PharmacoEconomics - Open
https://doi.org/10.1007/s41669-023-00409-y

ORIGINAL RESEARCH ARTICLE

Economic Evaluation Comparing Virtual Reality with Child Life Programming for Non-sedated Pediatric Medical Imaging: A Cost-Consequence Analysis

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Accepted: 14 March 2023

Abstract

Introduction Effective preparation of children for hospital procedures, including non-sedated medical imaging, is an important clinical issue. This study aimed to assess the costs and consequences (effects) of preparing pediatric patients using two methods of delivering preparation for a scheduled magnetic resonance image (MRI)—virtual reality (VR-MRI) and a certified Child Life Program (CLP).

Methods A cost-consequence analysis (CCA) was performed using a societal perspective in Canada. The CCA catalogs a wide range of costs and consequences of VR-MRI compared with a CLP. The evaluation uses data from a prior randomized clinical trial evaluating VR and a CLP in a simulated trial. The economic evaluation encompassed health-related effects, including anxiety, safety and adverse events, and non-health effects, including preparation time, displaced time from usual activities, workload capacity, patient-specific adaptation, administrative burden, and user-experience metrics. The costs have been categorized into hospital operational costs, travel costs, other patient costs, and societal costs.

Results VR-MRI has similar benefits to the CLP in managing anxiety, safety and adverse events, as well as converting patients to non-sedated medical imaging. Preparation time and patient-specific adaptation are in favor of the CLP, while displaced time from usual activities, potential workload capacity, and administrative burden are in favor of VR-MRI. Both programs rank favorably in terms of user experience. The hospital operational costs ranged in Canadian dollars (CAN$) from CAN$32.07 for the CLP to between CAN$107.37 and CAN$129.73 for VR-MRI. Travel costs ranged from CAN$50.58 to CAN$2365.18 depending on travel distance for the CLP, and CAN$0 for VR-MRI. Other patient costs involved caregiver time off, and ranged from CAN$190.69 to CAN$$1144.16 for the CLP and CAN$47.67 for VR-MRI. The total cost for the CLP ranged from CAN$315.16 (CAN$277.91–$426.64) to CAN$3843.41 (CAN$3196.59–$4849.91) per patient depending on travel distance and amount of administrative support required, while VR-MRI preparation ranged from CAN$178.30 (CAN$178.20–$188.76) to CAN$283.85 (CAN$283.71–$298.40) per patient. For every instance where patient travel to visit a Certified Child Life Specialist (CCLS) onsite was replaced with VR-MRI, between CAN$119.01 and CAN$3364.62 total costs could be saved per patient.

Conclusions While it is neither feasible nor appropriate to replace all preparation with VR, using VR to reach children who cannot otherwise visit the CLP onsite could increase access to quality preparation, and using VR in place of the CLP where clinically indicated could reduce the overall costs for patients, the hospital, and society. Our CCA gives decision makers a cost analysis and the relevant effects of each preparation program so they can value the VR and CLP programs more broadly within the potential health and non-health outcomes of pediatric patients scheduled for MRI at their facilities.

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Key Points for Decision Makers

Using virtual reality preparation for magnetic resonance imaging (VR-MRI) to reach children who cannot otherwise visit a Child Life Program (CLP) onsite could increase access to quality preparation materials, especially in situations where families experience barriers to accessing preparation because of high travel costs, displacement from usual activities, and hospital waitlists.

In situations where VR-MRI is clinically indicated, the total cost savings of replacing an onsite visit to the CLP with remote VR-MRI is between CAN$119.01 and CAN$3364.62 per patient.

1 Introduction

1.1 Background

Magnetic resonance imaging (MRI) is a type of non-invasive medical imaging that creates detailed images of the organs and tissues required for diagnosing or monitoring treatment for various conditions; however, the procedure requires patients to hold still for long periods of time, which can be problematic for obtaining diagnostic-quality MRIs in pediatric populations. The unfamiliar equipment, tight enclosure, and loud noises can induce psychological and physiological distress in up to 75% of patients [1]. Sedation or general anesthesia is commonly used to get patients through imaging without difficulty. Although sedation has become common practice, it has been linked to adverse events leading to significant morbidity and mortality, prolonged recovery, and several delayed adverse effects [2, 3]. Aside from the increased risk to the patient, sedation and anesthesia can lead to additional resource requirements, system impacts, and costs of care that are reported to be 3.24–9.56 times higher for sedated patients [4]. Alternative methods of preparing children for MRI exist and can decrease the frequency of sedation by up to 34.6% [5, 6].

At British Columbia Children's Hospital (BCCH) in Canada, > 4500 pediatric patients undergo MRI each year, with approximately 45% of patients requiring sedation. In the 2017/2018 fiscal year, the waitlist for sedated MRI reached a significant point where some patients were forecasted to endure a wait of over 1 year for their appointments. To address this, the hospital launched a coordinated strategy that included increased operational capacity for medical imaging and funding for clinical and support services. Certified Child Life Specialists (CCLS) are among these resources and are trained to prepare patients and families for procedures. CCLS aim to reduce the need for procedural sedation through education, training, and exposure therapy techniques involving simulated procedures and therapeutic play. Workshops or programs delivered by CCLS have been implemented in over 400 North American healthcare settings [7] and are considered a key contributing factor in enabling some patients to undergo imaging without sedation where it may otherwise have been indicated to address high preprocedural anxiety and non-compliant behaviors [8, 9].

