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Review Article

The use of virtual reality in patient education related to medical somatic treatment: A scoping review

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A B S T R A C T

Objective: To map the available evidence on the context, content and outcome of VR in patient education in situations related to preparation for medical somatic treatment.
Methods: A Scoping review. In October 2020, the Embase, CINAHL, MEDLINE and PsycINFO databases were searched with the terms 'Virtual Reality' and 'Patient Education'. The literature was synthesised and mapped with a narrative approach.
Results: 17 studies published between 2015 and 2020 were included in the qualitative synthesis.

VR was applied in (paediatric) surgery and radiation therapy treatment. VR interventions were heterogeneous regarding technical applications, context of implementation, guidance by healthcare professionals and integration in education sessions. Anxiety reduction was demonstrated significantly in some studies. Patients experienced VR education useful; it enhanced understanding, improved communication with healthcare professionals and encouraged treatment compliance.
Conclusions: The application of VR in patient education is a promising technology. Patients are highly satisfied and experience enhanced understanding. VR education was not effective in reducing all anxiety, pain and stress and improving preparedness for treatment.

Practice implications

It is important to develop VR interventions profoundly. The application of a methodological framework for VR development is recommended. Involve patients, educationalists and technology professionals in the development of technology interventions.

Contents

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1. Introduction

An increasing number of promising innovative technologies ensure the development of new treatments in healthcare [1]. Virtual Reality (VR) is one of these innovative technologies and is the subject of research in many areas of healthcare.

VR is a medium composed of interactive computer simulations that sense the participant's position and actions and replace feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation [2]. The users act as if they are physically there, experiencing virtual individuals or subjects as real [3].

In a learning environment, VR improves retention and recall in memory [4]. The VR experience becomes part of long-term memory due to patient involvement and personal relevance [5]. Although not everyone will agree, VR can be enjoyable. From an educational perspective, this is important; learning is easier if the experience is pleasant, which means a higher level of engagement and understanding [4].

In healthcare, VR is mainly used in the education and training of healthcare professionals [6–9]. VR also has the potential to be of added value in patient education but is relatively unexplored [9]. Patient education is the process of influencing patient behaviour and producing the changes in knowledge, attitudes and skills necessary to maintain or improve health [10]. In effective education, both cognitive and affective learning need to be stimulated. While cognitive learning is about gathering information and knowledge, affective learning is about attitude, satisfaction, emotional well-being [11], and the learner's beliefs, interests, attitudes and motivation [12]. Learning principles that promote patient education are interactivity and involve different senses to better remember the information [13]. VR can address these principles.

Although many VR publications in professional education are available, a comprehensive overview of VR in patient education related to the preparation for medical somatic treatment or procedure is lacking. To further develop VR interventions in patient education, the objective of this scoping review is to map the available evidence on the context, content and outcome of VR in patient education in situations related to preparation for medical somatic treatment. The following research questions have been formulated:

1. Why is VR applied in patient education?
2. What type of medical treatments apply VR in patient education?
3. How is VR applied in patient education?
4. What are the outcomes of VR in patient education?

2. Method

This scoping review maps existing published literature on this topic and is conducted according to the methodological framework for scoping studies [14,15]. This review adheres to the reporting guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [16].

An initial search of MEDLINE and CINAHL, using the terms 'virtual reality' and 'patient education', was undertaken followed by an analysis of the text words contained in the title and abstract. A search (October 5, 2020) using all identified keywords and derivates was undertaken in the Embase, CINAHL, MEDLINE and PsycINFO databases. No language or time restrictions were applied. A detailed overview of the search strategy is presented in appendix A. The reference lists of identified articles were searched for additional studies.

Studies were included if VR was the primary aspect of the intervention in patient education and patient education was applied prior to a medical somatic treatment. Both individual and group base education interventions were included. Experimental and non-experimental studies in peer-reviewed journals and dissertations/theses were included. Broad categories of outcomes were explored in this review: clinical outcomes, patient perceptions, knowledge and attitudes. Studies were excluded if they used nonimmersive VR [17], when the VR intervention was primarily focused on the healthcare professional, primarily focused on self-management or daily activities, or mainly focused on the developmental phase of the VR intervention. Letters, commentaries, editorials, conference abstracts and case studies were excluded.

Eligibility assessment was performed independently in a blinded standardised manner by two authors (SW and MvdL). Disagreements between reviewers were discussed and resolved by consensus. Agreement on screening title/abstract was acceptable with a Cohen's kappa of 0.98. The interrater reliability for full text screening was acceptable, with a Cohen's kappa of 0.92.

When needed authors were contacted for additional information of the studies. If only abstracts were available, full text articles were requested from the authors.

Data charting was conducted to summarise and to map the results [18] using a standardised data extraction sheet in Excel. Detailed information included basic study details such as author, title, journal, publication year, country of origin, aim and concepts of how VR was used in patient education. Methodological details of each study included setting, design, sample, intervention and comparator (if applicable), data collection, analysis and results. Data were verified for accuracy (SW). The final version of the charting form is included in appendix B.

The JBI Critical Appraisal Checklist for Randomised Controlled Trials (RCT), for Quasi-Experimental Studies and for Qualitative Research were used to measure risk of bias in the individual studies [19]. The items with equal weight can be evaluated as satisfactory (yes), nonsatisfactory (no), unclear or not applicable. Two items in the RCT checklist were omitted. Item 4 'Were participants blind to treatment assignment' and item 5 'Were those delivering treatment blind to treatment assignment?' as it is impossible to be blinded to wearing VR goggles or not. Two authors (SW and MvdL) independently evaluated the selected studies on their methodological quality. Disagreements were discussed and resolved by consensus.

Given the heterogeneity of studies, a narrative synthesis approach to collate, summarise, and map the literature was used. Initially, publications were grouped by setting, study design and study outcome depending on the research question to be answered. Quantitative data were converted to textual descriptions and visually supported and displayed in a tabular format.

3. Results

The literature search yielded 2 204 unique records. Based on the title and abstract, 39 records were included for full-text reading. Further, a cross-references search of included articles identified 12 additional references for full-text reading. After full-text reading of all eligible articles, 17 studies were included in the qualitative synthesis. The results of the search are presented in a PRISMA flow diagram (Fig. 1).

Research on VR in patient education was published between 2015 and 2020. All studies, except one [23], were conducted in Western countries. Different designs were used: eight experimental, six quasi-experimental, one mixed-method and two nonexperimental designs. The sample size varied between seven and 191 participants. Study characteristics and methodological quality are presented in Table 1.

