Impact of Audio-Visual Assisted Therapeutic Ambience in Radiotherapy (AVATAR) on Anesthesia Use, Payer Charges, and Treatment Time in Pediatric Patients

Running Title: AVATAR Reduces Pediatric Anesthesia Use

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Abstract

Purpose: Pediatric radiotherapy requires optimal immobilization that often necessitates daily anesthesia. To decrease anesthesia use, we implemented a novel XXX system which projects video onto a radiolucent screen within the child's line of vision to provide attentional diversion. We investigated its reduction on anesthesia use, payer charges, and treatment time, as well as its impact on radiation delivery.

Methods and Materials: A 6-year retrospective analysis was performed among children undergoing radiotherapy (n=224), 3 years before and 3 after introduction of XXX. The frequency of anesthesia use before and after XXX implementation, as well as radiotherapy treatment times were compared. The number of spared anesthesia treatments allowed for a charge to payer analysis. To document lack of surface dose perturbation by XXX, a phantom craniospinal treatment course was delivered both with and without XXX. Additionally, an ion chamber course was delivered to document changes to dose at depth.

Results: More children were able to avoid anesthesia use entirely in the post-XXX cohort, compared to the pre-XXX cohort (73.2% vs 63.4%, p=0.03) and fewer required anesthesia for each treatment (18.8% vs 33%; p = 0.03). XXX introduction reduced anesthesia use for all ages studied. Treatment time per session was reduced by 38% using XXX compared to anesthesia. There were 326 fewer anesthesia sessions delivered over three years after XXX was introduced, with an estimated savings of > $500,000. OSLDs revealed a small increase in dose of 0.8%-9.5% with XXX, while the use of a thermomolded face mask increased skin dose as much as 58%.

Conclusions: XXX introduction decreased anesthesia use in children undergoing radiotherapy; more avoided anesthesia entirely, and fewer needed it for every treatment. This resulted in a reduction in treatment time, and savings of nearly $550,000 in approximately 3 years, with minimal perturbation of radiotherapy dose delivery.

Introduction

Radiation therapy is an important component of pediatric oncologic care. Radiation requires optimal immobilization to precisely target the tumor while sparing normal tissues. Highly conformal radiation delivery is desired in children to reduce long-term adverse effects, which may impact: fertility, growth, organ function, cognition, and carcinogenesis.[1–3] While radiation is painless, it can be difficult to tolerate. Patients must be accurately positioned and remain immobile during treatment sessions. This can be challenging, as treatment sessions may take as long as 45+ minutes. Hence, many pediatric patients require daily anesthesia to ensure immobility. Anesthesia use is frequently required for children daily throughout their treatment course, which may be 4-6 weeks.

Administration of daily anesthesia may carry short and long-term risks and is associated with high healthcare costs. Patients undergoing general anesthesia at a young age have increased risk of hypoxia, acute allergic reactions, and hyperthermia.[4] Animal models have demonstrated an association between general anesthesia and long-term neurocognitive deficits including neuronal apoptosis, reduced cognitive function, and prolonged behavioral consequences.[5,6] A recent report described an association between anesthesia exposure and detrimental neurocognitive and neuroimaging changes in survivors of childhood acute leukemia.[7] Neurocognitive impairment was associated with cumulative propofol dose, flurane exposure, and cumulative duration of anesthesia time. Additionally, slower processing speed and imaging changes were associated with these factors.[7] Multiple reports advocate for limited use of general anesthetics.[8,9] Notably, the U.S. Food and Drug Administration (FDA) recently issued a warning on the negative impact of repeated use of general anesthesia on brain development in children.[10]

Daily administration of anesthesia requires an anesthesiologist, specific time allocation on the radiotherapy schedule, careful coordination between the radiation oncologist and anesthesiologist, and additional preparation – all increasing radiotherapy treatment time. Anesthesia also places a burden on healthcare charges; anesthesia for a 6-week course of radiation therapy has been quoted to equal approximately $50,000 in payer charges.[11] Given the risks and additional burden this places on pediatric patients and healthcare staff, it is necessary to reduce anesthesia use whenever possible.

