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Research article

Effects of immersive virtual reality exposure in preparing pediatric oncology patients for radiation therapy

Michelle Tennant [a,b,d], Nigel Anderson [c,e,*], George J. Youssef [a,f], Laura McMillan [a], Renae Thorson [c], Greg Wheeler [c,e], Maria C. McCarthy [a,d,g]

[a] Clinical Sciences, Murdoch Children's Research Institute, Parkville, Victoria 3052, Australia
[b] School of Psychology, Faculty of Health, Deakin University, Geelong, Victoria 3220, Australia
[c] Division of Radiation Oncology, Peter MacCallum Cancer Centre, Melbourne, Victoria 3000, Australia
[d] Children's Cancer Centre, The Royal Children's Hospital, Parkville, Victoria 3052, Australia
[e] Sir Peter MacCallum Department of Oncology, The University of Melbourne, Victoria 3010, Australia
[f] Centre for Adolescent Health, Murdoch Children's Research Institute, Parkville, Victoria 3052, Australia
[g] Department of Paediatrics, University of Melbourne, Parkville, Victoria 3052, Australia

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ABSTRACT

Background: Procedural anxiety in children undergoing radiation therapy (RT) is common and is associated with poor procedural compliance and an increased used of general anaesthesia (GA). There is emerging evidence that Virtual Reality (VR) technology may reduce medical procedural distress through realistic and educative exposure to actual procedures via virtual simulation.

Objective: To examine the feasibility, acceptability and efficacy of an Immersive VR exposure intervention aimed at reducing anxiety and enhancing preparedness for pediatric patients undergoing radiation therapy, and their parents.

Method: A convenience sample of patients (6–18 years) scheduled for RT, and their parent caregivers, were recruited consecutively over a 14-month period. Patients were exposed to a virtual simulation of both CT Simulation (Phase 1) and RT (Phase 2), prior to these procedures occurring. Pre-and-post VR intervention measures (anxiety, health literacy) were administered across multiple time points. GA requirement following VR intervention was also recorded.

Results: Thirty children and adolescents were recruited (88% participation rate). High VR acceptability and satisfaction was reported by patients, parents and radiation therapists. There were minimal adverse effects associated with VR. The VR intervention was found to improve children's understanding of the RT procedures (health literacy) and lower pre-procedural child and parental anxiety. Only one child in the study required GA (3.33%).

Conclusions: This study provides novel and preliminary support for utilizing VR to prepare children and families for RT. Subsequent implementation of VR into routine paediatric RT has the potential to improve clinical and operational outcomes.

Introduction

Radiation therapy (RT) is used in pediatric oncology to treat central nervous system (CNS) cancers and other malignancies. To optimize treatment and minimize damage to surrounding tissue, children are required to remain still for extended time periods during multiple RT fractions typically administered daily over several weeks. Prior to treatment, RT "simulation" is conducted to construct customized immobilization devices, which may include a mask or body cradle, to ensure stability and reproducibility for subsequent treatment[1].

Acute distress reactions are common in pediatric patients undergoing RT[2–4] related to factors such as child temperament or developmental limitations, separation from parents, unfamiliar environments, novel RT equipment and negative experiences with previous medical procedures [2,5,6], together with the anxiety associated with construction and use of immobilization devices[4,6,7]. Parental worry and anxiety are also

* Corresponding author at: Division of Radiation Oncology, Peter MacCallum Cancer Centre, Melbourne, Victoria 3000, Australia.
E-mail address: nigel.anderson@petermac.org (N. Anderson).

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commonplace and can influence children's fear and anxiety and reduce compliance with RT procedures[3,6,8,9]. As a result, there is sometimes a need to utilize general anesthetic (GA), particularly for younger patients, for their entire RT treatment course[2,10]. GA is routinely administered to all children under 3 years, to approximately 50% of children aged 7–8 years and to around 10% of children aged 13 years or older[4]. Although anesthetizing children and adolescents for RT has been generally considered safe[11], there are known negative acute (neurocognitive, emotional and behavioral)[6,12–14] and late (medical fears, ongoing post-traumatic stress response) health effects associated with repeated sedation[2,11,15–18]. GA usage in RT also utilizes significant economic healthcare resources (estimated at $30,000 AUD per patient at our institution for a 6-week course of RT). Despite good practice guidelines emphasizing the necessity of age-appropriate preparation, communication and supports for pediatric patients and their families undergoing RT treatment[19], persistently high distress and high sedation rates suggests the need for alternative interventions to manage procedural anxiety and promote procedural compliance without GA[2–4,6].