According to the critical appraisal checklists of the JBI, the experimental studies scored good [22, 24–27] to moderate [20, 23, 28]. The moderate score was due to unknown similarity of the groups at baseline [20], unblinding of the outcome assessor [23,28] and absence of power analysis and therefore unknown reliability of the results [23]. All experimental studies described the use of randomisation. Of the quasi-experimental studies, one study had the maximum score [29], two studies had a moderate score due to the absence of the control group [30,31] and two studies had a low quality score [32,33]. Next to the absence of the control group it was also unclear if the included participants in the comparisons were similar. The qualitative studies scored good [21] or moderate due to unknown information of the researcher (culturally or theoretically) and how patient voices were presented [34].

3.1. Arguments to apply VR in patient education

The arguments to apply VR technology in patient education have scarcely been described. Three out of eleven arguments were based on scientific knowledge; (a) learning and understanding are enhanced by audiovisual tools, (b) the immersiveness of VR, which is the mechanism in exposure-therapy for anxiety and related disorders, and (c) engagement of VR, especially in children. Other arguments reflect opinions of the authors as benefits over conventional patient education.

Audiovisual tools to *enhance learning and understanding* [20, 21, 23, 26–35] was the most frequent argument. This is important to communication between patients and healthcare professionals because it reduces literacy barriers [21, 23, 28, 29, 31]. Well-informed patients show improved consent and comprehension [9, 30, 33–35] and are more inclined to cooperate with treatment instructions [21, 23, 32, 34, 35]. *Simulation of a reality-based environment* that creates *familiarity with unknown environments*, specialised equipment and patient anatomy is also a frequently described argument [20, 22, 24, 25, 28, 29, 32, 33, 35]. This is especially important in radiation therapy because it is a difficult concept to explain to patients [21, 23, 29–31, 33, 34]. In an operation theatre setting sterility issues and full schedules make it impossible to plan life-guided tours [28]. Two key concepts of VR, '*immersiveness or feeling the sense of presence*' [20, 22, 24–26, 28, 31, 34] and *'interactivity'* [25, 26, 32, 34], have been partially cited as arguments. Other less frequently described arguments were the *inexpensiveness* of a VR tool compared to a life tour through the operating theatre [22], the application of VR *without limitations in time or physical environment* [22, 25, 28] and *time reduction of the healthcare professionals* in informing patients [23, 28, 32]. The possibility of incorporating a *personalised explanation* of diagnosis or treatment was described as an advantage of VR [9, 27, 31]. The *engagement* aspect of VR has been shown to a limited extent as an argument for applying VR in patient education [9, 24, 26]. VR could be offered in *different languages,* which could be an advantage for individuals facing barriers in language and literacy [28]. The opportunity to *involve relatives* in explaining the radiation treatment process is an additional advantage that engages relatives in the cancer patients' treatment and in attending to their psychosocial needs [33].

3.2. Context of VR intervention in patient education

The specific context and patient population of the VR intervention tools are presented in Table 1. Two contexts of application of VR in patient education prior to medical (somatic) treatment could be distinguished.

3.2.1. Preoperative setting

In paediatrics, the target population was children undergoing general anaesthesia and elective, low complex surgery such as maxillofacial, dental or ear-nose-throat (ENT) same-day surgery [22,24–26]. In adults, the studies were more diverse: spinal/cranial surgery, caesarean delivery, treatment of an abdominal aortic aneurysm (AAA) and knee surgery [9, 20, 27, 28]. The preoperative settings all applied individual patient education.

3.2.2. Radiation therapy treatment

The majority of RT treatment studies applied the Virtual Environment for Radiotherapy Training system (VERT) [21, 29, 30, 33, 35]. VERT is a 3D immersive simulation system designed as an educational tool that can simulate the entire radiation treatment environment and process. It demonstrates virtual patients and provides a visualisation of internal anatomy and RT dose [21]. Five studies applied individual education and four studies group base education sessions. In RT treatment, participants with different kinds of cancer were included: prostate cancer (n = 3), breast cancer (n = 2), tumours in the pelvis (n = 1), tumours in the chest (n = 1) and different types of cancer (n=2).

3.3. Content of VR applications in patient education

Different VR applications could be distinguished. Most studies concerned videos. Specifications of the developed VR intervention tools, including implementation conditions, are presented in Table 2.

VR video - A VR video described the preoperative and/or postoperative experience for the day of surgery [20, 22, 24, 25, 28] or RT treatment [31, 34]. The same VR intervention tool was applied in two studies [22, 25]. Patients watched the VR video through a VR headset or a smartphone. In the paediatric setting, an animation character was used to explain the preoperative procedure in detail [22, 25].

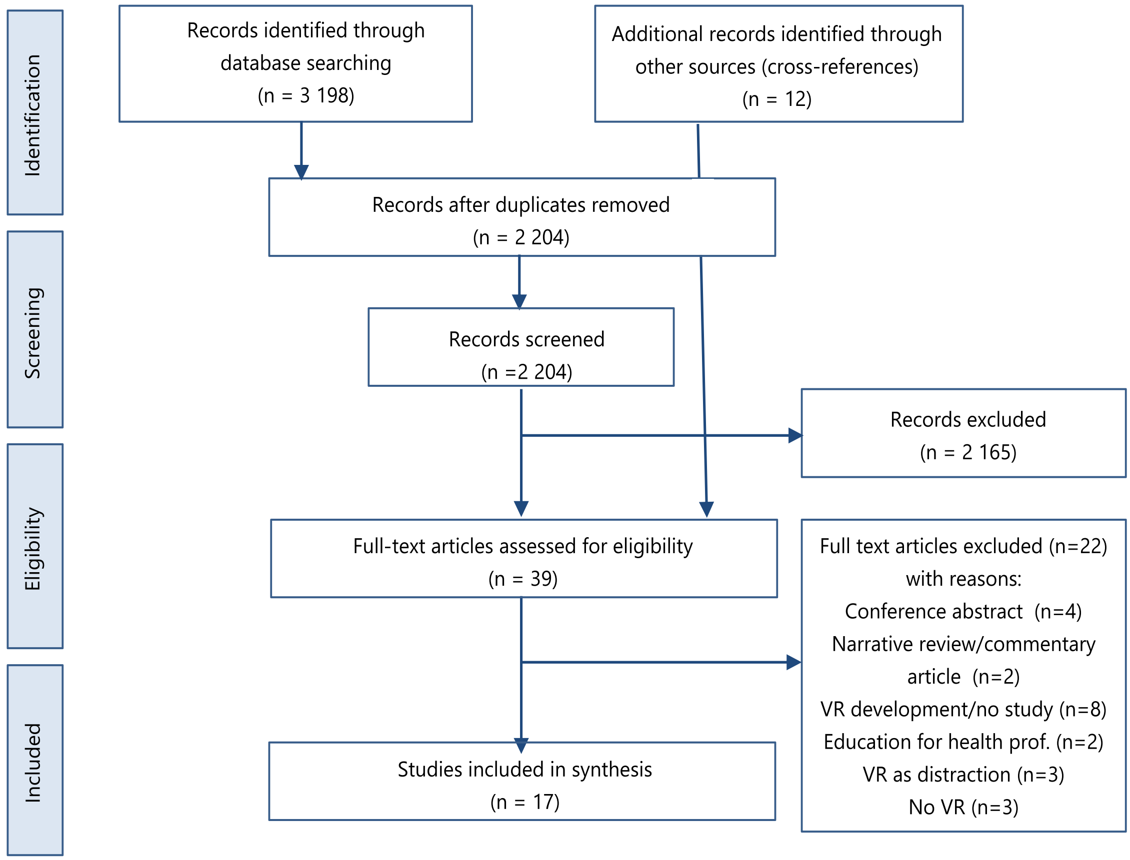

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flowchart of study selection.