The Child Life Program (CLP) at our hospital uses a replica of an MRI unit to orientate and practice the process with patients before the imaging procedure. This method has been documented in the literature by other investigators [6]. However, capacity limitations still exist and there are socioeconomic costs and logistical considerations of only having these units available onsite at tertiary care facilities. The coronavirus disease 2019 (COVID-19) pandemic also introduced additional barriers to accessing healthcare services, particularly for non-critical or indirect clinical activities, such as preparatory activities. Furthermore, as process and practice standards evolved during the pandemic responses, the efficiency was reduced due to added infection control requirements and the additional accommodations put in place to ensure individual comfort levels of both staff and patients [10]. Virtual reality (VR) is one tool that can be used to help educate patients and their families about medical imaging and simulate the experience of being scanned without coming to the hospital for onsite preparation [11–13]. VR refers to a simulated three-dimensional environment that enables end users to explore and interact with virtual surroundings in a way that approximates reality through artificial sensory inputs. Although the applications of VR in hospital settings are promising, to our knowledge there have been no economic analyses evaluating the costs and benefits of using this technology for medical imaging preparation.

1.2 Reported Outcomes

In a recent randomized clinical trial (RCT) that included 84 participants, we compared the effectiveness of our VR-based simulation application (app) [VR-MRI] with a standard preparatory manual and a hospital-based certified CLP on success and anxiety during a simulated pediatric MRI scan [13]. There were no clinically significant differences between the groups in terms of success during the MRI simulation or the children's reported anxiety at any timepoint [13].

We also compared the caregiver's reported anxiety, procedural data, caregiver usability, satisfaction, and fun. There were no differences found in ease of use, ease of learning, and usefulness between the groups; however, caregivers reported being significantly more satisfied with the VR-MRI app and the CLP than the manual [13]. Children reported the most satisfaction with the CLP [13]. There were no differences in how much fun the preparation materials were perceived to be [13]. The findings suggest that VR had outcomes comparable with in-person preparatory programs and could be a viable option for improving access to preprocedural preparation [13].

1.3 Objectives

The goal of this study was to assess the costs and consequences (effects) of preparing pediatric patients using two methods of delivering preparation to children scheduled for an MRI—VR-MRI and a certified CLP. The objective was relevant for management and clinical practice decisions because finding effective solutions for patients with geographical barriers and lower socioeconomic status could reduce sedation rates, generate cost savings, and improve hospital efficiency.

2 Methods

This study was a cost-consequence analysis (CCA) of the VR-MRI and CLP patient preparation methods for pediatric MRI, and was approved by the University of British Columbia Children's and Women's Research Ethics Board (#H19-00371). All costs are reported in 2022 Canadian dollars (CAN$). Given the results of our prior RCT, we have assumed that both VR-MRI and the CLP perform similarly in preparing children aged 4–13 years for medical imaging [13]. This study followed the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement [14, 15].

2.1 Setting and Location

BCCH is the province's leading teaching and research facility for child health and provides expert health care for the most seriously ill or injured children from across British Columbia, Canada. Historically, patients who require medical imaging have had the option of having their medical images completed with or without sedation. At BCCH, children under the age of 8 years who wish to have a non-sedated MRI must pass an MRI simulator assessment with a CCLS, otherwise they are recommended for a sedated MRI. VR provides an alternative option for patients limited by socioeconomic or geographical barriers to access standardized experiential preparation programming. VR is proposed here to be incorporated as part of routine care and provided by the CLP. The same program provides preparation programming one-on-one with children onsite.

2.2 Virtual Reality (VR-MRI)

VR-MRI is a custom-developed VR-based simulator comprised of a smartphone, headphones, and head-mounted display that introduces patients to the hospital and MRI procedures. The experience involves completing a real-time feedback training game and is described in detail within our prior publication [16]. VR-MRI can be administered at home by patients and families themselves, and VR-MRI equipment (e.g., headsets, hygiene supplies) can be ordered online and packaged/shipped from the hospital with instructions for use.

2.3 Child Life Program

During a CLP consultation, CCLS make targeted efforts to reduce the need for procedural sedation through training and exposure therapy techniques involving simulated procedures and therapeutic play. The CLP at our hospital uses a replica of an MRI unit to orientate and practice the process with patients before the imaging procedure. The hospital also offers physical materials such as preparatory manuals and telephone or email consultations as supplements to orient patients. At the real medical imaging appointment, our MRI machines are tailored to pediatric populations by being equipped with televisions so that the patient can be distracted by watching a movie during their scan. In terms of the process for qualifying for the CLP, the MRI technologist screens patients for CLP suitability. Exclusion criteria may include, for example, severe neurodevelopmental delay or inability to communicate verbally. If suitable, a CLP appointment is scheduled separately from the imaging appointment. In the case of patients who travel from afar, a CLP appointment is booked back-to-back with the medical image. A back-up sedated imaging slot is then booked the next day to account for if the patient fails the CLP assessment or the non-sedated medical image attempt. It is important to note that children are sometimes referred to our hospital to complete their scans even when medical imaging is available at a more convenient location because of the added support our hospital provides to pediatric patients.

