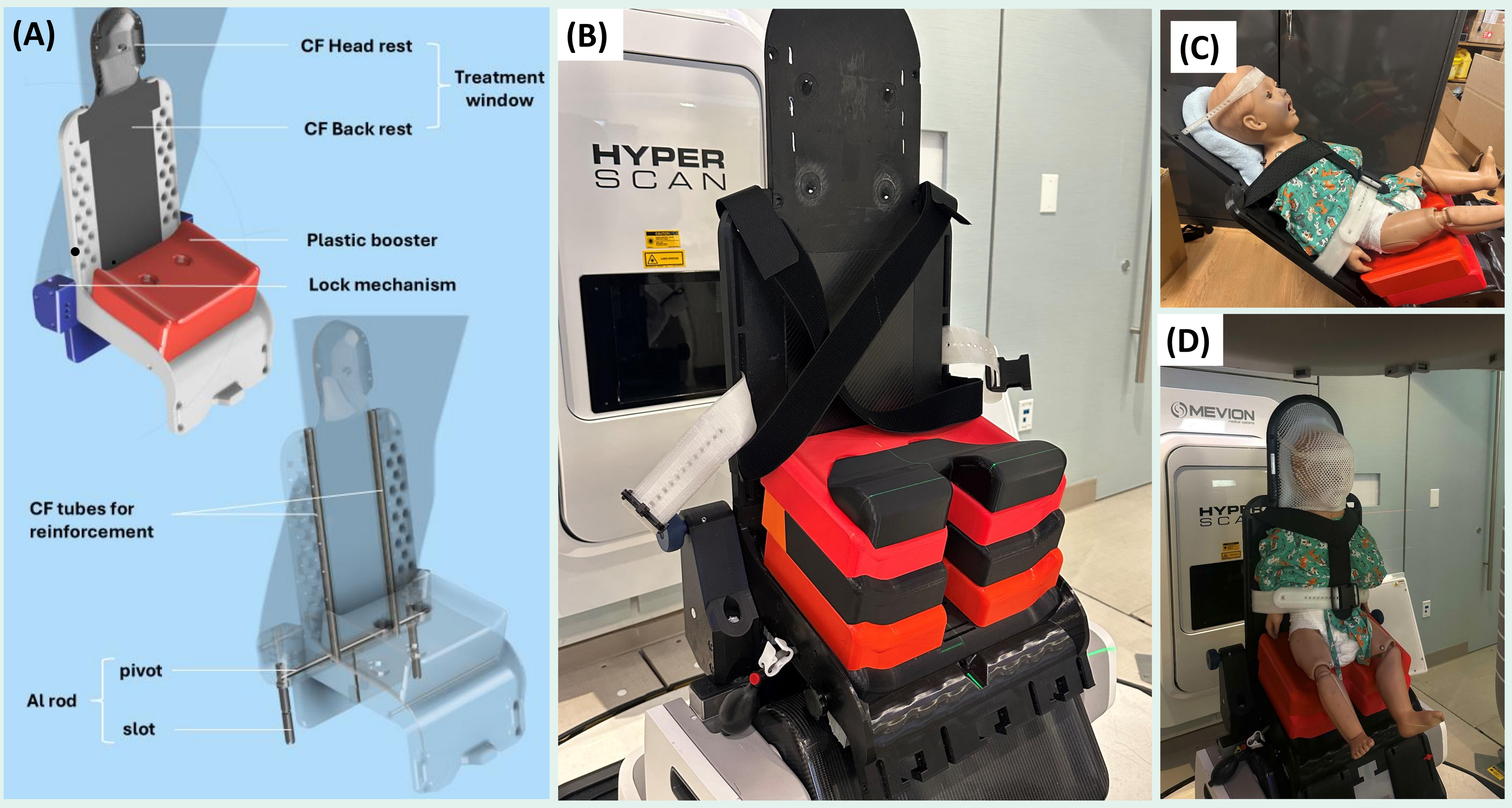

Figure 2. A) 3D diagram of chair design (external and internal components). B) 3D printed chair mounted on Leo chair system. Note 5cm boosters stacked, knee fix at top, waist belt and Velcro cross-body straps. C) Phantom in induction position with straps and Accuform. D) Phantom with mask and straps in upright position.

RESULTS

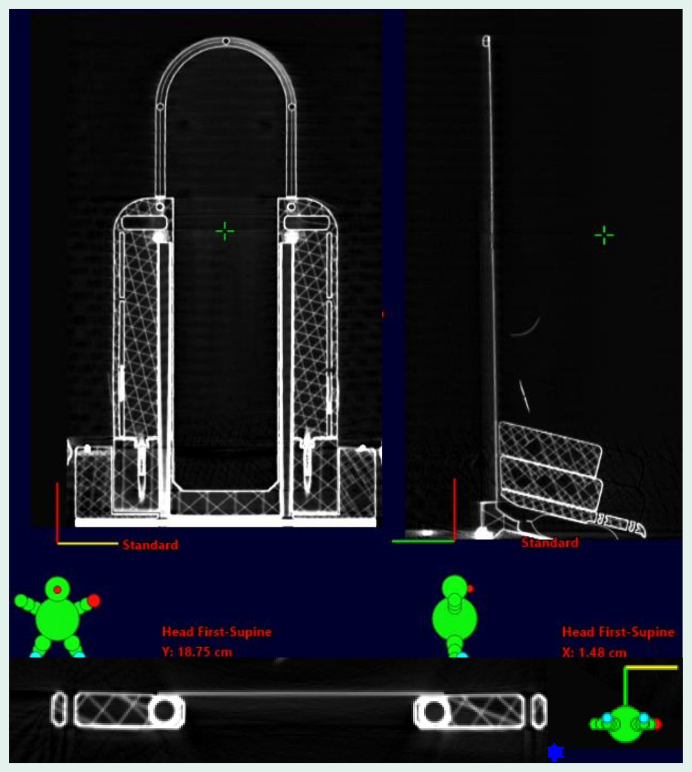

Figure 3. Upright CT scan of tilting pediatric chair verifies compatibility and CT number.