These videos were filmed from the observers' perspective. Alternativelly children received an explanation from computer-generated hospital personnel from the patient's perspective [24]. In this study, two versions were developed attuned to the child's developmental level. Parents were able to watch via a computer what the child was watching in real time [24].

In the adult setting, VR videos were set up from the patient's perspective [20, 34], partner's perspective in the case of VR video explaining a caesarean delivery [28] and observer's perspective in the case of VR application in RT treatment [31]. Real healthcare professionals acted in these VR environments. In two studies, the VR video could be watched an unlimited number of times [20, 28], whereas other VR videos could be watched only once. The timing of the VR intervention was short before surgery in paediatrics and a few days before surgery or treatment in the outpatient clinic for adults. The VR experiences were guided by healthcare professionals [20, 22, 25, 31], who encouraged the patients and parents/relatives to ask questions, or by researchers [24, 28]. Interactive features incorporated to provide an explanation of different instruments were described in only one study [24]. Most VR videos included audio features.

VR game – A VR game was developed to experience the preoperative process and general anaesthesia induction for paediatric same-day surgery [26]. The 5-minute interactive game could be played with VR goggles and a hand controller. A first-person perspective was applied. Game elements including virtual world, progression, exploration, challenge and rewards were incorporated. Famous animation characters explained the process in detail, encouraging players to cooperate appropriately [26]. Playing the game was guided by the researcher, who encouraged the child to ask questions at the end.

VR 3D model – Another VR application was a 3D anatomic model [9, 27, 31]. The 3D model regarding an abdominal aortic aneurysm (AAA) supported the treating physician in explaining diagnosis and treatment and could be experienced interactively. The 3D model was based on the anatomy of the patient by Computer Tomography (CT) [9]. Explanation was given by the physician in the outpatient clinic before discussing the proposed treatment plan. The 3D model of the knee viewed the anatomy and the lesion of interest in need of the arthroscopic procedure and was based on the patient's Magnetic Resonance Imaging (MRI) scan [27]. Patients viewed this model with a VR headset twice: the first time during the outpatient clinic visit guided by the physician and the second time one day before surgery guided by the treating surgeon. Viewing the 3D models in VR took a few minutes. Patients could interactively view the model by using the hand controller. No information was available regarding whether audio features were implemented [9, 27]. Wang et al. (2020) also described a 3D model, but this was incorporated within a VR program that displayed a visual animation of the patient's personalised radiation therapy treatment plan played on the virtual linear accelerator [31]. A separate 2D monitor that mirrored the headset view was available in the room for family members and research staff to view what the patient was seeing in real time. The experience was guided by a radiation oncologist one or two days prior to the first RT treatment.

Table 1
Summary of study characteristics and methodological quality of included studies that report the use of Virtual Reality in patient education related to a medical somatic treatment categorised by setting.

Author (Year)	Setting	Study design and sample size	Primary Outcome[a,b]	Secondary Outcome[c]	Key findings[a,b,d]	Quality Score[e]
Eijlers et.al. (2019) [24]	Paediatric Elective day care surgery	RCT (n=191)	Anxiety	Anxiety, pain, emergence delirium, need for rescue analgesia, parental anxiety	VR intervention did not have a beneficial effect on anxiety, pain, emergence delirium or parental anxiety.	Good
Ryu et.al. (2017) [22]	Paediatric Elective day care surgery	RCT (n=69)	Anxiety	Induction compliance anaesthesia, procedural behaviour, satisfaction	VR intervention reduced anxiety and increased compliance during anaesthesia. Satisfaction did not improve significant.	Good
Ryu et.al. (2018) [26]	Paediatric Elective day care surgery	RCT (n=69)	Anxiety	Induction compliance anaesthesia, procedural behaviour, satisfaction	VR game reduced anxiety and increased compliance during anaesthesia. Procedural behaviour and satisfaction were not significant improved.	Good
Ryu et.al. (2019) [25]	Paediatric Elective day care surgery	RCT (n=80)	Emergency delirium	Pre-operative anxiety and postoperative behaviour disturbance	VR intervention did not reduce the incidence and severity of emergence delirium during recovery and postoperative behavioural disturbances. It may be effective in alleviating anxiety.	Good
Bekelis et.al. (2017) [18]	Spinal and cranial surgery	RCT (n=127)	Satisfaction and anxiety	Pain	VR intervention increased satisfaction, improved preparedness and reduced anxiety and stress. Perioperative pain was not affected by VR exposure.	Moderate
Noben et.al. (2019) [28]	Caesarean delivery	RCT (n=97)	Anxiety	Motion sickness	VR intervention did not reduce anxiety. No discomfort or motion sickness was reported.	Moderate
Pandrangi et.al. (2019) [9]	Aneurysm Aortic Abdominalis	Quasi-experimental (n=19)	Patient perceptions	NA	Patients perceived VR to be an engaging and useful educational resource in their healthcare management.	Low
Yang et.al. (2019) [27]	Knee surgery	RCT (n=48)	Anxiety	Satisfaction, pain, preparedness, stress	VR intervention reduced anxiety and stress and improved satisfaction. Perioperative pain and preparedness were not affected by VR exposure.	Good
Flockton (2016) [21]	RT prostate cancer	Qualitative (n=9)	Perceived understanding of how radiation treatment is delivered	NA	The VR education enhanced the understanding of radiation treatment and the technology involved.	Good
Gao et.al. (2020) [23]	RT chest cancer	Experimental (n=60)	RT Comprehension, anxiety, blood pressure, heart rate, respiratory rate	NA	A VR educational program could have a positive effect on patients prior to their initial RT session by providing them with useful content and decreasing their anxiety about the process.	Moderate
Jimenez et.al. (2018 [35]	RT breast cancer	Quasi-experimental (n=19)	Perspective of VR education package	NA	Patient evaluation of the education program using VERT indicated that patients found it useful. Benefits of using VERT were high.	Low
Jimenez et.al. (2018) [29]	RT breast cancer	Quasi-experimental (n=37)	Knowledge, anxiety and RT experience	NA	High value of VERT breast cancer-targeted education programs in improving RT knowledge and perhaps decreasing patient anxiety.	Moderate
Johnson et.al. (2018) [34]	RT pelvis cancer	Qualitative (n=7)	Evaluating a VR video	NA	An immersive VR education tool has the potential to enhance standard patient education, increasing understanding of treatment and decreasing anxiety.	Moderate
Marquess et.al. (2017) [30]	RT prostate cancer	Quasi-experimental (n=22)	RT comprehension and anxiety	NA	The education tool VERT significantly improved comprehension of RT and decreased anxiety.	Moderate
Stewart-Lord et.al. (2016) [32]	RT prostate cancer	Quasi-experimental (n=38)	Knowledge, perceptions, limits and benefits of VR Patient education	NA	The VERT education program helped patients to gain an understanding of the importance of bowel and bladder preparation prior to treatment to ensure reproducibility of organ position for daily treatment.	Moderate
Sulé-Suso et.al. (2015) [33]	RT Cancer	Quasi-experimental (n=150)	Informational need	NA	VR aids could become an important tool for delivering information on RT to both patients and relatives.	Low
Wang et.al. (2020) [31]	RT Cancer	Quasi-experimental (n=43)	RT comprehension and anxiety	NA	VR experience gives many patients a better understanding of how radiation therapy will be used to treat their cancer, and it can decrease their anxiety.	Moderate