Watching videos can decrease anxiety in children during various hospital procedures.[12–14] We hypothesized that watching videos during radiotherapy would translate to better tolerance of daily radiotherapy without anesthesia. Thus, we developed and tested a novel audio-visual assisted therapeutic ambience in radiotherapy (XXX) system to enable children to watch videos during radiation. In an initial pilot study, XXX use was described in 25 patients of whom 23 (92%) completed a course of treatment without anesthesia, indicating promise for further investigation.[15] Here we describe our 6-year experience, analyzing the impact of XXX among 112 pediatric patients during the three years after its implementation, as compared to 112 controls during the three years prior to its implementation. We investigated XXX's effectiveness in reducing anesthesia use, payer charges, and treatment time and its impact on treatment delivery.

Methods and Materials

System Design

The XXX system is a novel technology enabling children to watch videos during radiation treatment delivery.[15] The system mounts a portable projector to the treatment table cephalad to the patient's head and displays streaming wireless video on a custom radiolucent screen (Figure 1). Allowing the radiation beam to pass through the screen with minimal degradation, minimal scatter, and minimal effect on the electronic operation of the video playback were critical design considerations.

For routine clinical use, we have improved our system from that reported in our pilot study. For setup flexibility we use tripod links combined with a 3D printed telescoping mount (Figure 1). The screen is attached to the links by carbon fiber strips which provide sufficient flexibility and strength to withstand potential gantry collisions. The system can be mounted at a single point, or the projector and the screen can be mounted separately. Additionally, we have added a louder speaker, a keystone correcting projector, and a webcam. The screen is constructed from 0.25mm thick matte plastic sheet supported by hollow 3D printed plastic arms with maximum water equivalent thickness of 2mm. The screen is curved to avoid potential interference with gantry rotation, and located approximately 15 cm above the patient's head. The telescopic mount allows the screen to pivot and adjust, facilitating customizable viewing while lying supine, and is comfortably in view even when wearing a face mask. The screen is constructed from low atomic number plastics and is thin to minimally attenuate the beam. Dosimetric analyses were performed to verify minimal changes in dose delivery.

Each XXX system costs approximately $500, including materials for the mounting system plus the video tablet. Our institution only required one system. Initial commissioning and setup of the XXX system requires roughly one hour. It takes approximately 1-2 minutes to setup per treatment.

Patient Characteristics and Anesthesia Use

We introduced the XXX system in September of 2015. Following Internal Review Board approval, we reviewed all children treated with radiation since the introduction of XXX between September 2015 and December 2018 (n=112) and compared them to an equal sized cohort of children treated prior to XXX (February 2012 to August 2015, n=112). Patients 3-12 years were included in the analysis, as all children 0-2 years required anesthesia, and none greater than 12 years did. The XXX system was made available to any patient who needed, or preferred, its use to assist with immobilization and comfort during treatment. All patients were candidates for XXX, unless they absolutely required anesthesia. 25 out of 112 patients did not require either anesthesia or XXX. Comparisons were made between the two cohorts overall, as well as within the following age categories: 3-4, 5-7, and 8-12 years.

Treatment Time Calculations

Treatment times were calculated for each individual session as the interval from when radiation therapists first open a patient's encounter when they bring them to the treatment room, to when radiation delivery is complete. 2470 treatment sessions since introduction of XXX were analyzed, and treatment times were compared between sessions delivered with anesthesia,

sessions delivered with XXX, or sessions delivered with neither. TBI patients were excluded as there was no standard documentation of treatment time.

Dosimetric Measurements

A CSI radiation course was delivered onto an Alderson RANDO phantom (Radiology Support Devices, Long Beach, CA). The delivered dose was measured using optically stimulated luminescent dosimeters (OSLDs, Landauer, Glenwood, IL) at 6 different locations: the forehead, left and right lens, maxilla, chin, and anterior neck. Three sessions of treatment were delivered to the phantom from which averages and standard deviations were calculated. Dosimetric data were collected using an earlier version of the radiolucent screen that was used by the majority of patients in this study and was three to five times greater in radiological thickness than our updated screen. To discern whether the dose perturbation was within a clinically acceptable range, treatment was delivered in three settings: with the phantom alone, with a thermoplastic mask in place, and with the thermoplastic mask plus XXX.