2.4 Cost-Consequence Analysis

Costs were estimated from a societal perspective. The costs and outcomes for VR-MRI and the CLP were calculated and compared using CCA principles. The CCA approach is recommended as an initial economic evaluation of emerging digital health products by several leading bodies, including the UK Government's Department of Health and Social

Care [17]. We did not include preparation with the standard preparatory manual from the original study for two reasons. First, in practice, the manual is not used to evaluate performance or decide the eligibility for a non-sedated MRI. Second, in our prior work, we found the manual increased anxiety in caregivers [13], which was in line with previous investigations that found preparation manuals to sometimes worsen anxiety-related outcomes [6, 18]. Costs were estimated from a societal perspective to result in optimal resource allocation in decision making and also support an informed public discussion for where VR-MRI provides value to families.

A CCA method was selected because VR interventions in health have several health and non-health effects. The method enabled us to include expanded consequence analyses, such as user experience, travel and transportation time. Our CCA gives decision makers a cost analysis and the relevant effects of each preparation program. Health systems leaders are particularly interested in the impact of VR on reducing sedation rates, and this presentation format will enable independent conclusions to be drawn, rather than other methods where calculations result in a single final cost and outcome number.

Effectiveness data were obtained from a single study that conducted an RCT, evaluating three methods of preparing children for a simulated non-sedated MRI [16]. This is the best study to use because, to our knowledge, no other research has been conducted to date comparing the effectiveness of VR-based preparation with a CLP. However, the study makes some assumptions based on preliminary findings, including that the results from the simulated trial transfer to the real world, that both programs are equivalent in converting children from a sedated to a non-sedated MRI, and that both programs are equivalent in managing anxiety among parents and children.

The time horizon was 8 months and discounting was not used for this analysis. The results are presented based on the number of patients who received a consultation with Child Life in 2020/2021 at our hospital, which more realistically represents preparation programs for MRI.

2.5 Costs

Implementation costs were estimated by identifying the relevant direct costs for VR-MRI and the CLP. Hospital operational costs, travel costs, patient costs, and societal costs were considered (Table 1).

2.5.1 Hospital Operational Costs

The hospital's operational costs were estimated by identifying the relevant direct and non-direct operational costs for running the programs, including human resources, equipment leases and licenses, hardware, and consumables. Start-up costs associated with capital and infrastructure investments related to hospital space, facilities upgrades, procurement, installation, and application development are already in place for both programs, therefore these costs were excluded from all analyses.

Costs Related to Child Life Programming: The costs of using the CLP were estimated using the CLS time required to prepare children for a medical image, and estimated using prior research [16] and average booking times administered by our hospital's CLP, then multiplied by the average hourly salary rate for a CCLS (CAN$35.94/h through the Provincial Health Services Authority as of March 2022). Additional administrative costs are expected; however, in the absence of additional administrative overhead data and documentation in the literature, we have generated hypothetical scenarios whereby administrative costs add 15%, 30%, 45%, and 60% of costs to the base costs calculated from the RCT. No software subscriptions are required to administer the CLP. Consumables include earplugs and personal protective equipment (e.g., headphone covers, hairnets).

Costs Related to VR-MRI Programming: The costs of using VR were estimated using caregiver time required to supervise children using VR-MRI. These costs were estimated using prior research [16], then multiplied by the average hourly wage in British Columbia (CAN$47.59/h as of February 2023) and average hourly wage in the Yukon (CAN$56.77/h as of February 2023), as reported by the Government of Canada [19]. The weighted averages were estimated to be CAN$47.67 based on population densities. Shipping rates were estimated using population statistics from the Government of British Columbia [20] and the Yukon Government [21] Canada Post shipping rates. Due to the nature of VR preparation, more administration time will typically be required for preparation and troubleshooting. Additionally, the patient may require someone to talk to if there are any questions. These costs are not documented in the literature. In the absense of data, we have generated hypothetical scenarios whereby administrative costs add 15%, 30%, 45% and 60% of costs to the base costs calulcated from the RCT. No software subscriptions are required to administer VR-MRI as the product was developed in-house. VR hardware was costed on a per unit basis, assuming deployment of a MERGE VR headset. It is expected that patients would use their own headphones and smartphones, as 88.1% of Canadians have a smartphone. No consumables are required for VR-MRI deployment at home.

The program development costs were not included in the analysis for either program since there is considerable variation beyond that reasonably expected in terms of how the development of each program originated, was funded, and was ultimately supported in the introduction to clinical care. Development costs of any program can constitute a

Table 1 Resources and costs (CAN$) included in the analysis

Resource	Child life program		Virtual reality (VR-MRI)		Source
	Unit	Cost (CAN$)	Unit	Cost (CAN$)	
Hospital operational costs					
Certified Child Life Specialist	1 h	$35.94 ($31.99–$39.98)			Provincial Health Services Authority – BC Children's Hospital Child Life Specialist
Consumables					
Earplugs	200 pieces	$27.99			Amazon.ca
OR caps	100 pieces	$12.86			Amazon.ca
Headphone caps	100 pieces	$34.10			Amazon.ca
MERGE VR headsets			1 headset	$61.42	MERGE Labs Inc.
Shipping rates					
Zone 1 (<40 km)			1 package	45.95	Canada Post
Zones 2, 3, 4 and 5 (40 km+)			1 package	68.31	Canada Post
Travel costs					
Parking	24 h	$14.25			BC Children's and Women's Hospital Parking Meter
Transportation (two-way)					
Zone 1 (<40 km)	$0.56/km	$28.53[a] ($0–$44.80)			Government of Canada Travel Assistance Program
Zone 2 (40–80 km)	$0.56/km	$66.10[a] ($44.80–$89.60)			Government of Canada Travel Assistance Program
Zone 3 (80–200 km)	$0.56/km	$135.45[a] ($89.60–$224.00)			Government of Canada Travel Assistance Program
Zone 4 (200–700 km)	$0.56/km	$496.59[a] ($224.00–$784.00)			Government of Canada Travel Assistance Program
Zone 5 (700 km+)	$0.56/km	$1275.23[a] ($784.00–$1657.60)			Government of Canada Travel Assistance Program
Accommodation (standard room, 1 adult + 1 child)	1 night	$319.00[c] ($244–$459)			Holiday Inn Vancouver Centre (Broadway) website
Meals	Per diem per day	$69.00			Government of Canada Travel Assistance Program
Childcare (2.5 extra children/family)	1 child	$10.00[b] ($10.00–$61.58)			Canadian Centre for Policy Alternatives, child care fees in Canada 2019
Patient costs					
Caregiver time off work	1 h	$47.67[a] ($47.59–$56.77)	1 h	$47.67[a] ($47.59–$56.77)	Statistics Canada 2019