VR is a uniquely immersive and interactive technology that is highly engaging to children and adolescents[20], with previous studies in healthcare settings demonstrating its effectiveness in reducing pain and distress in children undergoing invasive procedures[21] and various cancer treatments, including chemotherapy, port access, lumbar punctures[22–24] and in supportive care of children with cancer [25–27]. There are currently no studies that have reported on the application of VR as a preparatory exposure tool for RT procedures, although this novel approach, which aims to provide patients with a realistic simulation of actual procedures, has begun to be explored in other pediatric medical settings such as non-sedated MRI[28], chest radiography[29] and pediatric surgeries[30–34] with encouraging results. Previous work undertaken by this group, whilst not in the radiotherapy setting, have demonstrated VR acceptability in a pediatric cohort, and the impetus for this novel use of a VR intervention.

Based upon these promising findings, the primary aim of this exploratory study was to: (i) trial and evaluate the feasibility and acceptability of a customized Immersive VR exposure intervention in an RT setting with pediatric oncology patients. Secondary aims were to: (ii) examine the influence of VR exposure therapy on child and parent ratings of anxiety and procedure-related distress, (iii) explore the role of VR exposure therapy in educating children and their families about RT procedures, and (iv) evaluate the influence of VR exposure therapy on GA use during pediatric RT treatment.

Methods

Design

A single cohort, repeated measures design was utilized. The study was conducted over a 14-month period between 2018 and 2019, at the Peter MacCallum Cancer Centre (PMCC) in Melbourne, Australia (Ethics approval #37275).

Participants

Eligible participants were recruited consecutively. Written information about the study was provided by clinical staff and interested participants were then contacted by a member of the research team to obtain written consent. Eligible participants were oncology patients (6 – 18 years) and a parent caregiver, referred for RT treatment for the first time. Exclusion criteria included patients who: had undergone RT previously, had significant neurological or developmental difficulties, were deemed medically unstable or palliative; or were less than six years old (due to the cognitive and language skills required to complete study measures). Parents required sufficient English to provide informed consent and complete parent study measures.

Virtual reality intervention

Immersive VR experiences were provided using smartphones (Galaxy S7®; Samsung) and VR headsets (Samsung Gear VR® first-generation mobile HMD; released November 2015; Oculus Go® Facebook Technologies, LLC; released May 2018). The intervention content involved 360 video recording of actual treatment procedures at the PMCC, produced in collaboration with a VR production company (*Phoria*, Melbourne, Australia). Participants viewed two virtual simulation experiences, delivered by radiation therapists, that corresponded to their upcoming procedure i.e., VR CT Simulation [VR CT] and VR Radiation Therapy [VR RAD]. The VR experiences were 4–7 min long, depending on treatment location (i.e., head and neck/ brain with mask; or thorax/ abdomen/ pelvis/ extremities). VR CT was first viewed by the patient and carer/s prior to CT simulation. VR Rad was first viewed by patient and carer following CT simulation, but before treatment commencement, and could be taken home for subsequent use in between these two time points for family/friends to utilise. Radiation therapist members of the study guided the patient/carers at each initial viewing, and supplied instructions for when viewing away from the clinic. Fig. 1 presents images taken from the VR CT and VR RAD simulation experiences. Fig. 2 illustrates each step of the study, showing the schedule of intervention delivery, RT procedures, and outcomes measured across multiple time points (T1–T5). A detailed description of these steps can be found in the Supplementary Material.

Measures

A number of measures (listed below) were utilized to assess VR acceptability, feasibility, health literacy, anxiety and GA utilization. A detailed description of each can be found in the Supplementary Material.