Additional dose measurements were run with the use of the XXX system and a Markus A10 parallel plate ion chamber (Best Medical, Nashville, TN) placed in a rectangular water-equivalent plastic phantom. This allowed measurements of both dose at surface as well as a 5cm depth. The surface of the ion chamber was placed on the central axis of the beam at 100 cm from the linac source. A 6 MV, 200 monitor unit hemispherical arc was delivered onto the phantom. Measurements were made with and without the XXX screen in place.

Payer Charges Calculations

A 6 week/30 session course of anesthesia for radiation treatment costs $50,000 in payer charges, equating to $1667 per session. [11] We used this data to perform a savings analysis since XXX implementation. The number of anesthesia sessions avoided was calculated by obtaining the difference in anesthesia sessions prior to and after XXX use. From this we calculated the charges avoided in our XXX cohort over the time period September 2015-December 2018.

Statistical Analysis

In order to compare patients treated before and after introduction of XXX, T tests were used for continuous outcomes such as treatment volume and weight loss. Chi-square tests were used for categorical outcomes such as anesthesia use (yes/no).

To calculate odds ratios of anesthesia use, data was analyzed in a multi-variable logistic regression model at the patient level. The model controlled for: age, ECOG, treatment category (head/neck/brain, torso/extremities, CSI, TBI), use of pain medication, and recent surgery. Variables that were tested and had no impact on the model were excluded.

In order to compare treatment time between anesthesia and XXX system, a mixed effects model was used to account for within patient correlation between treatment sessions. Treatment volume, ECOG, age, and recent surgery were also included in the model. This outcome was analyzed for the whole cohort as well as for only those treated after the introduction of XXX. All tests performed were two-sided with an alpha level of 0.05. All analyses were performed using SAS v 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Patient Characteristics

Patients treated pre-XXX introduction and post-XXX introduction were well matched by: gender, age, treatment region, pain medication, anxiety medication, cancelled treatments, and treatment fractions (Table 1). The mean age of patients treated post-XXX introduction was 7.5 years while those treated pre-XXX was 7.6 years (p=0.76). There was no difference in total treatment sessions per patient between the two groups (p=0.55). Additionally, there was no increase in cancellations or treatment extensions in patients treated after the introduction of XXX (p=0.17). There were significant differences between the two cohorts in terms of treatment volume (the post-XXX introduction cohort had larger treatment volumes), performance status, and recent surgery. These variables were controlled for in our multivariable model. As expected, there was greater use of child-life services in the patients treated post-XXX introduction to support the system's implementation.

Decreased Anesthesia Use

We assessed whether XXX introduction resulted in decreased anesthesia use.

There were two patient measures of anesthesia usage: 1. Patients who required any anesthesia use during their treatment course, and 2. Patients who successfully avoided anesthesia entirely, or only required anesthesia at the beginning of their course but then transitioned off (these patients were designated as "successes").

More patients treated after XXX was introduced were able to avoid anesthesia, as compared to those treated prior to XXX introduction (73.2% vs 63.4% p=0.03) (Figure 2). On multivariable logistic regression analysis, the patients treated pre-XXX introduction had 3.04 times the odds of needing anesthesia during at least one treatment session, as compared to those treated post-XXX introduction (95% CI 1.19-7.78).

There were more "successes" in patients treated after XXX introduction - as compared to the patients treated pre-XXX (81.2 % vs 67%, p=0.015). On multivariable logistic regression analysis, post-XXX patients had 7 times the odds of not needing anesthesia or successfully transitioning off anesthesia (95% CI 2.56-19.15).