[a] RT: Radiation therapy
[b] VR: Virtual Reality
[c] NA: Not Applicable
[d] VERT: Virtual Environment for Radiotherapy Training
[e] The methodological quality is based on the score of the critical appraisal checklists: good – maximum or maximum-1 score; moderate – between maximum -1 score and half of the maximum score; low – less than half of the maximum score.

Table 2
Specifications of VR applications in patient education categorised by context.

Preoperative context – paediatrics

Author	System	Duration	VR tool[5]	Topic	Subjects	Perspective	Audio	Fre-quency	Timing	Interactive	Individual vs group-base education	Moderator:	Remarks
Eijlers et.al. [24]	VR headset + personal computer	15 min	VR video	Pre- and postoperative experience for the day of the surgery	Computer generated	Patient	Yes	Once	Before transport to holding	Yes	Individual	Research assistant	Two versions available to attune to the child developmental level. Parents can watch via a personal computer.
Ryu[a] et.al. [22]	VR headset or smartphone	4 min	VR video	Experiencing the perioperative preparation process for day surgery	Animation character	Observer	Yes	Once	One hour before entering OR	No information available	Individual	Anaesthetist	An animation character is to engage children Encouraged to ask questions
Ryu[c] et.al. [25]	VR headset or smartphone	4 min	VR video	VR video experiencing the perioperative preparation process for day surgery.	Animation character	Observer	Yes	Once	One hour before entering OR	No information available	Individual	Anaesthetist	An animation character is to engage children Encouraged to ask questions
Ryu[b] et.al. [26]	VR headset and a hand and finger motion controller	5 min	VR game	VR game experiencing the preoperative process and general anaesthesia induction for day surgery	Animation characters	Patient	Yes	Once	After hospital admission and prior to entering the OR	Yes	Individual	Researcher	Game elements incorporated, including: virtual world, progression, exploration, challenge, and rewards Encouraged to ask questions

Preoperative context – adults

Author	System	Duration	VR tool	Topic	Subjects	Perspective	Audio	Frequency	Timing	Interactive	Individual vs group-base education	Moderator:	Remarks
Bekelis et.al. [20]	VR headset	5 min	VR video	Describing the preoperative and postoperative experience for the day of the surgery.	Actors and real physicians and nurses	Patient	Yes	Unlimited	Prior to surgery, during visit outpatient clinic	No information available	Individual	Treating physician	Encouraged to ask questions at the end.
Noben et.al. [28]	VR headset or smartphone	5 min	VR video	Description of the preoperative and postoperative experience for the day of CD[2]	Physician and anaesthe-tists	Partner	Yes (narrated voice-over)	Unlimited	After CD scheduled, before hospital admittance	No information available	Individual	Researcher	Couples received a unique password to install and watch the video at the time of inclusion or later at home (unlimited views)
Pandrangi et.al. [9]	VR headset or smartphone and hand controller	few min	VR 3D model	VR video with 3D anatomic model to explain diagnosis and treatment of AAA[3]	NA	Observer	No, but explanation by physician	Once	During visit outpatient clinic, before discussing treatment plan	Yes	Individual	Physician	Personalized model (CT [4])

(continued on next page)

Table 2 (*continued*)

Yang et.al. [27]	VR headset + hand motion controller	No information available	VR 3D model	A VR video describing the anatomy of the knee as well as their own lesion of interest in need of arthroscopic procedure	NA	Observer	No, but explanation by physician/ surgeon	Twice	1st: During visit outpatient clinic 2nd: 1 day before surgery	Yes	Individual	1st: physician 2nd: surgeon	Personalized model (MRI[5]) based.
Radiation therapy treatment													
Author	**System**	**Duration**	**VR tool**	**Topic**	**Subjects**	**Perspective**	**Audio**	**Frequency**	**Timing**	**Interactive**	**Individual vs group-base education**	**Moderator:**	**Remarks**
Flockton. [21]	No information available (other ref. 3D glasses)	10 min	Education session VERT	Simulation of the entire radiation treatment environment and process.	Virtual patient	Observer	No information available	Once	One hour before first treatment session (one-on-one)	Yes	Group	Researcher	
Gao et.al. [23]	VR goggles + separate 2D monitor	30 min	Education session VRRT	Presentations, explanations, and simulation experience of the RT process.	NA	Patient	Yes	Once	After confirming diagnosis, before initial treatment	No information available	Individual + family members	Educator (mastery of the content)	Educator available to answer questions
Jimenez[a] et.al. [35]	No information available (other ref. 3D glasses)	1 hour	Education session VERT	Patients information on technical components of RT and treatment plan of RT delivery	Virtual patient	Observer	No information available	Once	Prior to treatment (in small group sessions)	Yes	Group	Radiation therapist	Personalized (CT based) Support person included to accompany patient
Jimenez[b] et.al. [29]	No information available (other ref. 3D glasses)	1 hour	Education session VERT	Patients information on technical components of RT and treatment plan of RT delivery	Virtual patient	Observer	No information available	Once	Prior to treatment (in small group sessions)	Yes	Group	Radiation therapist	Personalized (CT based) Support person included to accompany patient
Author	**System**	**Duration**	**VR tool**	**Topic**	**Subjects**	**Perspective**	**Audio**	**Frequency**	**Timing**	**Interactive**	**Individual vs group-base education**	**Moderator:**	**Remarks**
Johnson et.al. [34]	VR headset or smartphone	'short video'	VR video	The entire RT treatment appointment from set up until the end of treatment.	Radiation therapists	Patient	Yes	Once	NA	No information available	Individual	No information available	Patient feedback is used to further develop the VR intervention
Marquess et.al. [30]	No information available	No information available	Education session VERT	Information on technical components of RT and treatment plan of RT delivery.	Virtual patient	Observer	Yes	Once	Before first treatment	No information available	Group + family members	Experienced educators	
Stewart-Lord et.al. [32]	No information available	1 hour	Education session VERT	Preparation information for treatment.	Virtual patient	Observer	No information available	Once	4 weeks prior to CT scan (and prior to treatment)	No information available	Individual	No information available	

