

Review

Significance of Haptic and Virtual Reality Simulation (VRS) in the Dental Education: A Review of Literature

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Abstract: The significance of haptic and virtual reality (VR) has been acknowledged by eminent dental professionals and has transformed dental teaching in the modern dental world. With this novel technological concept, students can interact with digital simulation on the screen and learn treatment skills before transferring them to real situations. This is helpful for gaining skills confidence, revising exercises again and again without the waste of materials, and for student assessment controlled by a teacher or tutor. It is a promising technology to enhance dental education for the new era of post COVID-19 practice due to noncontact patient training environments. It can create a safe learning environment for the teacher and learner or participant. The prospect of this literature review is to highlight the significance and clinical applications of virtual reality and simulations in undergraduate dental education.



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1. Introduction

Simulation, an approximative imitation of a real system, is a constructive learning strategy which was introduced in the healthcare system for patient safety while assisting the operators to be confident before performing their first procedures [1]. Since the 18th century, humans have been in pursuit of seeking simulation techniques to facilitate learning strategies in affective, cognitive, and psychomotor disciplines, constituting a diversity of activities for novices, learners, or experts. Figure 1 illustrates the antecedent simulators used along with the advancements made in the modern era and the factors which led to their development [2].

Simulations in dental education date back to 1990s [3]. Currently, the utilization of robotics and haptics simulations with the evolution of virtual reality has revolutionized dental studies. Virtual reality (VR) offers a promising future in dental education and is attracting global attention as it provides an exceptional training environment along with instant feedback facility, thus creating tremendous opportunities for students to acquire standardized skills [4]. Figure 2 illustrates the advantages of virtual reality simulation in dental education.

The fundamental principle behind simulations involves the use of software technology to produce images (while another domain of VR, categorized as haptics, deals with sensations such as sounds, pressure, and vibrations, thus creating an imaginary environment for the user) [8]. Given the irreversible nature of human teeth, competency of dental students prior to basic dental procedures including root canal therapy, crown cutting, or oral surgeries is of immense importance. Thus, a virtual environment established by three dimensional (3-D) technology is an essential tool for effectively delivering psychomotor skills

to undergraduate dental students as it provides an avenue to augment their diagnostic skills along with efficient treatment planning [9].

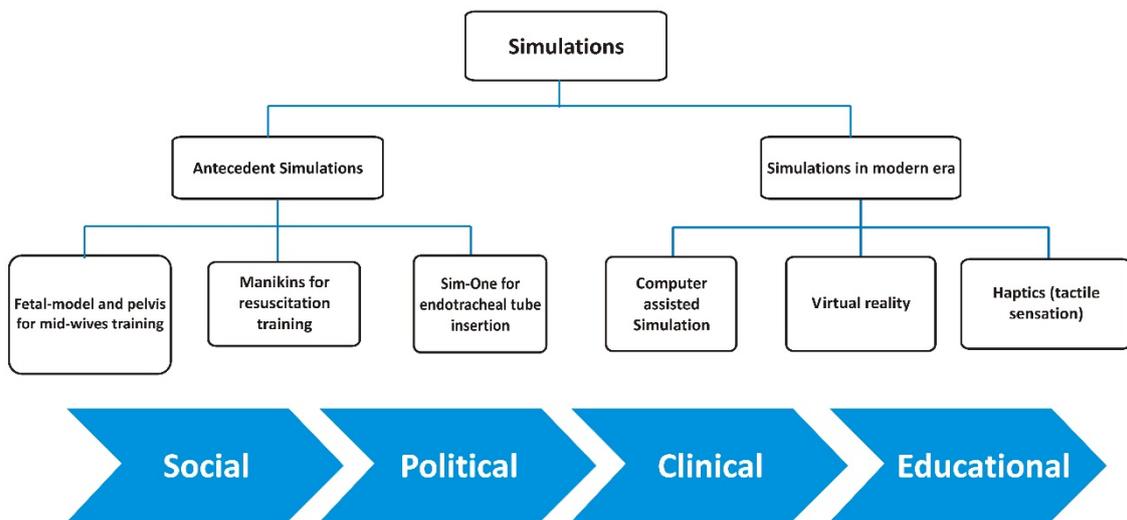


Figure 1. Illustration representing the antecedent simulators along with the modern era simulators.