CAN$ Canadian dollars, *VR* virtual reality, *MRI* magnetic resonance imaging

[a]Costs are estimated based on weighted population distributions from city centers. Estimates assume that 53% of the patient population will come from zone 1, 11% from zone 2, 15% from zone 3, 14% from zone 4, and 6% from zone 5

[b]Variation accounts for private versus public costs

[c]Median amount based on random selection of dates throughout the year

substantial component of costs and should be considered by decision makers who wish to develop these new programs and services.

2.5.2 Travel Costs

Travel costs were estimated using the non-emergency medical specialist reimbursement for travel expenses outside of the community using the Canadian Government fee structure for transportation, accommodation, meals, childcare, and parking. All costs were doubled to account for children requiring a caregiver to accompany them.

Transportation and Parking: The distance required to travel to the hospital was estimated using driving distance from Map Developers (https://www.mapdevelopers.com). The driving distances were estimated from major cities in British Columbia and the Yukon to BCCH. The transportation costs for people who travel were estimated at CAN$0.56/km from the Canadian Government's Travel Assistance Program. Parking costs were estimated using our hospital's parking meters (CAN$14.25/day).

Accommodation: For accommodation, we used the average nightly rate at the Holiday Inn Vancouver Centre (Broadway), near the hospital (CAN$319/night, obtained on 13 June 2022).

Meals: The costs of meals were estimated using the reimbursement rates of the Canadian Government Travel Assistance Program, which allows for a maximum of CAN$69/day.

Childcare: Childcare costs were included for 0.79 children, as Canada's average family size with children in 2020, according to Statistics Canada, was 1.79 children/family [22]. We used this rate, adjusted to account for the residual number of children/family, assuming childcare costs would only be incurred for those children not receiving medical care. The rate for childcare was estimated to be CAN$10/child/day using the set-fees guide reported by the Canadian Centre for Policy Alternatives [23].

2.5.3 Other Patient Costs

Loss of income and/or leisure time was included and was measured using a weighted average of the average hourly wage in British Columbia (CAN$47.59/h as of February 2023) and average hourly wage in the Yukon (CAN$56.77/h as of February 2023), as reported by the Government of Canada [19]. The weighted averages were estimated to be CAN$47.67 based on population densities. This hourly rate was used to calculate income losses and/or loss of leisure time to attend preparation appointments. We assumed the accompanying caregiver would need between 1 and 3 days off work to attend an onsite appointment, depending on where they were located within the province.

2.6 Consequences

CCA enables the program intervention health and non-health consequences to be considered. These can be viewed as outcomes or benefits. The two preparation programs examined have many attributes that will be considered for the analysis. For the evaluation, we assumed from our prior research that sedation rates will be similar, irrespective of the method [16]. The direct health-related effects include anxiety, safety and adverse events; these will be presented from our prior research [16]. The non-health effects include time to prepare, time away from usual activities, program workload capacity, ability to adapt to patient's specific needs, and user experience metrics [16]. In the absence of estimates for the administrative burden associated with VR and the CLP, we approximated effects from the telehealth literature and in consultation with clinical staff [24]. The consequences are outlined in electronic supplementary File 1.

2.7 Analysis

Analysis and visualizations were conducted using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Total costs were estimated using location data to estimate variety for subgroups. Impacts were not distributed or adjusted across different individuals. To characterize uncertainty, we conducted sensitivity analyses using potential variations in costs for applicable variables (Table 1).

3 Results

3.1 Costs

The total base cost for the CLP ranged from CAN$241.75 (CAN$241.66–$370.99) to CAN$3542.02 (CAN$2895.20–$4548.52) per patient depending on travel distance, while VR-MRI preparation ranged from CAN$155.04 (CAN$154.96–$164.14) to CAN$177.40 (CAN$177.32–$186.50) per patient (Table 2). The hospital operational costs included CCLS time, consumables, VR headsets, and shipping rates, which ranged from CAN$32.68 for the CLP to between CAN$107.35 and CAN$129.73 for VR-MRI. The travel costs were between CAN$50.58 in zone 1 (<40 km) and CAN$2365.18 in zone 5 (+700 km) for the CLP, and CAN$0 for VR-MRI. Other patient costs involved caregiver time off and included CAN$190.69–$1144.16 for the CLP, and CAN$47.67 for VR-MRI. A visual representation is depicted in Fig. 1. Assuming minimum travel (<40 km) and hypothetical administrative costs in all scenarios (Table 2), VR-MRI was still the lowest cost.