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Table 2 (*continued*)

Sulé-Suso et.al. [33]	3D glasses	30 minutes	Education session VERT	Information on technical components of RT and treatment plan of RT delivery.	Virtual patient	Observer	No information available	Once	After CT scan and prior to first treatment	No information available	Individual + relative/ friend	oncologist or radiographer	Personalized model (CT[4] based) and treatment plan
Wang et.al. [31]	VR headset + 2D monitor	30 min	VR video	VR app with 3D anatomic model of the personalized RT treatment plan.	Virtual patient	Observer	No information available	Once	1 or 2 two days prior to the first radiation therapy treatment	No information available	Individual + family member	Radiation oncologist	Personalized treatment plan. Explanation during the viewing in real time.

[1]CD: Caesarean Delivery; [2]AAA: Abdominal Aortic Aneurysm; [3]CT: Computer Tomography; [4]MRI: Magnetic Resonance Imaging; [5]VERT: Virtual Environment for Radiotherapy Training

VERT system/VR System - The Virtual Environment for Radiotherapy Training (VERT) System was applied in six out of nine of the radiation therapy papers that studied an education program [21, 29, 30, 32, 33, 35]. The VERT system is a virtual reality environment presenting the user with a linear accelerator, patient couch and the bunker the equipment resides in. Realistic movements and sounds are incorporated [29, 36]. This simulation system was originally designed as an educational tool to assist the training of radiation therapy students and allied health professionals [21, 35]. Computed tomography (CT) data and RT treatment plans could be loaded into the system, offering multiple visualisation options of patient anatomy, tumour volumes, dose and treatment techniques [35]. VERT also provides a number of training tools that help physicians explain specific concepts in RT to patients [33]. The VERT display could be watched with 3D glasses, although this was not described in all papers. Experiencing the VERT system was integrated in a thirty-minute to one-hour education session guided by an experienced educator, radiation therapist or oncologist. No information was available about interactive features. In several studies, the education sessions were arranged as small group sessions [29, 35], and family members were invited to attend [23, 29, 30, 33, 35].

Gao et al. (2020) [23] studied a VR system similar to VERT. Presentations, explanations and simulation experience of the RT process were included. In contrast to the VERT system, this education tool applied a first-person perspective and could be experienced with a VR headset [23].

3.4. Outcome of VR application in patient education

The outcomes of the included studies could be divided in terms of the effect and patient experiences of VR interventions in patient education.

3.5. Effect of VR in patient education

Outcome parameters of the (quasi) experimental studies [9, 20, 22–33, 35] were investigated. The design, sample sizes, critical appraisal, measurement instruments and outcome variables are summarised in Table 3. The number of patients included in the studies was relatively small and varied between 22 and 191, with a median of 69,0. Single-centre studies were conducted between 2015 and 2020. All RCTs compared the VR intervention group to care as usual (CAU), although CAU was often not well defined.

3.5.1. Preoperative anxiety

Preoperative anxiety was a primary or secondary outcome variable in almost all studies. The tools to measure anxiety were heterogeneous, mainly due to different measurements in adults and in children. In the paediatric setting, observation scales such as the modified Yale Preoperative Anxiety Scale (m-YPAS) or the Observational Scale of Behavioural Distress (OBSD) were used [22, 24–26]. In adults, the Amsterdam Preoperative Anxiety and Information Scale (APAIS) [20, 27, 30], the State Trait Anxiety Inventory (STAI) [23, 24, 29], self-reported anxiety with the aid of a visual analogue scale (VAS) [24, 28] and a purposed designed anxiety survey [31] were administered. A statistical significant reduction in preoperative anxiety post intervention was found in the following RCTs [20, 22, 35–27] and non-RCTs [23, 30, 31]. In three studies a statistical significant reduction in preoperative anxiety was not found. In two RCTs [24, 28] and one non-RCT [29]. The duration and timing of the VR experience, VR equipment and audio features applied by a voice-over were not diacritical and presumably not responsible for the inconclusive findings relating to anxiety. In the studies in which no anxiety reduction could be determined, other outcome measures (stress, pain and/or preparedness) were also not improved significantly [24, 28]. In these studies, the VR experience was guided by a researcher, not a physician, or other healthcare professional with mastery of the content, as in the other studies.

3.5.2. Parental or partner anxiety

Next to measurement of preoperative anxiety of the participant one study investigated parental anxiety [24] and one study partner anxiety [28]. Parental anxiety was measured by the STAI, partners anxiety by a VAS. In these studies a statistical significant reduction in participants anxiety as well as in parental or partner anxiety could not be confirmed.

3.5.3. Understanding

Comprehension or knowledge of the RT process is a frequently investigated clinical outcome [23, 29–33]. Although the methodological quality of the studies was limited, the findings were uniform; the VR intervention statistic significantly improved understanding. The questionnaires used consisted of purposed designed surveys with statements regarding simulation, planning and RT treatment. The level of understanding could be indicated on a 5 point Likert scale. One study evaluated understanding from answers to an open-ended question in the survey on patient needs [33].

Table 3
Critical appraisal, measurement instruments, outcome variables and findings of the (quasi-) experimental studies categorised by context.