VR acceptability

VR intervention acceptability was measured by calculating participation rates (number approached/ number consented) and parent perceived acceptability using The Abbreviated Acceptability Rating Profile (AARP; 8-items)[35]. Opened ended questions further evaluated parent perspectives on VR: *"What did you like most/least about the technology?"; "Add any other comments / opinions about using this technology with children with cancer"*. (Supplementary S.1).

VR feasibility

Child completion rates, technical issues and adverse events recorded throughout the study period. Feasibility was also assessed using the Child Simulator Sickness Questionnaire (CSSQ; 7-items)[36](Supplementary S.2) and radiation therapists' ratings of child procedural compliance and distress using Visual Analogue Scales (VASs). (Supplementary S.3).

Child health literacy

Procedural knowledge was evaluated via verbatim recording and transcription of children's description of forthcoming treatments pre and post the VR intervention (VR CT and VR RAD). Children's responses were analyzed by an independent radiation therapist using a checklist of relevant procedural characteristics (Supplementary S.4).

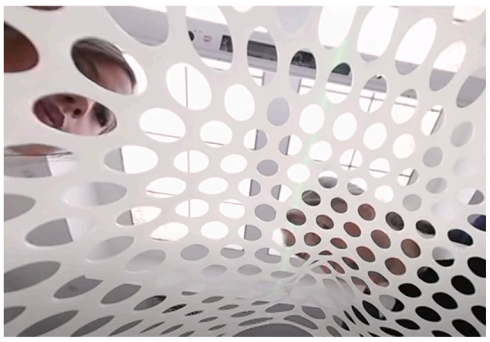
Procedural anxiety

Child and parent self-assessment ratings of state anxiety were measured using *Child Anxiety (VAS), Parent Anxiety (VAS)* and parent-proxy reports of child anxiety[37] (Supplementary S.5–S.7).

General anesthesia use

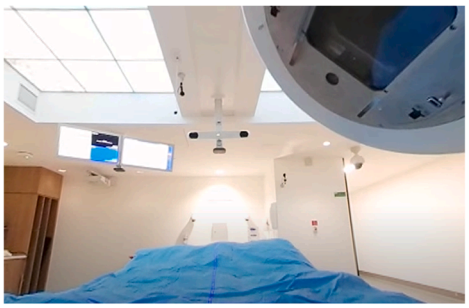
GA requirements (number awake/ number sedated) recorded throughout the study period.

(a)



(b)

(c)



(d)

Fig. 1. a, b. VR CT (head and neck/brain wearing a face mask) images of child as an observer and as an active participant in Phase 1 (CT Simulation procedure). Fig. 1c, d. VR RAD (thorax/abdomen/pelvis/extremities) images of child as an observer and as an active participant in Phase 2 (Radiation Therapy) treatment procedure. Note: as these are filmed for viewing in a VR headset, they appear distorted. When wearing the VR headset, actors in the video appear to be looking in the correct direction and the room appears as if you are in the room yourself.

Data analysis

Stata version 13 was used for all statistical analyses[38]. Descriptive statistics were used to analyze demographics and quantitative measures. Regression models were estimated to examine within-subject changes in parent and child anxiety levels, as well as procedural literacy across study time points (i.e., T1-T5). Specifically, each outcome was regressed on to a variable denoting time (e.g., pre- vs post-) and adjusted for child age, sex and treatment condition (i.e., RT with mask). To account for the clustering of time points within individuals, we used a cluster robust variance estimator. Qualitative data obtained from AARP were analyzed using inductive content analysis[39], to identify emergent themes in the data.

Results

Sample characteristics

Participants were 30 pediatric oncology patients (63.3% male, mean age 11.09 years, SD 3.24, 23/30 aged 6–12 years old) and their parent caregiver. Participant characteristics are presented in Table 1.

Intervention acceptability & feasibility

Study uptake and retention

A flow diagram of participant recruitment is presented in supplementary materials (see Supplementary S.8). From 115 pediatric patients that presented for RT during the study period, 34 families were deemed eligible and 30 consented to participate (recruitment rate 88%). Child and parent completion rates were 100% for both VR CT and for VR RAD. Two patients had RT treatment cancelled following VR RAD.