A total of 4,375 treatment sessions were delivered between the two patient cohorts. There were fewer sessions requiring anesthesia among those treated post-XXX introduction (494 sessions over three years, 22.1%) as compared to those treated pre-XXX introduction (820 sessions over three years, or 38.3%, p=<0.0001). Older age was associated with less anesthesia use; each additional year of age had 0.38 times the odds of anesthesia use (95% CI 0.29-0.50). However, even as patients age, XXX continues to reduce anesthesia use. We found decreased anesthesia use in every age category within those treated post-XXX introduction: age 3-4, 61.4% of sessions required anesthesia versus 88.4% in the cohort treated prior to XXX (p <0.0001); age 5-7, 35% of sessions required anesthesia versus 56% in those treated pre-XXX (p <0.0001); of those ages 8-12 years, no sessions of treatment required anesthesia after introduction of XXX (0%) versus 13% in the patients treated before introduction of XXX (p <0.0001) (Figure 3).

Shorter Treatment Time

There was significantly longer treatment time for sessions delivered with anesthesia versus those with the XXX system ($p < 0.0001$). Average treatment time per session was 36.7 minutes with anesthesia, 22.6 minutes with XXX, and 20.3 minutes with neither.

Sessions delivered with the XXX system were 38% shorter than sessions with anesthesia, saving 14 minutes per treatment ($p<0.0001$). There was no significant difference between sessions delivered with the XXX system and those delivered without it, indicating it is not a significant time burden to add the XXX system onto treatments ($p=0.4$).

Impact on Dosimetry

Analysis of any change in delivered surface dose to the head and neck area with the XXX system in place was compared to changes using a thermoplastic face mask alone. Both the mask and the XXX system resulted in an increase in delivered surface dose. However, the mask gave a substantially greater increase in dose than did the XXX system in all measured areas except the lens of the eye. XXX demonstrated an average increased surface dose of 0.8% to 9.5% depending on the treatment site: 0.8% (SD 5%) to the forehead, and 9.5% (SD 5%) to the lens. By comparison, the thermoplastic mask resulted in an increased dose from 2% to 58% depending on the treatment site: 2% (SD 5.2%) to the anterior neck, and 58% (SD 9.17%) to the forehead.

The ion chamber measurements analyzed any changes for dose at depth, and revealed 4.6% excess surface dose with the XXX system in place, and a 0.7% dose reduction at 5 cm depth. The uncertainty in these measurements was 0.2%.

Payer Charge Savings

There were 820 sessions delivered with anesthesia in patients treated pre-XXX introduction, versus 494 sessions delivered with anesthesia in those treated post-XXX introduction. Thus, there was an avoidance of 326 anesthesia sessions after XXX was introduced. This equates to a projected savings of $543,333.00 in payer charges.

Discussion

XXX is a novel system allowing children to watch video on a radiolucent screen during radiotherapy, diverting their attention during treatment, and providing increased comfort so as to successfully complete radiotherapy without the need for anesthesia. In this report we demonstrate a significant decrease in anesthesia use during pediatric radiotherapy after introducing the XXX system. This decrease was seen both in the number of children who required anesthesia, and the total number of treatment sessions that required anesthesia.

Previous work documented frequent anesthesia use in children undergoing radiation with rates as high as 100% for those <3 years, over 90% for those ages 3-5, and 45-70% for those ages 6-7.[16] Frequent anesthesia use carries concerns: long-term adverse effects, complexity of delivering anesthesia in an outpatient radiation department, prolonged treatment time, and increased charges to payer and patient.

Given the frequent anesthesia use for pediatric radiotherapy, it is important to understand its consequences. These include neurocognitive dysfunction, prompting the FDA to issue warnings

about repeated anesthesia use causing potential brain damage. Most recently, Banerjee et al found increased risk of neurocognitive impairment with increased anesthesia exposure in survivors of pediatric leukemia.. Additionally, propofol exposure and total anesthesia time demonstrate higher white matter mean diffusivity in the corpus collosum, which correlates with decreased processing speed.[7]

There have been other proposed strategies to reduce anesthesia use in pediatric radiation therapy, including psychoeducation intervention, child life specialists, and even mounted television screens that are stationary and located outside the radiation beam.[11,17–19] Most of these interventions have shown some success, with the child life specialist decreasing anesthesia use in children ages 3-12 from 57% to 40.8%,[11] however these methods have shortcomings and require hiring and training specialists to coordinate schedules, and the use of an inflexible TV mount that cannot be manipulated between patients.

