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HENRY M. GOLDMAN SCHOOL OF DENTAL MEDICINE

MASTER'S THESIS

COMPARATIVE EVALUATION OF DENTAL HAPTIC SIMULATORS AND THEIR APPLICATIONS IN PEDIATRIC DENTISTRY- A SCOPING REVIEW

by

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DEDICATION

I would like to dedicate this work to my father, eternally in loving memory, and to my mother who enabled me the opportunity of pursuing a further education in the United States.

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NASTARAN CHOKHACHI ZADEH MOGHADAM

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ABSTRACT:

Background: Almost all fields of dentistry are very reliant on dentists' well-developed dexterity and psychomotor skills. Simulation preclinical dental training is important for dental students to acquire preliminary manual dexterity before interacting with real patients. In the recent years, virtual reality specifically haptic simulations have drawn a lot of attention due to their multiple advantages including lack of the threat of spreading air-borne diseases.

Purpose: The overall purpose of this study was to provide a review of the available dental haptic simulators in the market, and specific aim was to report the available evidence from the current scientific literature about the use and benefit of them during early preclinical pediatric dentistry training.

Methods: Information about Haptic VR simulators was obtained through manufacturers' websites and current scientific literature. For the specific aim, the review is reported using the PRISMA-Scoping Review (ScR) guidelines and bibliographic databases such as PubMed, Cochrane library, Embase, and Dentistry and Oral Sciences Source.

Results: The systematic search identified 79 titles of which 14 full-text articles were selected for detailed review. Based on inclusion and exclusion criteria 4 studies were included in this review.

Conclusion: Evaluation evidence from reviewed studies indicates the usefulness of the haptic simulators in preclinical pediatric dental training. The haptic simulators complement the existing phantom head simulators by offering different beneficial features. Further studies are necessary to evaluate the effectiveness of the simulators in pediatric dental training and to support the current availability of evidence.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION:

Importance of Simulation in Dental Education

Almost all fields of dentistry are very reliant on dentists' well-developed dexterity and psychomotor skills. Dental students must obtain a certain level of competence prior to actual patient care since most procedures are irreversible, and patient harm can occur if students do not perform with acceptable levels of skills. Hence, it would be better to master initial psychomotor skills in a simulated manner prior to actual patient care. (1)

The effective use of dental simulation systems has become an increasing necessity in the current era (1), particularly in unprecedented emergencies such as the recent COVID-19 pandemic where patient care access became restricted due to the nationwide shutdown of clinical care. Simulators that are currently used in dental schools have realistic manikins along with dental models incorporated in a simulated operatory. These simulated models allow the instructors to explain and improve on students' hand-eye coordination and dexterity, but verbal description of tactile sensation is difficult to explain. (2) Several advantages are offered by dental simulation systems, including effective learning without any fear of making mistakes on a patient, possibility of repeating various dental operations in any time and place, ease of evaluating student performance, avoid the need for water pipes and suction, and low-cost dental training. Moreover, the threat of air-borne and water-borne diseases such as COVID-19 and Legionella is eliminated in simulation settings. (1,2)

What are haptic simulators?

Currently, two main groups of simulation systems are available:

1) Contemporary non-computer-assisted simulation system (CS), which is the traditional laboratory-based system with mannequin heads with jaws containing plastic teeth mounted on metal rods, accompanied by basic dental appliances.

2) Computer-assisted simulation system, which includes Augmented Reality (AR) simulators and Virtual Reality (VR) such as Haptic simulators. (3)

Traditional simulation system lacks the real tactile sensation and force feedback experience, whereas Virtual Reality technologies have been developed to provide haptic (sense of touch) along with realistic force feedback in the virtual lab environments. Haptic devices allow students to touch and feel objects such as dental tools and tooth in a virtual environment, and to perform operations like pushing, pulling, and cutting of soft or hard tissue. (4)

Although VR simulator has disadvantages of high installation costs and time-consuming staff training and software updates, its long-term cost savings in terms of handpiece replacements, disposables such as plastic teeth, and supervision and teaching time. Additionally, VR offers an objective assessment and reduces the subjectivity of evaluations conducted on plastic teeth. (1,3)

The overall aim of this review is to provide an overview of the available dental haptic simulators currently available in the worldwide market and specific aim was to review the current scientific literature about the utility of haptic virtual reality simulation during early preclinical pediatric dentistry training.