Parent acceptability

The mean VR acceptability rating from parents was 37.71 (out of 48) (SD = 9.95; median = 40; range 19– 48) (AARP), indicating high satisfaction with VR intervention. Table 3 summarizes parents' perspectives on usefulness of the VR intervention, presented as main themes and excerpts of parents' responses to the open-ended survey questions. Under perceived benefits, three main themes were identified. Procedural knowledge/literacy was regarded as one of strongest advantages of the VR intervention. Knowledge sharing and benefit in using VR to lower anticipatory and procedural anxiety were other key themes identified. Under perceived concerns, four main themes emerged- reliability of the technology, accuracy and age-appropriateness of the video (in particular, older children), comfort and fit of the headsets for children and child-friendly language.

Technical issues

The VR intervention was found to be highly reliable during the intervention trial. Minor technical issues were recorded when using Samsung Gear VR equipment, which did not disrupt participation or intervention.

Adverse events

No children reported symptoms indicative of significant simulator sickness following a 4- to 6-minute VR experience (see Table 2).

Procedural compliance

During CT simulation, mean scores for radiation therapists' ratings of patient distress were 24.12 (SD = 22.94, median = 16.5, range = 0 – 78), and patient compliant were 90.12 (SD = 14.24, median = 93, range = 47 – 100). During RT treatment, mean scores for radiation therapists' ratings of patient distress were 33.1 (SD = 30.4, median = 21.5, range = 0 – 94), and patient compliance 87.55 (SD = 16.51, median = 95, range = 45 – 100) (maximum score is 100). Results indicate low overall observed distress and high awake compliance during CT and RT treatment procedures for patients receiving VR intervention.