Author	Sample Size	Study design	Critical appraisal	Measurement instruments [a]	Outcome variables and findings	
					Significant [b] difference	No significant difference
Preoperative context						
Bekelis et.al. [20]	127	RCT	Moderate	Anxiety: APAIS Satisfaction: EVAN-G and VAS Pain and satisfaction: VAS	Anxiety, stress, satisfaction, preparedness	Pain
Eijlers et.al. [24]	191	RCT	Good	Anxiety: mYPAS and VAS Pain: FPS, VAS, FLACC and PPPM Emergence delirium: PAED Behaviour child: CBCL Need for rescue analgesia Parental anxiety: STAI	Need of rescue analgesia in subgroup analysis (more painful surgery)	Anxiety, pain, emergency delirium, behaviour child, parental anxiety
Noben et.al. [28]	97	RCT	Moderate	Anxiety: VAS Simulation Sickness and discomfort: SSQ Stress: TPDS and CPS Quality of Care: PCQ	Quality of Care in subgroup analysis (patients without history of Emergency Delivery)	Anxiety, partners anxiety, stress, preparedness
Ryu[a] et.al. [22]	69	RCT	Good	Anxiety: mYPAS Induction Compliance: ICC and PBRS Parental satisfaction: VAS	Anxiety, compliance during induction,	Parental satisfaction
Ryu[b] et.al. [26]	69	RCT	Good	Anxiety: mYPAS Induction Compliance: ICC and PBRS Parental satisfaction: VAS	Anxiety, compliance during induction,	procedural behaviour, Parental satisfaction
Ryu[c] et.al. [25]	80	RCT	Good	Emergency delirium: PAED Anxiety: mYPAS Postoperative behaviour disturbances: PHBQ-AS	Anxiety	Emergency delirium, postoperative behaviour disturbance
Yang et.al. [27]	48	RCT	Good	Anxiety: APAIS Satisfaction, preparedness, stress and pain: VAS	Anxiety, stress, satisfaction	Pain
Radiation therapy context						
Gao et.al. [23]	60	Pilot study (post-test)	Moderate	RT comprehension, satisfaction: purposed designed survey Anxiety: STAI Temporal psychological state regarding RT (VAS) Physiological data (blood pressure, heartrate, respiratory rate)	Anxiety, satisfaction, understanding, heartrate, systolic blood pressure	Blood pressure, diastolic blood pressure
Jimenez[b] et.al. [29]	37	Quasi-experimental (control/ VERT)	Good	RT knowledge: purposed designed survey Anxiety: STAI	Understanding	Anxiety
Marquess et.al. [30]	22	Pilot study (pre/ posttest)	Moderate	Anxiety: m-APAIS Comprehension: Purposed designed survey	Anxiety, understanding	
Stewart-Lord et.al. [32]	38	Survey (posttest)	Low	Knowledge: Purposed designed survey	Understanding	
Sulé-Suso et.al. [33]	150	Pilot study: (posttest)	Low	Information on understanding: open ended question	Understanding	
Wang et.al. [31]	43	Prospective clinical trial (pre/posttest)	Moderate	Anxiety, satisfaction and understanding: purposed designed survey	Anxiety, satisfaction, understanding	

[a] EVAN-G: Evaluation du Vecu de l' Anesthesie General; VAS: Visual Analogue Scale; APAIS: Amsterdam Preoperative Anxiety and Information Scale; mYPAS: modified Yale Preoperative Anxiety Scale; STAI: State-Trait Anxiety Inventory; OBSD: Observational Scale of Behavioural Distress; FPS: Faces Pain Scale (FPS); FLACC: Faces, Legs, Activity, Cry and Consolability scale; PPPM: Parent Postoperative Pain Measure (PPPM), PAED: Paediatric Anaesthesia Emergency Delirium scale; CBCL: Child behaviour Problems with Child Behaviour Checklist; SSQ: Simulation Sickness Questionnaire (SSQ); TPDS: Tilburg Pregnancy Distress Scale; CPS: Childbirth Perception Scale (CPS); PCQ: Pregnancy subscale of the Childbirth Questionnaire (PCQ); ICC: Induction Compliance; PBRS: Procedural Behaviour Rating Scale; PHBQ-AS: Post Hospitalization Behaviour Questionnaire for Ambulatory Surgery.

[b] Statistical significant difference $p < 0{,}05$ 95% Confidence Interval.

3.5.4. Satisfaction

Satisfaction can be divided into patient satisfaction and parent satisfaction [20, 22, 23, 26, 27, 31]. The findings showed a statistically significant increase in preoperative patient satisfaction [20, 23, 27, 31], whereas in parent satisfaction, no statistically significant improvement could be measured [22, 26]. Satisfaction was measured by VAS scores or purposed designed surveys.

3.5.5. Postoperative pain

None of the results showed a statistically significant reduction in pain [20, 24, 27]. In the adult setting a self-reported VAS score was used. In the paediatric setting, multiple observational questionnaires were applied: the Faces Pain Scale (FPS) reported by the children, the Pain intensity with the Faces, Legs, Activity, Cry and Consolability scale (FLACC) by the recovery nurse and the Parents' Postoperative Pain Measure (PPPM) by the parents [24].

3.5.6. Compliance during the induction of anaesthesia, procedural behaviour and emergency delirium

In paediatrics, preoperative anxiety has been associated with adverse clinical, behavioural and psychological effects, such as delirium and maladaptive behavioural changes [22]. In this regard compliance during the induction of anaesthesia and procedural behaviour, emergency delirium and/or the need for rescue analgesia was measured [22, 24–26]. Results showed no reduction in emergency delirium. Only a statistically significant reduction was found in the need for rescue analgesia in a subgroup analysis of patients who underwent more painful surgery [24]. Compliance during induction was significantly improved in the intervention group, whereas procedural behaviour in only one of three studies was significantly improved [22]. Three of the four studies were conducted in the same university hospital with similar study designs, populations and measurement instruments [22, 25, 26]. Two studies applied the same VR intervention [22, 25].

3.5.7. Stress and preparedness prior to surgery

No uniform results regarding stress and preparedness prior to surgery were found [20, 27, 28]. A VAS scale was used [20, 27], or patients in the intervention group were asked if they felt more prepared after seeing the VR video (yes or no) [28].

3.5.8. Physiological outcome parameters

Only one study combined subjective questionnaires and scales to objective physiological data [23]. The physiological data consisted of blood pressure and heart and respiratory rates by means to reflect the physiological state of a human being. Only heart rate and systolic blood pressure were significantly reduced in the intervention group. This pilot study had limited quality due to the small sample size and the use of non validated questionnaires. The author concluded that future research should more completely assess the effectiveness of VR interventions in radiotherapy patient education [23].

3.5.9. Motion sickness and discomfort

The Simulation Sickness Questionnaire (SSQ) to collect information on motion sickness during VR encounters was applied in only one study. No discomfort was found [28].

3.6. Patients experiences of VR in patient education

A summary of the outcome variables, measurement instruments and patient experiences is presented in Table 4. Patient experiences of the VR interventions were investigated in single-centre studies with a qualitative study [21, 34], mixed method [35] and (part of) quasi-experimental study design [9, 29, 32, 33]. The number of included patients in the studies was small and varied between 7 and 150, with a median of 19,0. Just two out of seven studies described the period of data collection, between 2015 and 2018 [9, 32].