By design, XXX is simple and customizable from patient to patient, does not require additional personnel, and has been highly successful. After XXX introduction, <20% of children needed anesthesia for their full treatment course, while prior to XXX it was 33%. Seventy-three percent of our patients ages 3-12 were able to avoid anesthesia entirely after XXX introduction, while before only 64% did so. The ability for a child and family to go through an entire treatment course without requiring daily anesthesia improves quality of life.

Any reduction in anesthesia use is of clinical significance. We observed a 16% reduction in treatment sessions requiring anesthesia after XXX was introduced, and it was useful in each age

group investigated. It was beneficial in the young children (ages 3-4), where most children still required some anesthesia, but 17% fewer sessions required it with XXX. It was also greatly beneficial in older children (8-12) where no session of treatment required anesthesia in those treated post-XXX introduction, entirely negating dependence on anesthesia in this age group.

Further, our finding that XXX reduces treatment time by approximately 15 minutes leads to several opportunities. Children and their parents can return from the radiation department and back to their lives substantially sooner each day. In the cases where patients transitioned off anesthesia, parents have noted a reduction in stress on their children in preparing for daily visits to the clinic. While our results demonstrate decreased treatment machine time, there is also important time savings from not having to check in for daily anesthesia nor recovery from anesthesia care. Furthermore, decreasing treatment time by half potentially allows radiation departments additional treatment time periods for other patients.

Given treatment is delivered with the XXX radiolucent screen in the line of the beam, there are inherent concerns about its impact on radiation dosimetry. Our measurements using a phantom did demonstrate a small increase in radiation surface dose, and a small decrease in dose at depth. The maximum increase in dose was measured on the lens of each eye and was <10% of the planned dose to the lens. It is notable though that the change in dose is less than that from the thermoplastic face mask which is used regularly during pediatric treatment. The decrease in dose measured at a 5cm depth with the XXX system in place was <1%.The XXX system assists with immobilization, but on balance there are small dosimetric consequences.

Monetary savings in health care are highly relevant in the current healthcare landscape. . Previous studies have demonstrated a 30-session treatment course is charged to the payer as $50,000 (accounting for both the anesthetic medications as well as the medical professional fees). Given that we found a 40% decrease in sessions delivered with anesthesia after the introduction of XXX, over a three-year period, this translates to over half a million dollars saved in payer charges. This does not account for decreased payer charges from the PACU recovery time. There are additional departmental savings due to decreased treatment time and ability to get additional patients on the machines.

We acknowledge limitations of our study, including its retrospective nature. There are only limited scenarios when the XXX system would be contraindicated, such as orbit or optic pathway tumors where treatment relies on minimizing eye movement. This system has not yet been studied with proton therapy. However, if treatment was designed so that incoming beams only passed through the 0.2mm screen, we would project minimal disturbance of the proton beam. Our departmental data only captures treatment times, but does not capture total time associated with daily treatment including time to check in for anesthesia, and the time for anesthesia recovery. Finally given the charges analysis utilizes national means and previously reported values, it is an early analysis, and future work could involve analysis of cost savings due to decreased time on the machine and additional patient throughput.

To our knowledge, we report the first pilot program of this device allowing streaming video through which a radiation beam can pass, is mounted to the treatment table and customized for optimal viewing patient to patient. There are numerous future potential uses for this device,

including streaming more interactive content such as video feed with family, or utilizing the system for other patients struggling with immobility such as adults suffering from pain or anxiety. To further delineate the benefits of the XXX system, there is a currently enrolling multi-institutional clinical trial prospectively examining the effects of XXX on anesthesia avoidance and outcomes among pediatric patients (NCTXXXXXXXX).