Efficacy of VR exposure on outcomes

Health literacy

Table 4 presents the pre-post changes in children's procedural

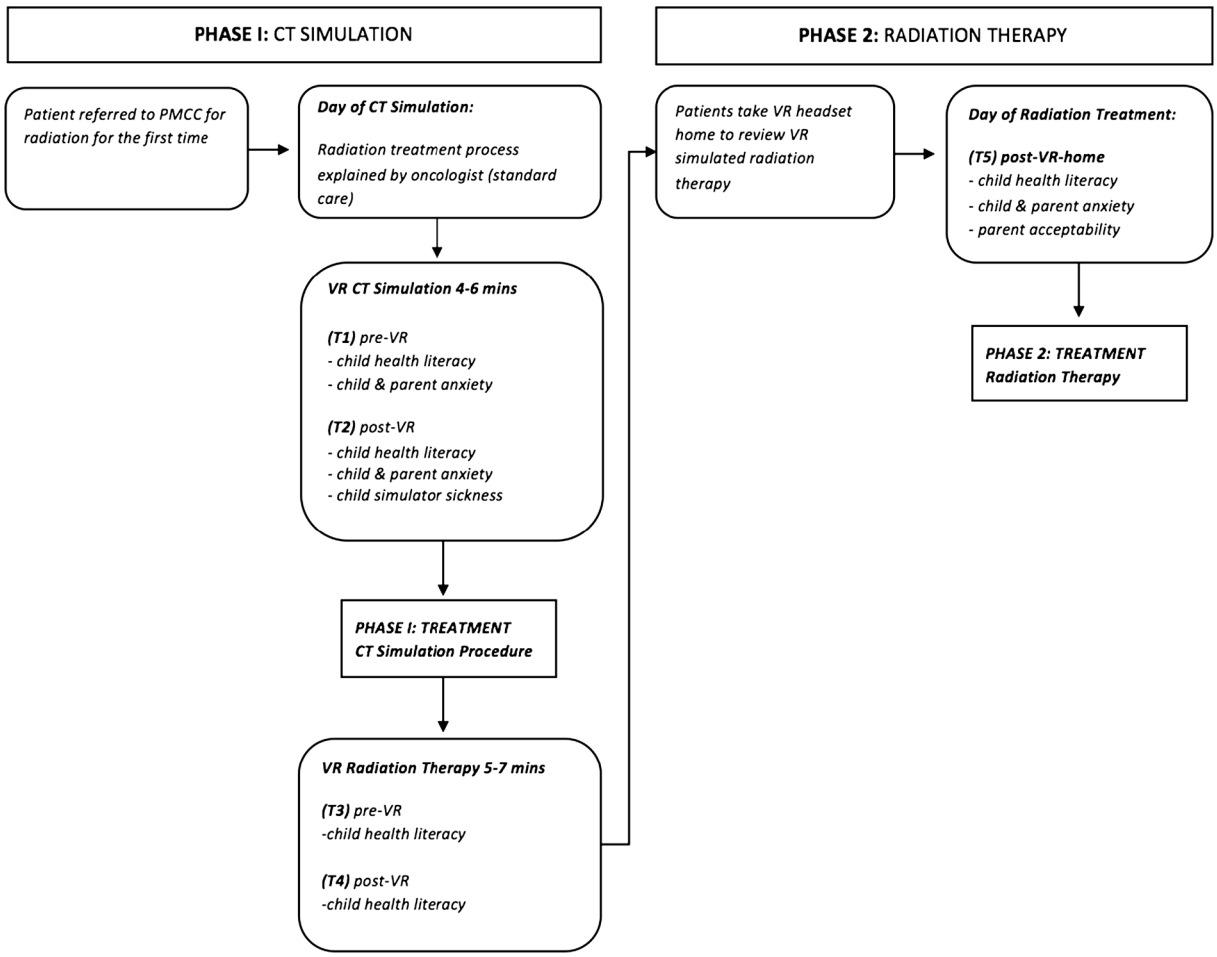


Fig. 2. Details about each step of the study, including *Phase 1* (CT Simulation) and *Phase 2* (Radiation Therapy) VR exposure intervention and treatment schedule, and study measures across multiple time points (T1–T5).

knowledge. Overall, when compared to baseline assessment of these measures, all children demonstrated an immediate increase in procedural knowledge following VR exposure (VR CT, $p = .000$; VR RAD, $p = .000$). Following exposure to VR RAD, children also demonstrated knowledge retention of RT procedures at 2-week follow up (on day of RT commencement), with the increase maintained from baseline ($p = .009$).

Child and parent anxiety

Table 4 presents the change in child and parent anxiety throughout the intervention trial (i.e., T1–T5). Overall, exposure to VR CT led to reductions in both child and parent anxiety compared to baseline measurements, with statistically significant reductions found on measures of parent report of children's anxiety ($p = .001$) and parent-report of their own anxiety ($p = .028$) at post-intervention.

Parent and child anxiety was assessed again on day of RT commencement (approximately 7–10 days following the first VR viewing), following multiple exposures to VR RAD and were compared to baseline and post-VR CT anxiety to highlight change over time. Child-report of their own anxiety showed an increase at follow up from levels at post-VR CT ($p = .01$), while parent report of children's anxiety and parent anxiety illustrated no change (indicating parents perceived their child's lowered anxiety was maintained from *Phase 1*).

General anesthesia use

A successful 'awake' CT simulation and initial RT treatment was achieved in 29 out of 30 patients following VR exposure (96.67%). In one case, the child's behavioural/anxiety levels prohibited them from safely undergoing CT simulation and GA had to be administered (3.33%).

Discussion

This exploratory study evaluated the potential benefits of an Immersive VR exposure intervention as a preparatory resource for children undergoing RT treatment and their parents. The VR intervention had several purposes: to increase patient procedural knowledge, lower patient and parent anxiety, and to reduce the need for GA through simulation of RT behavioral requirements. As application of VR to clinical healthcare is rapidly gaining momentum, this study provides novel data on VR acceptability, feasibility and efficacy in a tertiary radiation oncology setting.

Overall, our results indicate the VR intervention was highly acceptable among patients, parents and radiation therapists. It was also feasible to implement with low-cost, commercially available technology and cleaning protocols that adhered to institution-specific infection-control standards, with minimal adverse events and technical difficulties encountered. Strong intervention uptake (88%) and child completion rates (100%) were comparable to previous studies utilizing VR exposure in other pediatric radiology settings, including MRI[28] and chest radiography[29] as well as previous studies in pediatric oncology, where patients have shown a preference for VR intervention over usual care strategies to manage distress and improve coping during cancer-related procedures (e.g., chemotherapy, lumbar puncture) [22,23,26,40,41].