- The chair successfully supported a rigid phantom loaded to twice the maximum expected pediatric weight in the supine and upright positions.
- Carbon-fiber back and head support measured 2.1±0.1 mm water-equivalent thickness (WET).
- End-to-end workflow was tested with anesthesia team to verify compatibility with timelines, patient positioning, and cable management protocols.
- Preliminary prototyping / testing of AVATAR integration emphasized feasibility.

Figure 4. A) AVATAR system modified to fit upright chair setting. B) 3D model of upright Leo CT and chair for pediatric familiarization.

DISCUSSION

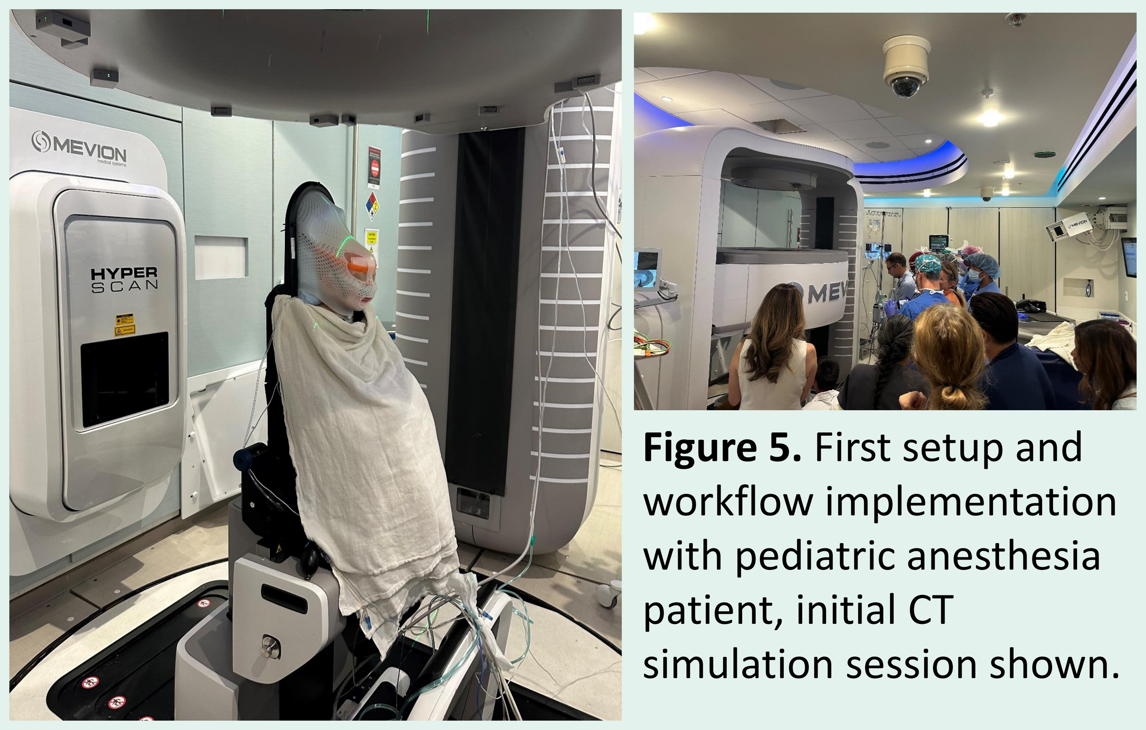

Figure 5. First setup and workflow implementation with pediatric anesthesia patient, initial CT simulation session shown.

- We designed and commissioned a novel tilting pediatric chair to accommodate patients requiring anesthesia & UPT.
- Commissioning demonstrates the chair meets mechanical, geometric, imaging, dosimetric, and safety tolerances derived from AAPM TG-224 and TG-185.
- The chair fills a gap: upright systems are largely adult-focused. It enables supine anesthesia induction transitioning to upright treatment while accommodating pediatric anatomy, with full compatibility to the existing imaging and delivery chain.
- *Important consideration*: simulation vs treatment workflows differ. The hardened mask can guide positioning without head straps for treatment.
- Clear documentation and trainings of these workflow distinctions is needed.
- *Limitations*: single-institution, custom device; commissioning data from phantoms only; first pediatric patient treatment pending (next week!).
- Pediatric familiarization tools require engagement across the clinical team (e.g., child-life specialists' tools) and effective communication and collaboration are essential for adoption.

CONCLUSIONS

We are implementing a holistic solution that addresses the multifaceted challenges of pediatric UPT. By combining a specialized, tilting anesthesia chair with advanced patient engagement and distraction technologies (AVATAR) to reduce anxiety, this system moves beyond a single-device solution to set a new standard for compassionate, safe, and accessible pediatric radiation therapy.

Future work: report clinical experience with the first cohort, quantify setup reproducibility and intrafraction stability against literature benchmarks, and write / implement detailed standard of work protocols for tilting chair clinical implementation.

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