Conclusions

XXX is a novel system allowing children to watch video during treatment, which both helps distraction and immobilization. Introducing the XXX system decreases anesthesia use in children undergoing radiotherapy; more children are able to avoid anesthesia entirely, and fewer need anesthesia for every treatment. XXX reduces anesthesia use for all ages. Treatment time is reduced by over one-third with XXX when compared to anesthesia. Additionally, use of the XXX resulted in an estimated savings of nearly $550,000 in approximately 3 years. These benefits come with minimal dose perturbation. XXX is currently being studied in an ongoing prospective multicenter trial (NCTXXXXXXXX).

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Figure Legends

Figure 1: Updated XXX System. Audiovisual system design projects videos while patient lies supine. The system, including a pico-projector, speaker, and screen, mounts to the head of the treatment table. An adjustable arm positions the screen display in the patient's field of view while avoiding collision with the treatment machine. Video and sound are transmitted wirelessly and power is provided by a rechargeable battery.

Figure 2. Decreased Anesthesia Use Between XXX Cohort and Pre-XXX Cohort. Use of anesthesia comparing patients who were treated using the XXX system, and those who were treated before XXX implementation. There is a significant difference in the percentage of patients who were able to avoid anesthesia entirely, and those who were able to transition off of anesthesia amongst the XXX cohort vs the pre-XXX group.

Figure 3. Increased Number of Treatment Sessions Performed Without Anesthesia in the XXX Cohort vs Pre-XXX Cohort. Anesthesia use in patients using XXX compared to those without XXX according to age group. Patients using XXX had significantly more treatment sessions without anesthesia in each age group

Table 1. Baseline Characteristics of XXX Cohort Compared to Pre-XXX Cohort

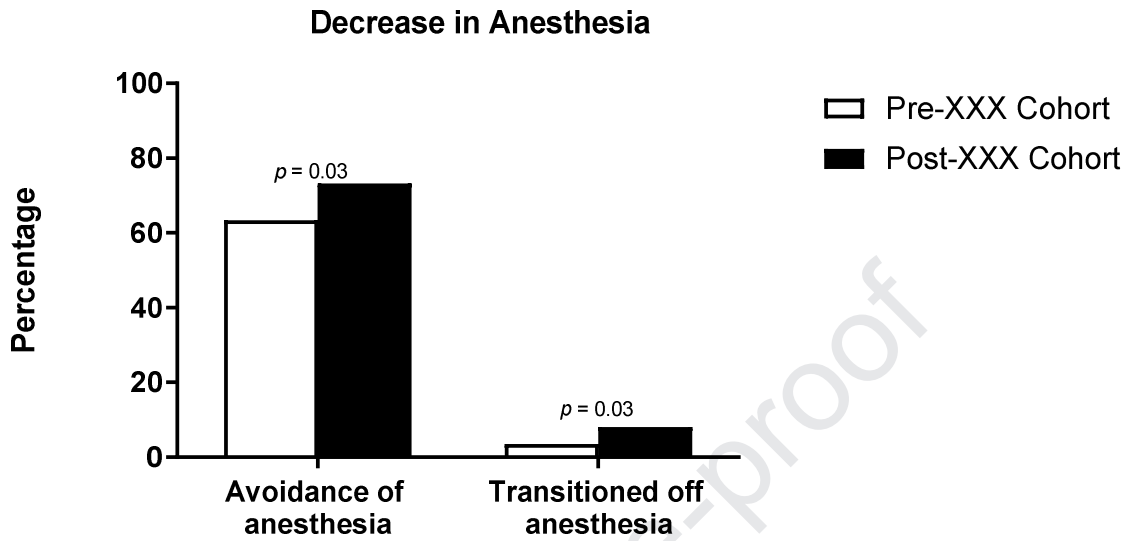
Characteristic	Pre-XXX (%) n = 112	XXX (%) n = 112	p value
Gender			0.42
Female	47 (42)	53 (47)	
Male	65 (58)	59 (53)	
Age			0.76
Mean (years)	7.63	7.52	
Categories			0.85
3-4	19 (17)	18 (16)	
5-7	41 (37)	37 (33)	
>7	53 (47)	56 (50)	
Treatment Volume (mean $cm^{3)a}$	842.8	1171.8	**0.03**
Treatment Region			0.13
Brain/Head/Neck	41 (37)	34 (30)	
Torso	26 (23)	35 (31)	
Extremity	9 (8)	2 (2)	
CSI*	17 (15)	22 (20)	
TBI*	19 (17)	19 (17)	
ECOG			**0.02**
0	21 (19)	44 (39)	
1	70 (63)	48 (43)	
2	13 (12)	13 (12)	
3	5 (4)	4 (4)	
4	3 (3)	3 (3)	
Recent Surgery[b]	31 (28)	18 (16)	**0.04**
Pain Medication[c]	36 (32)	44 (39)	0.26
Anxiety Medication[d]	21 (19)	21 (19)	1.00
Child-life Services[e]	54 (48)	81 (72)	**0.0002**
Cancelled Treatments			0.17
0	87 (78)	95 (85)	
1	14 (13)	11 (10)	
≥2	11 (10)	6 (5)	
Patients with any cancelled treatments	25 (22)	17 (15)	
Treatment Fractions			0.55
Total	2142	2233	
Mean, per patient	19.1	19.9	
Categories			0.33
0-10	23 (21)	29 (26)	
11-20	38 (34)	26 (23)	
21-30	41 (37)	44 (39)	
>30	10 (9)	13 (12)	
Fractions with Anesthesia			**<0.001**