<u>METHODS:</u>

For the overall aim, information about each Haptic VR simulator was obtained through manufacturers' websites and brochures and searching through the current scientific literature.

For the specific aim, the methods used to conduct this review are based on the guidelines outlined in the Cochrane's Preferred Reporting Items for Systematic Review and Meta-Analyses extension for Scoping Review (PRISMA-ScR). The scoping review methodology is a valuable approach to knowledge synthesis. It broadly maps evidence on a specific topic, facilitates the identification of knowledge gaps, and summarizes existing evidence. (5)

Formulating the research question

The Population–Concept–Context (PCC) framework (6) was used to formulate the research question for the specific aim:

- Population (predoctoral dental students, pediatric dental residents),
- Concept (haptic virtual reality dental simulator),
- Context (preclinical/early dental training in pediatric dentistry).

Overall aim: To provide a brief review of the available dental haptic simulators in the market.

Specific aim: "What is the available evidence from the current scientific literature about the utility of haptic virtual reality simulation during early preclinical pediatric dentistry training?"

Eligibility criteria

Inclusion criteria

Articles describing new or already existing applications for Virtual Reality (VR) Haptic in dentistry and relevant information including field of interest, user satisfaction, impact on dental students' psychomotor skills, precision and timing efficiency and combination of software and hardware used were considered. Articles in English, and VR Haptic related to pediatric dentistry were included. No limit for study design was applied.

Exclusion criteria

All the articles describing augmented reality systems were excluded, such as use of or any concept which does not refer to the exact definition of Haptic Virtual Reality. All the application areas not related to dentistry and pediatric dentistry were excluded as well.

Search strategy

To identify potentially relevant studies, a comprehensive search was conducted in PubMed, Embase, Dentistry and Oral Sciences Source, and Cochrane Library. The search was last updated in June 2022 for articles in peer-reviewed English-language journals published in the last 10 years. The keywords were related to pediatric dentistry, haptic virtual reality, and dexterity training.

Figure 1: PubMed search MESH terms.

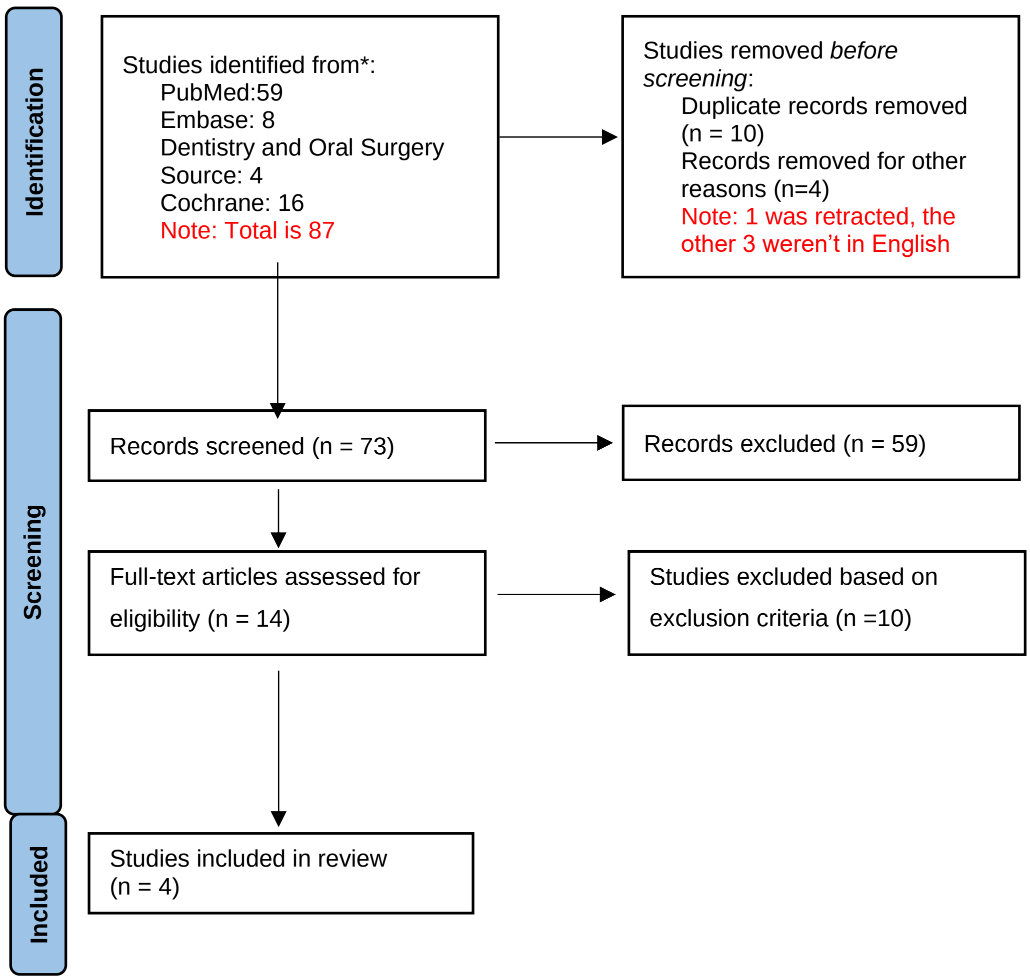
((pediatric OR paediatric) AND (dentistry OR "dental student" OR "dental education" OR "preclinical dent*")) AND ("Virtual Reality"[Mesh] OR VR[tiab] OR "Virtual reality" OR "haptic simul*" OR "dental simul*" OR (dexterity AND (simul* OR train*)))
Figure 1. PubMed search string