Cost savings are most apparent when reviewing the travel costs. When including administrative scenarios, for every instance where patient travel to visit a CLP onsite was replaced with VR-MRI, between CAN$119.01 and CAN$3364.62 total costs could be saved per patient (Table 3). While it is neither feasible nor appropriate to replace all preparation with VR-MRI, using VR-MRI to reach children who cannot otherwise visit the CLP would increase access, and when VR-MRI is clinically indicated to replace the CLP, it can reduce the overall costs for patients, the hospital, and society.

Our scenario modeling for potential administrative costs suggests that even with only 15% of additional costs allocated for administration of the CLP and 60% of additional costs allocated to administration of VR-MRI, VR-MRI is still cost saving across all travel zones (Table 3).

3.2 Consequences

Consequences were gathered through the clinical trial, literature review, and consultations with health service providers. When comparing the consequences for each preparation type, the CLP was better able to mitigate adverse events, build rapport with patients, and adapt to patient's specific needs than VR-MRI (Table 4). VR-MRI had less overheads in terms of delivery with less time away from usual activities, being able to engage in preparation in any location, and having unlimited capacity for use (Tables 3, 4). With VR-MRI, a guardian is required to watch over the child since the headset blocks perception of the actual surroundings. The CLP and VR-MRI preparation programs were similar in terms of effects on patient anxiety, caregiver anxiety, usefulness, ease of use, ease of learning, patient satisfaction, caregiver satisfaction, fun factor, and recommendation to peers (Table 4). Consequences were reviewed with specialists from our CLP.

4 Discussion

4.1 Summary of Findings

VR-MRI can provide cost savings to patients and families attending, and hospitals providing, medical imaging preparation programs for children who wish to attempt a non-sedated MRI but have additional burdens associated with travel, childcare, and finding time to attend a scheduled appointment onsite with the CLP. Although the benefits of VR are clear from this analysis, cost effectiveness will likely vary by context and will reflect the successful integration of the VR program into the workflow of the CLP in which they operate. A successful VR-based program requires appropriate infrastructure, trained staff, and revised processes to support the service (such as referral processes, administrative and technical support, shipping technology, documentation, and billing). Introducing VR also requires effective change management strategies to assist with embedding VR into operations and administration methods. These strategies need to support both clinical and administrative staff, as well as patients and families involved in the VR program.

Even when VR may be clinically appropriate, some patients or providers may still prefer seeing a CCLS onsite. Common problems with the adoption of new technology include being unaware of the service offered, distrust of the internet and technology, poor technology literacy, and preference for in-person appointments [25]. There are some reports indicating that it is easier to build a connection with patients by meeting in person and this is considered very important for particular patient populations [26]; however, our analysis shows that the costs and socioeconomic impacts of traveling for care can be particularly burdensome for patients and their families. Moreover, CCLS and booking staff have workload capacity limitations that can contribute to longer wait times and higher sedation rates. In these situations, VR-MRI provides a viable alternative.

There are no studies that explore the substitution of the CLP with VR in real-life clinical settings; however, our previous study evaluated the use of VR-MRI compared with the CLP in a simulated setting and found that VR-MRI performs similarly to the CLP [16]. VR has also been found to be an effective, acceptable, and safe way to educate patients and their families to learn about medical imaging and simulate the experience of actually being scanned by other investigators [11–13]. There is a need to apply VR-based preparation to real-world needs and settings, and document practitioners' use and referral patterns during regular use. There are no studies that explore the substitution of the CLP with VR in real-life clinical settings; however, our previous study evaluated the use of VR-MRI compared with the CLP in a simulated setting and found that VR-MRI performs similarly to the CLP [16]. VR has also been found to be an effective, acceptable, and safe way to educate patients and their families to learn about medical imaging and simulate the experience of actually being scanned by other investigators [11–13]. There is a need to apply VR-based preparation to real-world needs and settings, and document practitioners' use and referral patterns during regular use.

Lessons from the implementation of other technologies in telemedicine suggest we need to pay particular attention to how VR-based programming can be integrated into busy practice workflows [27]. One hurdle to overcome will include effectively triaging patients who use VR versus the CLP [28] and identifying workflows for how their eligibility for a non-sedated scan will be determined. If medical imaging technologists and the CLP are no longer involved in the appointment process for VR, systems need to be in place to triage patients and stratify their risks for both using VR and completing referral to the non-sedated scan accurately. Some VR programs and hardware are incompatible with certain medical conditions, such as epilepsy and certain medical devices, and consultation with a doctor may be required before safely using the program. Moreover, our prior research suggested that patient-reported outcomes related to readiness for the procedure may not be reliable

Table 2 Estimated costs per patient for preparation in each program (CAN$)