Anesthesia	820 (38)	494 (22)	
No anesthesia	1,322 (62)	1,739 (78)	

[a]Treatment volumes calculated for patients with 3D or IMRT plans and did not include electron plans or TBI. There were 91 treatment volumes included in the pre-XXX cohort and 93 treatment volumes in the XXX cohort
[b]Recent surgery defined as within 30 days of radiation start
[c]Any pain medication, standing or PRN, at the start of radiation
[d]Any anxiolytics, standing or PRN, at the start of radiation
[e]Use of Child-Life services anytime during the course of radiation

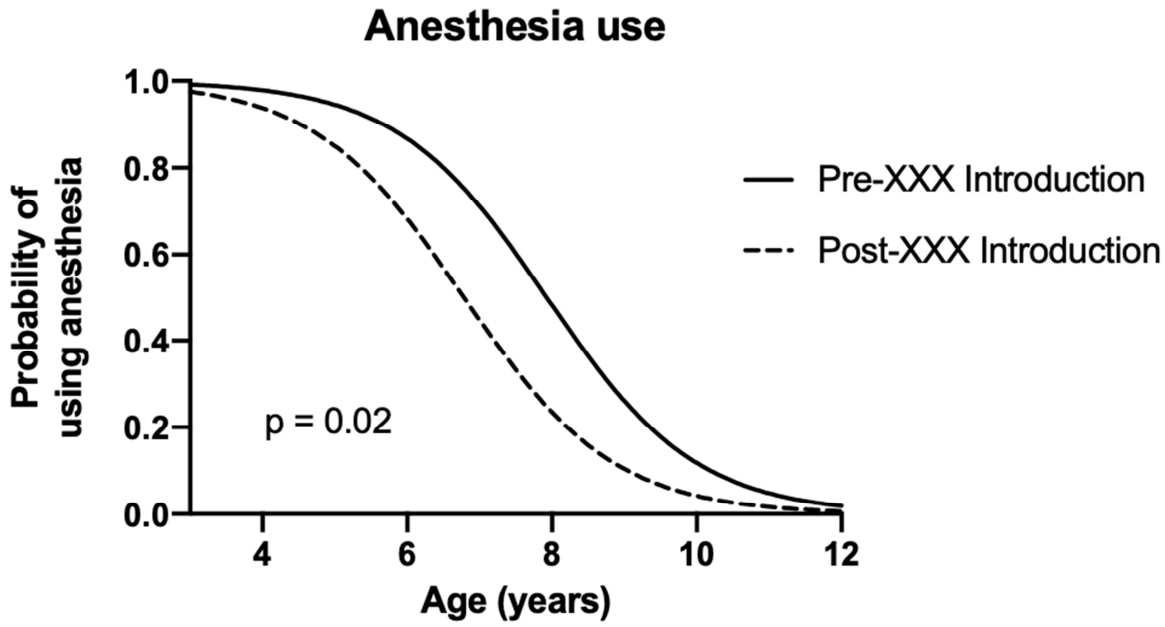
*Abbreviations: Craniospinal irradiation (CSI), total body irradiation (TBI)
Comparison of characteristics between the pre-XXX and post-XXX cohorts. Importantly, fractions delivered to patients using anesthesia significantly differed between each cohort.