The study results were also positive with respect to VR feasibility,

Table 1
. Sample characteristics

Socio-demographic, disease, treatment characteristics	(N = 30)
Child Age [Mean, SD]	11.09 (3.24)
'Younger' (i.e., 6–12)	23 (77)
'Older' (i.e., 13–18)	7 (23)
Sex [n, %]	
Male	19 (63.3)
Female	11 (36.7)
Country of birth [n, %]	
Australia	30 (100)
Other	0 (0)
Disease type [n, %]	
Brain tumor/CNS	13 (43)
Leukemia	3 (10)
Lymphoma	3 (10)
Bone	4 (13)
Soft tissue	6 (20)
Germ cell	1 (3)
Location of treatment	
Neuro	18 (64.3)
Head & Neck	1 (3.6)
Chest	5 (17.9)
Abdomen	1 (3.6)
Pelvis	2 (7.1)
Extremities	1 (3.36)
Not reported	2
Treatment (immobilization used [n, %])*	
Mask	23 (76.7)
Body cradle	10 (33.3)
No intervention	1
Radiation Therapy Regime [Mean, SD, range]	
Number of fractions	23.5+/-9.1 (2–33)
Radiation dose (Gy)	43.2+/-16.2 (14.4–59.4)
Parent sex	
Female	13 (46)
Male	15 (54)
Not reported	2
Parental marital status	
Single	3 (11%)
Married/defacto	23 (85%)
Separated/divorced/widowed	1 (4%)
Not reported	2
Parental employment	
Full time	14 (52%)
Part time/ Casual	7 (26%)
Not currently employed/Home duties	6 (22%)
Not reported	2
Parental education	
Did not complete high school	4 (14%)
Completed high school/trade/certificate/diploma	17 (61%)
Completed tertiary education	
Not reported	7 (25%)
	2

Note: *Some patients utilise both a mask and cradle for their radiation therapy. These patients are shown the VR experiences of a mask patient only.

Table 2
. Child-reported simulator sickness in VR condition, time point 1 (N = 30)

Total scores for each sickness category	n (%)
Nausea	
0 (No symptoms)	30 (100)
1–2 (Reported symptoms)	0 (0)
3> (Simulator sickness indicated)	0 (0)
Occulomotor (i.e. eye strain)	
0 (No symptoms)	21 (70)
1–2(Reported symptoms)	9 (30)
3> (Simulator sickness indicated)	0 (0)
Disorientation (i.e. dizziness)	
No symptoms	27 (90)
1–2 (Reported symptoms)	3 (10)
3> (Simulator sickness indicated)	0 (0)

Note. A total score of 3 or more for any category indicates the presence of simulator sickness within that category

Table 3
. Parent perspectives on the acceptability of VR intervention in paediatric oncology radiation settings.

	Main theme	Illustrative quotes
Perceived benefits *(What did you like most?)*	Procedural knowledge/literacy	*It was a good insight into the procedure* *It was great to be able see what was going to happen and the surroundings* *(My child) was able to see what would happen exactly* *We were able to see what will happen* *Easily explained what is happening* *It gave my son the experience of his treatment prior to actually receiving it.* *Visual understanding* *Gave me a great understanding* *Helpful in understanding what's to be expected with treatment*
	Knowledge sharing	*Gave everyone in our family a good understanding of what my child will be going through* *Others to be able to see what (my child) has to go through* *Being able to use it to explain to others what would be happening in (my child's) treatment* *(My child) liked showing family what she is going to be doing* *I thought it as a great way of showing friends and family also what was going to happen.*
	Anticipatory/ procedural anxiety	*If the video truly shows what the experience will be like, this could be a powerful educational tool to put children (and their parents) at ease.* *I think it made the difference of him being calm and avoiding a GA.* *I think this may have been the key in avoiding a GA for the duration of his treatment. It took away any anxieties of the unknown in a setting which could have been very confronting. I think this is an incredible non-medical intervention that has helped make my son unafraid of the radiotherapy.*
Perceived concerns *(What did you like least?)*	Comfort and fit	*Too bulky for little kids* *Slight discomfort in wearing the mask, also mask was fogging up a little*
	Child-friendly language	*A bit complex to understand the prompts*
	Reliability	*Was sometimes a bit glitchy* *It cutting out and having to starting over* *The lenses fog easily* *We were unable to operate the VR at home*
	Accuracy and age-appropriateness	*It seems like the technology was more aimed at younger children as opposed to teenagers as the planning video did not truly reflect my child's actual experience, eg my child was asked to remove her clothes (this was my child's first question; child in video had clothes on), my child had marks drawn on her body (nothing like this shown on the video).* *For (my child)'s age (male, 8 years), would be better as a video rather than 3D I think*
Additional comments/ opinions	Home use	*We're thankful for the use of the VR headset and the trust that the hospital placed in us to be in possession of their equipment*