	Child Life Program		Virtual reality (VR-MRI)	
	Unit	Cost (CAN$)	Unit	Cost (CAN$)
Hospital operational costs				
Certified Child Life Specialist time	0.75 h	$32.07 ($28.55–$35.59)		
Consumables	1 set	$0.61		
VR headsets			1 device	$61.42
Shipping rates				
Zone 1 (<40 km)				$45.95
Zone 2 (40 km < 80 km)				$68.31
Zone 3 (80 km < 200 km)				$68.31
Zone 4 (200 km < 700 km)				$68.31
Zone 5 (700+ km)				$68.31
Travel costs				
Parking	24 h	$14.25		
Transportation				
Zone 1 (<40 km)	Per patient	$28.53 ($0–$44.80)		
Zone 2 (40 km < 80 km)	Per patient	$66.10 ($44.80–$89.60)		
Zone 3 (80 km < 200 km)	Per patient	$135.45 ($89.60–$224.00)		
Zone 4 (200 km < 700 km)	Per patient	$496.59 ($224.00–$784.00)		
Zone 5 (700+ km)	Per patient	$1275.23 ($784.00–$1657.60)		
Accommodation				
Zone 1 (<40 km)				
Zone 2 (40 km < 80 km)				
Zone 3 (80 km < 200 km)	2 nights	$638.00 ($488.00–$918.00)		
Zone 4 (200 km < 700 km)	2 nights	$638.00 ($488.00–$918.00)		
Zone 5 (700+ km)	2 nights	$638.00 ($488.00–$918.00)		
Meals (2 people)				
Zone 1 (<40 km)				
Zone 2 (40 km < 80 km)				
Zone 3 (80 km < 200 km)	2 nights	$414.00		
Zone 4 (200 km < 700 km)	2 nights	$414.00		
Zone 5 (700+ km)	2 nights	$414.00		
Childcare (0.79 extra children/family)				
Zone 1 (<40 km)	1 day	$7.90 ($7.90–$48.65)		
Zone 2 (40 km < 80 km)	1 day	$7.90 ($7.90–$48.65)		
Zone 3 (80 km < 200 km)	3 days	$23.70 ($23.70–$145.94)		
Zone 4 (200 km < 700 km)	3 days	$23.70 ($23.70–$145.94)		
Zone 5 (700+ km)	3 days	$23.70 ($23.70–$145.94)		

Table 2 (continued)

	Child Life Program		Virtual reality (VR-MRI)	
	Unit	Cost (CAN$)	Unit	Cost (CAN$)
Hospital operational costs				
Patient costs				
Caregiver time off work				
Zone 1 (<40 km)	4 h	$190.69 ($190.35–$227.09)	1 h	$47.67 ($47.59–$56.77)
Zone 2 (40 km < 80 km)	8 h	$381.39 ($380.70–$454.17)	1 h	$47.67 ($47.59–$56.77)
Zone 3 (80 km < 200 km)	24 h	$1144.16 ($1142.09–$1362.52)	1 h	$47.67 ($47.59–$56.77)
Zone 4 (200 km < 700 km)	24 h	$1144.16 ($1142.09–$1362.52)	1 h	$47.67 ($47.59–$56.77)
Zone 5 (700+ km)	24 h	$1144.16 ($1142.09–$1362.52)	1 h	$47.67 ($47.59–$56.77)
Total costs				
Zone 1 (<40 km)	1 patient	$241.75 ($241.66–$370.99)	1 patient	$155.04 ($154.96–$164.14)
Zone 2 (40 km < 80 km)	1 patient	$502.32 ($476.81–$642.88)	1 patient	$177.40 ($177.32–$186.50)
Zone 3 (80 km < 200 km)	1 patient	$2402.24 ($2200.80–$3114.92)	1 patient	$177.40 ($177.32–$186.50)
Zone 4 (200 km < 700 km)	1 patient	$2763.39 ($2355.20–$3674.92)	1 patient	$177.40 ($177.32–$186.50)
Zone 5 (700+ km)	1 patient	$3542.02 ($2895.20–$4548.52)	1 patient	$177.40 ($177.32–$186.50)

CAN$ Canadian dollars, *VR* virtual reality, *MRI* magnetic resonance imaging

[16]. VR programs are not currently funded by the healthcare system, which is an important factor for the adoption and growth of VR-based services, especially for publicly funded healthcare systems. However, this study suggests that a VR-based program could both reduce costs and address the community's unmet needs, especially in situations with capacity limitations onsite, and when there are higher burdens associated with travel to receive preparation.

4.2 Limitations

This study makes several assumptions. First, it assumes that the results from the simulated trial transfer to the real world. Simulated trials are not always good representations of what happens in real life. Second, it assumes that both programs are equivalent in converting children from a sedated to a non-sedated MRI. The RCT found no differences in outcomes between programs, but large confidence intervals are presented and an equivalency trial was not conducted [16]. Third, it assumes that both programs are equivalent in managing anxiety for both parents and children. The RCT found no differences, but children in the study were, on average, anxiety-free to start, which is not an accurate representation of the actual clinical environment [16]. Decision making should consider future work that evaluates the real-world outcomes of VR in clinical scenarios.

This analysis was also dependent on various assumptions associated with hospital operations, travel, and patients, which have been outlined throughout. Cost comparisons between interventions would change if these costs were to increase significantly (e.g., if travel costs changed) or if the administrative burden of delivering the programs was different than what was estimated. Productivity losses could not be included and measured. The aggregated costs associated with missed work are complicated to estimate since the income of the person is also a society cost associated with the expenditure of the company employing that person. Our calculations could end up double-counting incomes and expenditures of interacting units. Productivity losses should be explored in future research.

We made administrative estimates based on the literature describing other technology-based programs [29], but VR could operate differently than telemedicine. One instance that could alter our results is in the case of patients who travel large distances. In these situations, a CLP appointment may be booked back-to-back with the medical image.