Relevant articles were identified beforehand, and reference lists were manually searched. Articles were not restricted by publication type and studies in languages other than English were not included in the initial screening.

RESULTS

A total of 87 articles were identified in the initial search, with duplicates discarded (n=10), as well as articles that were retracted (n=1) or were not in English (n=3). Fifty-nine of the remaining of 73 screened articles were discarded during the title and abstract screening because they did not meet the inclusion and exclusion criteria. After full-text reviewing of the remaining articles, 10 articles did not meet the inclusion and exclusion criteria. Finally, a total of 4 full-texts articles were selected. (Figure 2) The systematic search was finalized on June 10th, 2022.

Figure 2: The PRISMA flow diagram of the current scoping review



<u>Existing Dental Haptic Simulator systems:</u>

With the use of the technology from the aeronautical industry and surgical fields, prototype dental haptic simulators began to be constructed, leading to the implementation of the first dental haptic simulator in dental schools in the early 2000s. (7)

Since then, several dental haptic virtual reality simulators have been developed by various institutions worldwide for the different dental specialty trainings. This review will provide a quick insight into the currently available dental Haptic VR simulators, their advantages, and limitations. (Table 1)

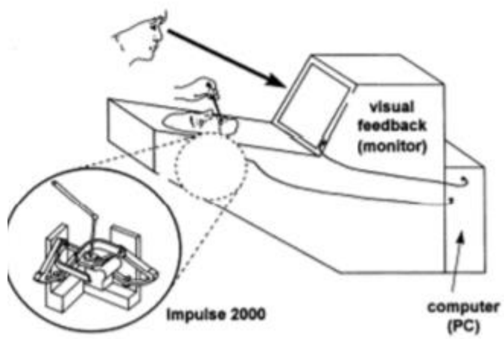
1. ***Virtual Reality Dental Training System (VRDTS):*** It was initially designed for cavity preparation in 1990’s (USA). Then upgraded to virtual restoration of teeth by Novint Technologies in collaboration with the Harvard School of Dental Medicine. It has ability to restore the preparation is something that is not possible with some other systems. It can also track the student's operation in real time and provides quantifiable feedback to both student and teacher. This system consists of a desktop workstation, a Phantom Desktop haptic interface, and dental simulation software. Its Phantom Desktop has the combination of Haptic, Visual, and Auditory feedback sensors and a 3D display. The entire system is virtual, and the students work with a virtual decayed tooth using virtual hand and rotary instruments to prepare and restore a tooth preparation. The software includes simulated dental instruments (drill, explorer, carvers, carrier, and a packer), amalgam material, and enamel, dentin, caries, and pulp materials of a juvenile molar. The dental instrument, tooth and decay in the teeth are displayed as virtual simulated images on the monitor when the haptic device is held in the air. The disadvantage is that it does not support correct positioning and finger rests therefore the

student has to hold the interface in the air. (8,9) This could lead to discomfort when used for longer time and lower precision of performing the simulated procedure. (Figure 3)