Table 4
. Influence of the VR intervention on children's procedural knowledge (health literacy), and child and parent anxiety when delivered prior to radiation therapy procedures.

Treatment phase	Phase 1 CT Simulation		Phase 2 Radiation Therapy			
VR intervention	*T1*	*T2*	*T3*	*T4*	*T5*	Pw comparisons
	Pre-VR CT	*Post-VR CT*	*Pre-VR RAD*	*Post-VR RAD*	*Post-VR-home RAD*	
Measures						
Child Health literacy						
For CT simulation	2.52(0.3)	4.96(0.26)	-	-	-	T1 < T2 ($p < .001$)
For Radiation	-	-	3.1(0.36)	4.52(0.45)	4.71(0.52)	T3 < T4 ($p < .001$); T3 < T5 ($p < .01$)
Child anxiety (VAS)						
Self-report	26.32(3.79)	21.08(3.88)	-	-	31.29(5.39)	T2 < T5 ($p = 0.01$)
Parent-proxy	39.97(3.34)	31.0 (3.66)	-	-	32.25(3.76)	T1 > T2 ($p = 0.001$)
Parent anxiety (VAS)	42.7(4.06)	33.96(4.78)	-	-	38.54(4.62)	T1 > T2 ($p = 0.28$)

Note: VR CT = VR simulation of CT simulation procedure; VR RAD = VR simulation of RT treatment appointment; VAS = visual analogue scale; Pw = pairwise comparison; Linear regression analysis (with cluster robust variance estimator) performed, with a $p < 0.05$ deemed statistically significant.
NB: Child Health Literacy scores are based on number of key CT Simulation and Radiation events recalled before and after watching respective VR interventions (refer to Supplementary S4). Anxiety scores were captured on a Visual Analogue Scale (VAS) on a Scale of 0 (No Anxiety) to 100 (Extremely Anxious) (refer to Supplementary S5-7).

with clinical radiation therapists highly rating child compliance during RT procedures, supporting the potential clinical utility of VR exposure as a tool to support patients to prepare for RT without GA. These findings align with previous investigations on the feasibility of VR exposure in practice, with one prior study reporting VR exposure as '*easy to use*', '*helpful*' and '*enjoyable*' in supporting extremely anxious patients as young as 4 years to undergo awake MRI scans[28], while another study found VR exposure to be associated with reduced procedure times, need for parental presence and repeat procedures in patients, aged 4 – 8 years, undergoing chest radiography[29]. Taken together, these findings provide emerging evidence for the role of VR exposure in supporting young and/or anxious patients to successfully undergo potentially frightening medical treatments without sedation. Similarly, parents reported positive attitudes towards the VR intervention, and in particular described the benefits of enhanced knowledge about their child's procedure and the opportunity of a shared experience gained through virtual simulation. Encouragingly, parents perceived direct benefit with respect to reducing anticipatory/ procedural anxiety, a finding consistent with other recent VR studies[26,28,29,31].