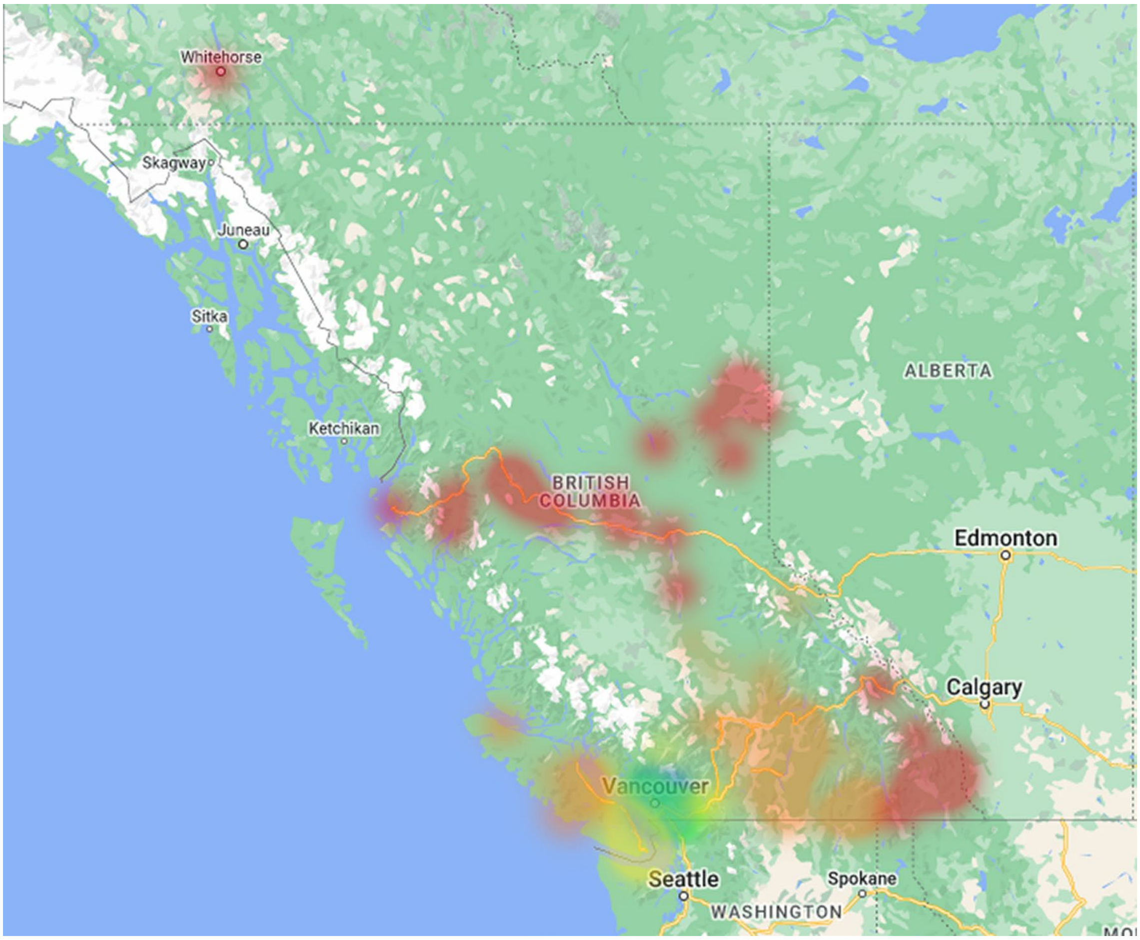

Fig. 1 Total costs (Canadian dollars) for Child Life Programming according to geographical region

A back-up sedated imaging slot is then booked the next day to account for whether the patient fails the CLP assessment or the non-sedated medical image attempt. The literature suggests that for maximum benefit, children should receive practice at least 5 days in advance of their procedure. If children are not given preparation until the day of their medical image when they live longer distances from the hospital, they may be unfairly disadvantaged in their preparation for medical imaging. Our modeling does not account for when patients bundle their travel appointments, nor does it account for losses due to vacancies when sedated appointments cannot be re-filled after a successful non-sedated image.

Costs will likely vary substantially by program components, application area, equipment used, and services provided. We could not find modeling associated with VR program implementation in any healthcare field. In an attempt to test potential hypotheses, we looked into the telemedicine literature, but there are limited studies in telemedicine that contain quantitative cost data. Furthermore, even when they include the data in their report, the investigators do not provide a breakdown cost category, which limits our ability to extrapolate findings for hypothetical scenarios [29]. We also estimated patient costs and societal costs based on the average income in British Columbia, which has a wide range within British Columbia.

5 Conclusion

The costs of administering the CLP were more than VR-MRI due to the associated travel costs and time away from usual activities. The use of VR cannot completely replace the need for child life specialist preparation; however, it may be appropriate and beneficial to provide VR-based programming for patients who need to travel long distances to a medical imaging facility or to increase the frequency, opportunity, and capacity for preprocedural preparation. VR-MRI could reduce the overall cost of providing preparation for non-sedated MRI to patients, which in turn may have positive impacts on the patient and hospital, including increasing the efficiency of medical imaging, increasing patient safety through reduced sedation rates, and reduced