Experiences of the VR intervention tool were a topic of research in the studies concerning education sessions using VERT and in the study of the 3D anatomic model for patients with AAA [9]. The majority of patients indicated VR intervention education as useful. It enhanced their understanding of radiation treatment and the technology involved. It improved communication with the healthcare professional and compliance with preparation for treatment. Patients also mentioned the potential reduction of anxiety as a benefit of VR education (32,-34). During in-depth interviews patients indicated the following challenges to take into account when developing a VR education tool: generalisability issues (patients need individualised information), language, age and visual issues, the importance of creating a realistic environment and the duration and timing of the VR session [34]. Although the methodological quality of the studies was limited, the findings were similar. Patients highly appreciated the VR intervention tools.

4. Discussion and conclusion

4.1. Discussion

This scoping review maps the available evidence on the context, content and outcomes of VR tools in patient education in situations related to preparation for medical somatic treatment.

The main findings of this scoping review consist of four parts. First, various arguments to apply VR in patient education are described in the literature: in general, audiovisual tools enhance learning and understanding. Second, VR patient education tools are applied in the context of (paediatric) surgery and radiation therapy treatment. Third, the content of VR interventions is heterogeneous regarding technical applications, context of implementation, guidance by a healthcare professional and integration in an education session. Fourth, VR patient education tools are mainly developed to reduce anxiety and to improve understanding about the upcoming treatment. Anxiety reduction, in addition to reduction of pain and stress and improvement of preparedness, could not be unanimously determined. Patients experienced VR education to be useful, as it enhanced understanding, improved communication with healthcare professionals and increased compliance with treatment.

The context in which VR has been applied in patient education is restricted to (paediatric) surgery and radiation therapy treatment. This context could be extended to other invasive procedures, such as interventional cardiology or endoscopic procedures. Recently a RCT study in the context of colonoscopy was published. The investigators concluded patients who received VR video education before colonoscopy had better bowel preparation, improved compliance and satisfaction [37].

Based on the results of this scoping review, the following aspects in VR development regarding content should be carefully considered: connect the VR application to the target population and the context the VR tool should be applied in, the VR experience should be guided by a healthcare professional, and consider the timing of the experience and its incorporation in an education session.

An important issue for further research is the presence, task and influence of a guiding moderator during patients' VR experience. The findings of this review suggest that the guidance of a healthcare professional is highly appreciated by patients and promotes positive

Table 4
Critical appraisal, measurement instruments and key findings of patient experiences.

Author	Study design	Participants	Sample Size	Critical Appraisal	Primary outcome(s)	Measurement instruments	Key Findings
Flockton [21]	Qualitative	Men with prostate cancer	9	Good	* Perceived understanding of RT treatment * Understanding of prescriptions related to RT treatment. * RT treatment experience	Semi-structured interviews	The VERT education enhanced understanding of radiation treatment and the technology involved. Visualization of the process helped to feel prepared for treatment. There is a preference to have VERT education delivered sometime near the first treatment appointment.
Jimenez[a] et.al. [35]	Mixed method	Women with breast cancer	19	Low	Patients perspective of education package VERT	VERT program: purposed designed survey with additional open-ended questions to yield qualitative feedback	VERT is found useful, it enhanced understanding. Visualization of the virtual body did not cause distress.
Jimenez[b] et.al. [29]	Quasi-experimental	Women with breast cancer	37	Good	Patient RT experience	RT Experience: Purposed designed survey	VERT offered an important support tool for RT patients through effective preparatory RT education due to its rich visual display.
Johnson et.al. [34]	Qualitative	Patients with RT in the pelvis	7	Moderate	Patient evaluation of a VR video for patients having RT treatment to the pelvis	Focus groups	An immersive VR education tool has the potential to enhance standard patient education by increasing understanding of treatment and decreasing anxiety. Four themes emerged: i: Efficacy of Traditional Education (satisfactory, but can also be overwhelming) ii: VR Benefits (supplemental to traditional education, increase in understanding and potential anxiety reduction) iii: VR Challenges/Limitations (age, language and visual issues, realistic environment) iv: VR Logistics (timing, duration of the video)
Pandrangi et.al. [9]	Quasi-experimental	Patients with Abdominal Aortic Aneurysm (AAA)	19	Low	Patient perceptions on an VR education tool	Opinion on VR interaction: purposed designed survey with additional list of educational resources to mark which helped patients understand their health status	Patients indicated high satisfaction with VR health education. Patients were better informed and felt more engaged in their healthcare. Almost all patients felt comfortable using V and enjoyed the technology. Patients perceived VR to be an engaging and useful educational resource in their healthcare management.
Stewart-Lord et.al. [32]	Quasi –Experimental	Men with prostate cancer	38	Low	* Patient perceptions * Limits and benefits of VERT patient education	Attitude and beliefs regarding pre-treatment information provided prior to their RT-treatment: Purposed designed survey	VERT was found helpful as information giving tool. High level of satisfaction was found. Benefits of the VERT session mentioned: improved communication and compliance of preparation to treatment and reduced stress.
Sulé-Suso et.al. [33]	Quasi -Experimental (part QCA[a] of open ended question)	Cancer patients and relatives	150	Low	The need of patients during the whole process from planning the RT up to treatment delivery.	Patients Need: Purposed designed survey with one additional open ended question	The majority of the patients had a moderate or high need to better understand how RT is planned and delivered. The open ended questions revealed patients had a greater understanding of the RT treatment process and side effects. Also improvement of involvement of family and reduction of anxiety.

[a] QCA: Quality Content Analysis

clinical outcomes [31]. VR technology has impact on cognitive and affective learning [38], however, VR technology is unable to enter into a relationship with a human being. The relationship of trust between the physician and a patient is important as it is associated whit patient adherence satisfaction and better health outcomes [39]. Further research is needed to determine whether VR in patient education contributes to this relationship or whether a guiding moderator in addition to VR education is crucial to achieve this relationship of trust.

Although the aim of the majority of the reviewed studies was to reduce anxiety, this finding could not be demonstrated in all studies. In addition to the intervention itself being ineffective, there are a number of other possible causes that should be considered. In two experimental studies, usual care aimed to reduce anxiety, which might have led to small differences between the control and VR groups [24, 25]. In addition, some patients underwent less complex surgery, which might be associated with lower anxiety levels compared to more complex surgery [24, 25]. Moreover anxiety is a complex phenomenon that is influenced by many aspects, and anxiety reduction cannot be attributed solely to a VR intervention.

The inability to demonstrate anxiety reduction in the reviewed studies is in line with findings from research on preoperative education interventions. Variability in context, measurement instruments, content of the preoperative education interventions and low quality of evidence complicate determination of the effectiveness of these interventions [40, 41]. Moreover, a recently published meta-analysis on VR education tools and anxiety reduction supports our findings [42]. The meta-analysis showed a statistically significant reduction in anxiety in the intervention group. However, in subgroup analysis, this was not found in adults, only in paediatric patients [42]. The assumed explanation is the higher level of anxiety and engagement with audio-visual techniques by paediatric patients [42].