Figure 2. Decreased Anesthesia Use Between Post-XXX Cohort and Pre-XXX Cohort



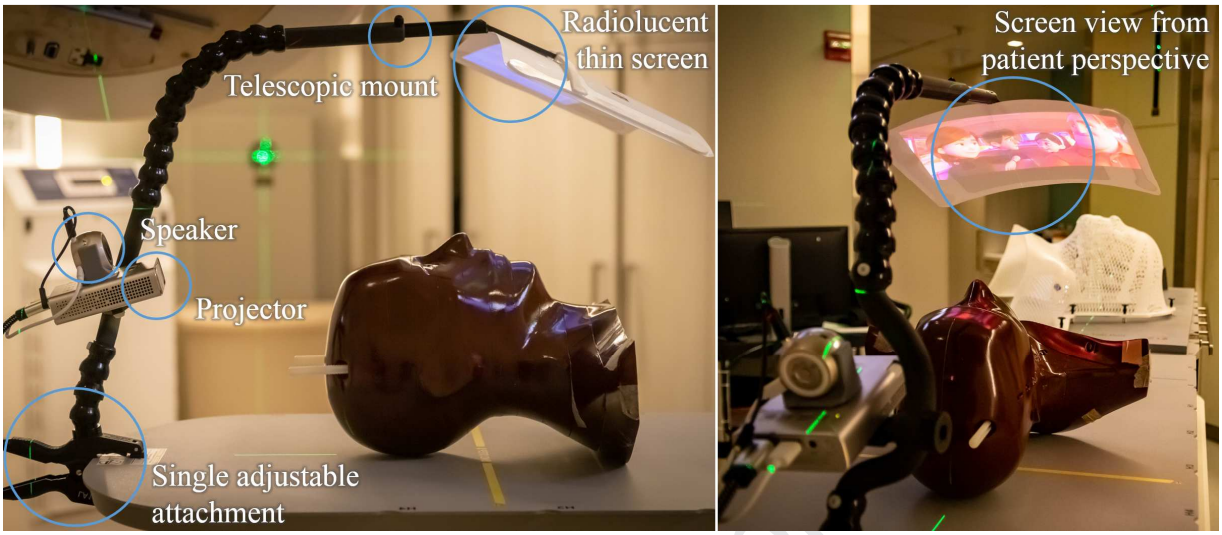
Use of anesthesia in comparing patients who were treated while using the XXX system, and those who were treated before XXX implementation . There is a significant difference in the percentage of patients who were able to avoid anesthesia entirely, and those who were able to transition off of anesthesia amongst the post-XXX cohort vs the pre-XXX group.

Figure 3. Increased Number of Treatment Sessions Performed Without Anesthesia in the XXX Cohort vs Pre-XXX Cohort.



Anesthesia use in patients using XXX compared to those without XXX according to age group. Patients using XXX had significantly more treatment sessions without anesthesia in each age group

Figure 1: Updated XXX System



Audiovisual system design projects videos while patient lies supine. The system, including a pico-projector, speaker, and screen, mounts to the head of the treatment table. An adjustable arm positions the screen display in the patient's field of view while avoiding collision with the treatment machine. Video and sound are transmitted wirelessly and power is provided by a rechargeable battery.