Figure 3: Virtual Reality Dental Training System (VRDTS)

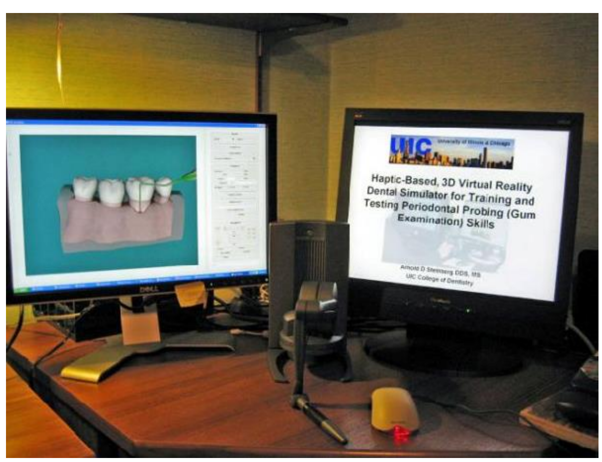
2. ***Iowa Dental Surgical Simulator (IDSS):*** The IDSS unit is still in its initial stages of development. The College of Dentistry at the University of Iowa and Graphical Representation of Knowledge (GROK) Lab. designed the simulator. It consists of three hardware components: the computer, a monitor, and a force feedback device with software. Its Impulse Engine 2000 device includes Haptic and Visual sensors. It focuses more on teaching subtle tactile skills relevant to clinical detection of carious lesions through providing realistic force in the force feedback device when students interacting with enamel, healthy dentin, and carious dentin. Hopefully in the future, the IDSS will be able to provide an extended range of haptic tasks to help developing psychomotor skills. (10) (Figure 4)

Figure 4: Iowa Dental Surgical Simulator (IDSS)



3. ***PerioSim***: It was designed especially for periodontics in 2009 by the University of Illinois in Chicago. Its Phantom Desktop has the combination of Haptic, Visual, and Auditory feedback sensors and a 3D display. It trains the user to select and manipulate the dental instruments properly. It can simulate three typical operations including pocket probing, calculus detection and calculus removal. It provides students with the immediate, unlimited, and objective feedback of their work. Operators can feel realistic tactile sensations as they navigate through various procedures in a 3D mouth model. Moreover, it encourages the user to practice correct ergonomic positioning by using LED sensors to detect incorrect operator or patient positioning. (11-13) (Figure 5)

Figure 5: PerioSim simulator.



4. ***Virtual Dental Patient (VDP):*** It was developed by Aristotle University, Greece in 2006. Its Phantom Desktop has the combination of Haptic and Visual feedback sensors and a 3D display. It aids users in becoming acquainted with tooth anatomy, handling of instruments used for drilling, identify landmarks, and plan their approach. (14,15)

5. ***Voxel-MAN***: The VOXEL-MAN Dental was developed by the University Medical Center Hamburg-Eppendorf, Germany in 2007. Its Phantom Omni device has the combination of Haptic, Visual, and Auditory feedback sensors and a 3D display. It provides training of cavity preparation and carious lesions with automatic skills assessment. This simulator offers simulated burs of different shapes, controls high and low speed bursts by a foot pedal. Operator can view teeth in all angles using virtual dental mirror. The technology can magnify teeth and show cross-sectional images at the same time. (16-18) (Figure 6)

Figure 6: Voxel-MAN simulator.