Concerns remain regarding the safety of VR, especially in younger children and vulnerable groups[26,42]. Interestingly, no safety issues were raised by study participants, although this has been evident in previous studies and can negatively influence the success of VR adoption in clinical practice[26,42]. In the current study, total time in VR was limited to 4 – 7 min, similar to the maximum exposure time used by previous studies[28,29,31–34]and is in line with current recommendations that aim to protect younger children from any adverse effects[20]. Overall, only mild cases of eyestrain or dizziness and no nausea from VR use were reported by patients, consistent with the very mild or infrequent side effects observed in other VR distraction studies with pediatric hospitalized patients[26,40,43–45] and VR exposure with pediatric patients[28].

Regarding efficacy, several beneficial effects of the VR intervention were found. First, reductions in child and parent pre-treatment anxiety levels were observed following VR exposure to CT Simulation (i.e., VR CT intervention) and 29 out of 30 patients proceeded to their actual CT Simulation appointment without GA. On the day of RT commencement, parent-report of children's anxiety and parent anxiety demonstrated lowered anxiety was maintained from Phase 1 (CT Simulation) and likewise, all but one patient underwent their first RT treatment without GA. We did observe an increase in children's self-reported pre-treatment anxiety from baseline on the day of RT commencement. As treatment becomes 'real' for the patient there is an expected level of anticipatory anxiety, however the fact that all but one child proceeded to their first RT treatment without pharmacological intervention was an important clinical outcome, indicative of adaptive coping despite increased arousal, and endorsed by parent and radiation therapist's observation of the child. Given persistently high rates of distress among pediatric patients undergoing RT [2–6], our results suggest pre-treatment VR exposure may be used to support children's adjustment to RT procedures.

A notable finding in this study, was the significant improvement in children's health literacy, with patients' showing increased knowledge of both CT simulation and RT treatment procedures following VR intervention. These findings validate previous predictions that the effect of Immersive VR exposure on preoperative or preprocedural anxiety may be influenced by an increase in patients' knowledge, in addition to familiarity with treatment environment (e.g. operating theatre, machines, equipment) and processes [28,29,33,34] so that they may feel more confident and positive when approach their upcoming procedure. Furthermore, our results suggest VR may play an important role in reducing GA use. Children represent a particularly sensitive patient group in RT settings, in which there is often a need for GA to ensure compliance rather than pain control [4,7]. Through effective use of preparation resources, anesthesia rates may be reduced [6,46]. In this study, 29 of 30 patients were able to tolerate CT simulation and initial RT treatment without GA after Immersive VR intervention, highlighting the benefits of this engaging, and novel technique for educating children about each step of their RT journey. RT under GA adds risk and significant expense to a procedure. In this setting, the VR intervention may also be used during the anesthetic pre-assessment process to guide clinical decisions regarding whether an awake RT is achievable based on patients' reactions to realistic virtual procedures.

Study limitations and future directions

There are several limitations to this pilot project. First, while use of randomized controlled trials is the preferred method of testing effectiveness of new interventions, it was important to first establish feasibility and safety with utilizing VR in this setting. Future studies should continue to document adverse events related to VR-use to establish feasibility and safety, however determining VR effectiveness in real clinical settings, particularly in relation to procedural anxiety and GA outcomes, will be improved through controlled designs. Second, only 30 patients could be recruited during the study period. Post-hoc evaluation of the participant flow highlighted a large cohort of patients excluded due to age (i.e., 24 under 6 years of age). Of this excluded cohort, 14 patients were aged 4–6 years old and ten required a GA for their RT treatment. In an equivalent PMCC cohort in the 18 months preceding study commencement, 10 out of 16 patients aged 4–6 years also required GA. We therefore recommend as an important next step that future studies consider widening inclusion criteria to trial VR with 4 and 5 year olds, where there is greatest need to reduce sedation rates compared with older age groups [46], and potentially an opportunity for high

impact results in terms of reducing healthcare costs.

Conclusion

Current results suggest that patients, parents and radiation therapists demonstrated a highly feasible and acceptable VR intervention, with positive effects of VR exposure on children and parent's anxiety and procedural-related distress, child procedural heath literacy and subsequent compliance.. Furthermore, VR shows promise as an effective preparatory resource to improve distress management and reduce GA use in the pediatric RT setting. The results of this study will inform future improvements in the VR intervention in preparation for a randomized controlled trial to assess efficacy in reducing GA requirements.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethical standards: The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tipsro.2021.06.001.

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