VR patient education tools are effective in improving understanding, not only in preparation for medical- and somatic treatment but also in preventive healthcare. In preventive healthcare, VR is introduced to improve health outcomes by improving medication use skills [43], compliance with treatment [44] and self-management training [45].

Our review showed that patient satisfaction was high [9, 32, 46]. This is consistent with the satisfaction of VR users in healthcare education, for example, in radiation therapy students [47] and in neuroanatomical teaching [48]. Virtual learning significantly improved students' satisfaction, engagement and recall. The 'engagement' factor was important, but in our review, it was only explicitly incorporated to a limited extent [9, 20, 26].

Some strengths and limitations of this study should be considered when interpreting its findings. In this review, we synthesised and assessed previously published studies with the guidelines for scoping reviews [14, 15]. This scoping review offers a broader perspective. To increase the reliability and validity of the findings, a methodological quality appraisal was also applied. The search strategy without limitations in timeframe and language strengthened the findings.

Several limitations of this review should be acknowledged. As a result of the heterogeneity in the study setting, intervention tools, study design, measurement instruments and outcome parameters, we could not quantify the effect of the VR intervention tools. Small sample sizes and the single-centre results limit generalisability. Findings should therefore be interpreted with caution.

4.2. Conclusion

In preparation for a medical somatic treatment VR patient education tools are applied in the context of (paediatric) surgery and radiation therapy treatment. The VR interventions are heterogeneous regarding technical applications, context of implementation, presence of a moderator to guide the VR experience and individual or group base education session. The application of VR in patient education is a promising technology. Patients were highly satisfied and experienced VR education tools to be useful, as they enhanced understanding, improved communication with healthcare professionals and increased compliance with treatment. However, no unambiguous statements on the effectiveness of VR on health-related outcomes (anxiety, pain, stress and preparedness) could be determined. Future research with attention to substantiating the added value of VR in patient education, whether VR can address patients' needs regarding personal guidance and attention by a healthcare professional and larger-scale trials are needed. The application of a methodological framework for VR development is recommended.

4.3. Implications for VR development in clinical practice and research

The substantiation of the application of VR in patient education in the reviewed studies is scarcely described. Arguments are reasonable, but not necessarily applicable to VR technology. In developing a VR intervention, essential VR elements such as immersiveness, interaction within the environment and engagement are optimally used. Otherwise, consider other innovative technologies, such as serious gaming, e-Health apps or e-learning programs. It is recommended to involve educationalists and technology professionals in the development of web-based technology interventions.

Although the scientific evidence is limited and VR tools in patient education are still in their infancy, the development and application of VR as a patient education tool should not be dismissed. Patients' experiences support further development.

It is important to develop VR interventions profoundly. Scientific evidence on VR in patient education is limited, and VR investigations are fragmented. To promote scientific evidence in the development of VR tools recommendations for the methodology of VR clinical trials in healthcare are proposed [49].

Disclosures

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CRediT authorship contribution statement

Marijke van der Linde: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **Omayra C.D. Liesdek:** Writing – review & editing. **Fiona Slond:** Conceptualization. **Willem J. Suyke**r: Supervision, Writing – review & editing. **Saskia M.W. Weldam:** Conceptualization, Methodology, Validation, Writing – review & editing.

Appendix A. Search strategy

Database	Date performed search[1]	Search Terms
Pubmed/ Medline	March 3rd 2020	((Virtual reality[Title/Abstract] OR virtual environment[Title/ Abstract] OR virtual experience[Title/Abstract]) AND (patient education [Title/Abstract] OR patient information[Title/Abstract] OR informational need[Title/Abstract] OR information need[Title/ Abstract] OR information needs[Title/Abstract] OR Informational needs[Title/Abstract] OR prehabilitation[Title/Abstract] OR pre-admission information[Title/Abstract) OR level of received knowledge[Title/Abstract] OR Received knowledge[Title/Abstract] OR patient preparedness[Title/Abstract] OR Preparation tool[Title/ Abstract] OR Information tool[Title/Abstract] OR educate patient [Title/ Abstract] OR educate patients[Title/Abstract] OR education [Title/Abstract]))
CINAHL (Ebsco-Host)	March 3rd 2020	((Virtual reality OR virtual environment OR virtual experience OR Serious Games) AND (patient education OR patient information OR informational need OR information need OR information needs OR Informational needs OR prehabilitation OR pre-admission information OR level of received knowledge OR Received knowledge OR patient preparedness OR Preparation tool OR Information tool OR educate patient OR educate patients OR education)) In: Title OR Abstract
Embase	March 6th 2020	((Virtual reality: ab/ti OR virtual environment: ab/ti OR virtual experience: ab/ti OR Serious Game: ab/ti) AND (patient education: ab/ ti OR patient information: ab/ti OR informational need: ab/ti OR information need: ab/ti OR information needs: ab/ti OR Informational needs: ab/ti OR prehabilitation: ab/ti OR pre-admission informatio: ab/ti n OR level of received knowledge: ab/ti OR Received knowledge: ab/ti OR patient preparedness: ab/ti OR Preparation tool: ab/ti OR Information tool: ab/ti OR educate patient: ab/ti OR educate patients: ab/ti OR education: ab/ti))
PsycINFO (Ovid)	March 6th 2020	(Virtual Reality.m_titl. OR Virtual Environment.m_titl. OR Virtual experience.m_titl. OR Serious Game.m_titl.) AND (patient education.m_titl. OR patient information.m_titl. OR informational need.m_titl. OR information need.m_titl. OR information needs.m_titl. OR Informational needs.m_titl. OR prehabilitation.m_titl. OR pre-admission information.m_titl. OR level of received knowledge.m_titl. OR Received knowledge.m_titl. OR patient preparedness.m_titl. OR Preparation tool.m_titl. OR Information tool.m_titl. OR educate patient.m_titl. OR educate patients.m_titl. OR education.m_titl.)

[1]Last updated search: October 2020

Appendix B. – Charting Form

(1) Author(s)
(2) Year of publication
(3) Title
(4) Journal
(5) Country
(6) Aims/purpose
(7) Study population (participants) and sample size (if applicable)
(8) Methodology
(9) Critical Appraisal
(10) Critical appraisal tool Joanna Briggs Institute
(11) Intervention and comparator (if applicable)
(12) Concept
(13) Duration of the intervention (if applicable)
(14) Primary and secondary outcome (if applicable)
(15) Measurement instruments
(16) Key findings of the paper
(17) Key findings that relate to the review questions

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