6. ***Forsslund Systems AKA The Kobra***: This was developed by Forsslund Systems AB, Sweden in 2008. Its Phantom Omni/PHANTOM Desktop includes the combination of Haptic and Visual feedback sensors and a 3D display. It provides VR training for practicing dental drilling and wisdom tooth extraction along with the ability of being controlled by a foot pedal. The core components of this system are the Kobra and FS-Wisdom, whilst the Kobra simulator is the hardware set upon which the software application FS-Wisdom runs. (19,20) (Figure 7)

Figure 7: The Kobra simulator.

7. ***Simodont***: The Simodont Dental Trainer is a virtual reality simulator developed by MOOG Inc., and the Academic Centre for Dentistry Amsterdam (ACDA), Netherlands, in 2009. It contains Force feedback robot arm (adapted from Moog Haptic Master) along with the combination of Haptic, Visual, and Auditory feedback sensors and a 3D display. It includes a physical handpiece and mirror connected to force feedback sensors, 3D glasses, wrist fixture, and a foot pedal. Its high-fidelity simulation and haptics technologies provides virtual drilling, removal of tooth decay, restoring cavity preparations, crown and bridge preparations as well as mirror reflection. In addition to practicing manual dexterity skills, the system allows users to select virtual patient profiles and then perform diagnosis, treatment planning and provides

automatic user evaluation. The 3D images of teeth, the hand instruments, and dental burs are all simulated for tooth preparation and to generate a virtual drilling feel. The system allows for objective comparison of the student's individual results. Mistakes can easily be corrected by 'stepping back' or 'rewinding' in the simulator and immediately repeating part of a procedure. Although 3D images are realistic, the texture of healthy decayed and restored tooth structures still needs improvement. (21-23) (Figure 8)

Figure 8: Simodont simulator.

8. ***Haptic Technology Enhanced Learning for dental students (HapTEL):*** Kings College London (KCL) dental school developed the prototype I of Haptic Technology Enhanced Learning (HapTEL) in 2008 and prototype II in 2010 in collaboration with the University of Reading. Its NOVINT Falcon device has the combination of Haptic, Visual, and Auditory feedback sensors and a 3D display. Their system allows users to learn and practice procedures such as tooth drilling, caries removal and cavity preparation for tooth restoration. (24)

9. ***VirDenT***: The VirDenT system prototype was developed by Ovidius University, Romania, in 2011. It helps users to learn how to prepare teeth (crowns and bridges) for ceramic crowns. (25-27)

10. ***VirTeaSy Dental***: VirTeaSy Dental was developed by DIDHAPTIC (Laval, Pays De La Loire, France) in 2011. Its Virtuoso 6D Desktop has the combination of Haptic and Visual feedback sensors and a 3D display. It is initially designed for teaching implantology, however, it can also be used in endodontics and prosthodontics procedures to perform virtual drilling and caries removal. (28,29) (Figure 9)

Figure 9: VirTeaSy Dental simulator.

11. ***iDental***: The prototype was developed by Beihang University, China, in 2011. Its Phantom Omni/Phantom Desktop includes the combination of Haptic, Visual, and Auditory feedback

sensors and a 3D display. The iDental system can simulate typical endodontic access prep, drilling and periodontal procedures, including pocket probing, calculus detection and calculus removal. In addition, it can be used to practice drilling and removal of tooth decay. A main advantage is bimanual dexterity exercises such as use of a scaler to remove calculus whilst also holding a mirror in the other hand to retract the tongue. (30-32). (Figure 10)

Figure 10: iDental simulator.

Table 1: Comparison of dental simulators.