Table 3 Potential administrative costing scenarios

Administrative costs	Child life program		Virtual reality (VR-MRI)	
	Unit	Cost (CAN$)	Unit	Cost (CAN$)
Scenario 1: 15% added administrative costs				
Zone 1 (<40 km)	1 patient	$315.16 ($277.91–$426.64)	1 patient	$178.30 ($178.20–$188.76)
Zone 2 (40 km < 80 km)	1 patient	$577.66 ($548.33–$739.31)	1 patient	$204.01 ($203.91–$214.48)
Zone 3 (80 km < 200 km)	1 patient	$2402.24 ($2276.15–$3190.27)	1 patient	$204.01 ($203.91–$214.48)
Zone 4 (200 km < 700 km)	1 patient	$2763.39 ($2410.55–$3750.27)	1 patient	$204.01 ($203.91–$214.48)
Zone 5 (700+ km)	1 patient	$3542.02 ($2970.55–$4623.87)	1 patient	$204.01 ($203.91–$214.48)
Scenario 2: 30% added administrative costs				
Zone 1 (<40 km)	1 patient	$356.27 ($314.16–$482.28)	1 patient	$201.56 ($201.44–$213.38)
Zone 2 (40 km < 80 km)	1 patient	$653.01 ($619.85–$835.74)	1 patient	$230.62 ($230.51–$242.45)
Zone 3 (80 km < 200 km)	1 patient	$2552.94 ($2351.50–$3265.62)	1 patient	$230.62 ($230.51–$242.45)
Zone 4 (200 km < 700 km)	1 patient	$2914.08 ($2485.90–$3825.62)	1 patient	$230.62 ($230.51–$242.45)
Zone 5 (700+ km)	1 patient	$3692.72 ($3045.90–$4699.22)	1 patient	$230.62 ($230.51–$242.45)
Scenario 3: 45% added administrative costs				
Zone 1 (<40 km)	1 patient	$397.38 ($350.41–$537.93)	1 patient	$224.81 ($224.69–$238.01)
Zone 2 (40 km < 80 km)	1 patient	$728.36 ($691.37–$932.17)	1 patient	$257.24 ($256.11–$270.43)
Zone 3 (80 km < 200 km)	1 patient	$2628.29 ($2426.85–$3340.96)	1 patient	$257.24 ($256.11–$270.43)
Zone 4 (200 km < 700 km)	1 patient	$2989.43 ($2561.25–$3900.96)	1 patient	$257.24 ($256.11–$270.43)
Zone 5 (700+ km)	1 patient	$3768.07 ($3121.25–$4774.56)	1 patient	$257.24 ($256.11–$270.43)
Scenario 4: 60% added administrative costs				
Zone 1 (<40 km)	1 patient	$438.48 ($386.65–$593.58)	1 patient	$248.07 ($247.93–$262.63)
Zone 2 (40 km < 80 km)	1 patient	$803.71 ($762.89–$1028.60)	1 patient	$283.85 ($283.71–$298.40)
Zone 3 (80 km < 200 km)	1 patient	$2703.63 ($2502.19–$3416.31)	1 patient	$283.85 ($283.71–$298.40)
Zone 4 (200 km < 700 km)	1 patient	$3064.78 ($2636.59–$3976.31)	1 patient	$283.85 ($283.71–$298.40)
Zone 5 (700+ km)	1 patient	$3843.41 ($3196.59–$4849.91)	1 patient	$283.85 ($283.71–$298.40)

CAN$ Canadian dollars, *VR* virtual reality, *MRI* magnetic resonance imaging

Table 4 Consequences for preparation in each program (CAN$)

	Child life program	Virtual reality (VR-MRI)
Patient anxiety	Anxiety free	Anxiety free
Caregiver anxiety	Low anxiety	Low anxiety
Time to prepare	15.06 min (SD 3.32, 95% CI 13.82–16.30)	22.05 min (SD 4.41, 95% CI 20.40–23.69)
Patient and caregiver time away from usual activities	1.5 h–3 days	0.75 h
Workload capacity	Limited	Not limited
Ability to adapt to patient's specific needs	High	Moderate
Ability to build rapport with direct clinical care team	Yes	No
Environment familiarization of hospital	High	Moderate
Useful	Yes	Yes
Easy to use	Yes	Yes
Easy to learn	Yes	Yes
Patient satisfaction	90% satisfied (IQR 23, SD 12)	80% satisfied (IQR 22, SD 27)
Caregiver satisfaction	Yes, satisfied	Yes, satisfied
Fun factor	Really good	Really good
Recommendation to peers	80% recommended	93% recommended
Adverse events	Mild	Mild

CAN$ Canadian dollars, *VR* virtual reality, *MRI* magnetic resonance imaging, *SD* standard deviation, *CI* confidence interval, *IQR* interquartile range

length of hospital stay and overall costs to the system. VR-MRI may also have other benefits for the patient and society as it reduces the time away from usual activities for both the patient and their caregiver. However, more information is needed on the effectiveness in practice and the implementation process to ensure effective adoption in real-world clinical settings, at scale.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41669-023-00409-y.

Declarations

Funding Dhayanand Deenadayalan was funded through the Mitacs Business Strategy Internship and BC Children's Hospital Foundation. No other funding was provided for this project.

Conflicts of interest John Jacob, Chelsea Stunden, Dhayanand Deenadayalan, and Luke Thomas have no conflicts of interest to declare.

Ethics approval This study was approved by the University of British Columbia Children's and Women's Research Ethics Board (#H19-00371).

Consent to participate Written informed consent was obtained from participants whose information was used in this study.

Consent for publication Written informed consent for publication was obtained from participants whose information was used in this study.

Availability of data Data used are referenced throughout. For additional access to data, please contact the corresponding author.

Code availability For access, please contact the corresponding author.

Author contributions JJ, LT, and CS conceived the study, researched the literature, and were involved in protocol development. CS and DD were involved in costing data collection. All authors were involved in data analysis and interpretation. CS developed the initial draft of the manuscript, with input from JJ and LT. All authors reviewed, edited, contributed to, and approved the final version of the manuscript. JJ provided the overall direction for the study and economic evaluation.

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