#	Haptic VR	Designed by	Procedure classification	Pediatric dentition module	Instant feedback	Exam simulation	Ergonomic postures	Prototype	3D display	Bimanual
1	**Virtual Reality Dental Training System (VRDTS)**	Harvard (USA)	Operative (Cavity prep + restoration)	No	Yes	No	No	Yes	Yes	No
2	**Iowa Dental Surgical Simulator (IDSS)**	University of Iowa and GROK Lab (USA)	Detection of dental caries	No	Yes	No	No	Yes	No	No
3	**PerioSim**	University of Illinois at Chicago (USA)	Periodontics	No	Yes	Yes	Yes	No	Yes	No
4	**Virtual Dental Patient (VDP)**	Aristotle University (Greece)	Drilling	No	Yes	No	No	Yes	Yes	No
5	**Voxel-MAN**	Medical Center Hamburg-Eppendorf (Germany)	Surgery Operative (Cavity prep)	No	Yes	Yes	No	No	Yes	Yes
6	**Forsslund Systems (The Kobra)**	Forsslund Systems AB (Sweden)	Surgery (tooth extraction) Apicoectomy (Bone Drilling)	No	Yes	No	Yes	No	Yes	No
7	**Simodont**	MOOG Inc. & Academic Centre for Dentistry Amsterdam (Netherland)	Prosthodontics Operative (Cavity prep + restoration) Endodontic access prep	Yes	Yes	Yes	Yes	No	Yes	Yes
8	**HapTEL**	The Kings College London & University of Reading (UK)	Operative (Cavity prep)	No	Yes	Yes	Yes	No	Yes	No
9	**VirDenT**	Ovidius University (Romania)	Prosthodontics	Yes	Yes	Yes	No	Yes	No	No
10	**VirTeaSy Dental**	DIDHAPTIC (France)	Implantology, Endodontic access prep, Prosthodontics Operative (Cavity prep)	Yes	Yes	Yes	No	No	Yes	Yes
11	**iDental**	Beihang University (China)	Periodontics, Endodontic access prep, Operative (Cavity prep)	No	Yes	Yes	Yes	No	Yes	Yes

Virtual reality simulators in pediatric dentistry:

A total of four studies were included on the use of virtual reality simulators in pediatric dentistry with total participants of 334. Summary of the selected studies are shown in Table 2.

Virtual reality simulators have been shown to be useful for training of local anesthesia methods compared with traditional LA teaching methods.(33) Students also agreed that using VR assisted their learning and facilitated their understanding of pediatric dentistry clinical procedures.(34) Moreover, pediatric virtual patient significantly improved communication and behavioral management of pediatric patients and could be used to improve empathy, self-perceived comfort and ability at managing children in dental students (35,36).

Table 2. Summary of selected studies.

Author	Year, Country	Sample size	Study design	Assessment	Main findings
Papadopoulos et al. (35)	2013, Greece	#103 (DS4)	RCT	MCQs knowledge questionnaire Virtual Patient feedback	VP group had significantly higher scores and the majority evaluated the aspects of the simulation very positively
Zafar et al. (34)	2020, Australia	#100 (DS)	Cross-sectional	Traditional and Simodont training on pulpotomies and stainless-steel crowns (SSCs), followed by a questionnaire	Over 50% agreed that Simodont-assisted learning, and facilitated understanding of pediatric dentistry tasks, although they felt more comfortable with the conventional training setup
Zafar et al. (33)	2021, Australia	#71 (DS2)	Cross-sectional	Self-administered questionnaire before and after the use of dental LA VR simulator	Most of the participants reported improved LA skills, more engaged in the learning activity, improved understanding of anatomical landmarks, and added value compared with traditional LA teaching methods
Hu et al. (36)	2022, Singapore	#60 (DS3)	Cohort	Jefferson Scale of Empathy test Pre- and Post VR intervention and post-clinical experience	Pediatric virtual patient intervention significantly improved communication and behavioral management of pediatric patients and could be used to improve empathy and ability at managing children by dental students

Discussion

The application of VR in dental education has evolved increasingly, and there is significant scientific evidence that describes different virtual setups in different dental educational modules. However, the actual significance of VR simulation on dental education outcomes is not entirely clear. Earlier, VR may have been considered luxurious or optional, nevertheless in the shadow of the global COVID-19 pandemic, the advantages of using simulators to continue training dental students has been recognized to maintain the continuity of the curriculum without any setbacks. VR may provide an opportunity for dental students to build and retain theoretical and clinical dental expertise without the need for waiting for clinic time.

In comparison to traditional phantom-based training methods, VR-based dental simulators have strengths and shortcomings that are briefly listed blew:

Advantages of Haptic VR Dental Simulators:

- Acquire dental operation skills along with relevant theoretical knowledge. (37)
- Repeatable and reversible preclinical training thus more flexible training experience. (38)
- Provides digital objective evaluation and feedback. (39)
- Recreating situations that are similar to those in a real clinical environment. (40)
- Save the time of faculty and reduce the teaching burden while allowing students to practice repeatedly whenever they want, thus improving convenience for both teachers and students. (41)
- Reduce transmission of air-born and water-born microbiome.

Current Disadvantages of Haptic VR Dental Simulators:

- Using 3D glasses can slightly change the color of the tissues and the image quality. Also, a lower resolution may result in inaccuracy in the dental operations which need precision. (42)
- The 3D glasses can also cause unpleasant effects for some people such as vertigo and nausea. (43)
- In some haptic dental simulators such as the Kobra, Haptel, Periosim, and VirDenT, there is a lack of bimanual operation such as using the left hand for holding mirror to stretch and protect the soft tissues, indirect vision and reflect light. For optimal experience, it is important to have training on bimanual operation in a dental simulator. (44)
- Not precise enough force feedback. Currently, the force feedback of them is based on a force-generating algorithm. This is different from a real instrument in touch with the oral tissue, particularly soft tissue. More improvement is needed for the fidelity of force feedback in the future. (45)
- For all simulators, professional instruction and performance feedback from teachers are still needed for a comprehensive evaluation. (46)

Overall, in summary, to provide good dental skills training with VR simulator, it should contain comprehensive training contents, teaching, practice and evaluation systems, precise force feedback for soft and hard tissue, and realistic operation environment.

Despite the fact that VR dental simulators have some shortcomings, many researchers are yet positive about the roles that they play in dental skills training in combination with the guidance and feedback from instructors. Al-Saud et al reported that students could acquire basic manual dexterity faster when their training is a combination of the guidance from an experienced faculty as well as practice with virtual reality dental simulators. (47)

Currently, most simulators are specific to only one area of dentistry and none of them meet the training requirements for all disciplines of dentistry. Nevertheless, pediatric dentistry is a field that operates a comprehensive treatment on kids and adolescents ranging from restorative, prosthodontics, endodontics, periodontics, to esthetics procedures. Hence, most of the existing simulators can be considered as viable teaching options in the academic and clinical setting. Moreover, a simulation of a virtual patient based on a virtual reality, may improve students' knowledge in behavior management for pediatric dentistry when used as a supplementary teaching tool. (36) In a study conducted by Papadopoulos, et al., the majority of the participants evaluated the aspects of the simulation very positively while 69% of the simulation group expressed their preference for using this module as an additional teaching tool. (35)

Based on our search, so far only four studies have been conducted to investigate VR simulators use in pediatric dentistry. One of the studies conducted by Zafar, et al., investigated dental student's perception of dental local anesthesia VR simulation on a pediatric patient and determined whether this can improve students learning experience. Among the study participants 56.4% agreed that it added value compared with traditional LA teaching methods**.** In another study conducted by the same author, 51% of the dental students who completed pulpotomies and stainless-steel crowns (SSCs) training in Simodont and conventional pre-clinical simulation laboratory agreed that using Simodont assisted their learning, and 56% felt Simodont training facilitated their understanding of pediatric dentistry tasks. However, 88% of students disagreed that Simodont should replace conventional simulation.

Some studies investigated the VR simulators in sedation training in medical field, however, there is no data about its use in pediatric dentistry. It has gained recent popularity as an immersive approach to medical sedation training, but minimal content has been developed. (48) As the same concept of sedation can be expanded to pediatric dentistry, more research is needed to explore it as the educational training modality. Lastly, further studies are required to assess haptic virtual reality simulators' potential for further development in various pediatric dentistry educational settings.

Conclusion

As a complement to the current traditional teaching methods, haptic virtual reality dental simulators are valuable educational tools that could serve as a powerful aid to the preclinical training in dentistry. In the modern education era with improvements in hardware and software technologies, virtual reality dental simulators are promising tools to facilitate and advance dental trainings. This review also offered some insights into the current literature on the use of haptic dental simulators for early pediatric dental training. The studies included had predominantly cross-sectional design with short-term evaluation data. However, further studies on the benefits of long-term use of the haptic simulator and its advantages should be conducted. Moreover, more studies should be conducted to help improving their software and hardware effectiveness and overcoming their limitations in dentistry.

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