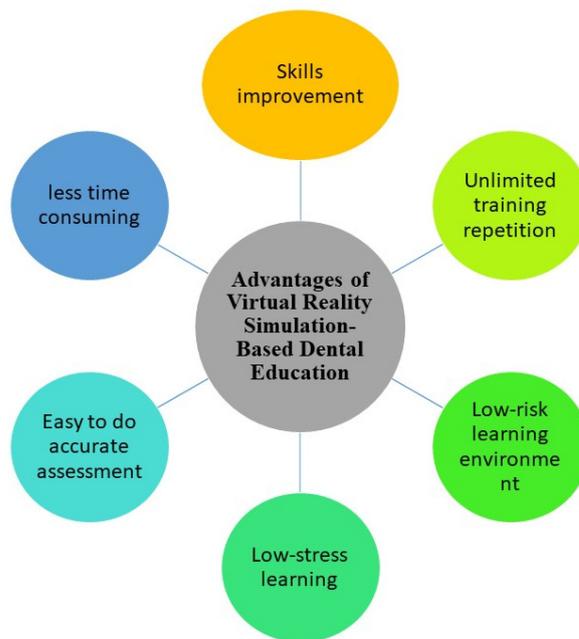


Figure 2. Advantages of virtual reality simulation in dental education [3,5–7].

Additionally, VR-based dental simulations also prevent the operator from clinical catastrophes such as a prick from an infected needle or sharp instruments, hence providing them with ample time to get familiar with the tools and practice clinical procedures without supervision. Raghav et al. reported the efficacy of VR exposure therapy (VRET) for treating dental phobia. This therapy is quite useful in treating dental phobia and anxiety for dental treatments. Regrettably, as yet there is a dearth of content and trained facilitators in the majority of dental schools (mostly due to the massive initial investment required) [6]. Table 1 provides a description of commercially available dental virtual reality-based simulators with their complete software and hardware details. This young generation is more technology oriented and learn skills more quickly than by conventional methods. We all are currently in the era of digitalization where everything is going to be digitalized.

Table 1. Comparison of commercially available dental simulators. (Adapted and modified from the E. Roy et al. [10]).

Devices	PerioSim®	Voxel Man	DentSim™	IDEA Simulation	Simodont®	SIMtoCARE	Virteasy Dental ©
Software used	Modified version of Ghost™ (SensAble Technologies, MA) Coin3D software Fast Light ToolKit (FLTK)	VOXEL-MAN Dental (University Medical Centre Hamburg-Eppendorf, Hamburg, Germany)	DentSim™ software Tracking software Proprietary tracking cards Proprietary interface card to A- Dec hardware (Image Navigation Ltd.'s, NY, USA)	Manual Dexterity™, Caries Detection, Scaling & Root-Planning™, OralMed™ and PreDenTouch™ (IDEA Dental, Las Vegas, NV, USA)	Nissin Simodont Dental Trainer Courseware software (Nissin B.V., Nieuw-Venep, ND)	SIMtoCARE B.V. SIMtoCARE student App. Case editor application. Reporting in MS Excel on Teacher station. Supports many procedures: manual dexterity, operative dentistry, prosthodontics, endo access to the root cavity, implantology, periodontics.	HRV Simulation Virteasy Dental—Simulation software capable of 3D and full VR. Virteasy Editor—Exercise management and creation. Virteasy Assistant—Data management tool for progress tracking, student feedback and grading.
Hardware specifications	Two computer monitors with haptic device Crystal Eyes Stereo Glasses™ and a Crystal Eyes Workstation™ (Stereo Graphics Corp.™, San Rafael, CA) used for 3D viewing APHANToM™ haptic device from SensAble Technologies™ (SensAble Technologies, MA) with 3-degrees of freedom VR William’s periodontal probe (Hu-Friedy™, Chicago, IL) or periodontal explorer (Hu-Friedy)	Workstation computer, 3D LCD monitor, 3D glasses, force feedback device, and a space navigator Similar to the Phantom device used in IDEA	The A-dec patient manikin used in conjunction with DentSim™ Pentium IV PC 2.66 GHz with 512 MB RAM	A stylus, with six degrees of freedom, attached to a stand (Phantom Omni, Sensable Technologies, Wilmington, MA, USA)	Two projectors Panel Pc 3D glasses Handpiece connected to force feedback sensors, mirror measured in 6 DOF with limited range.	4K autostereo screen (3D) No need for 3D glasses Integrated iPad Handpiece and mirror with large working range. Handpiece connected to force feedback sensors Finger support for upper and lower jaw	Fully integrated simulator with two HD screens. No need for 3D glasses. Oculus VR headset (optional use). 3D printable and customisable finger rest. High fidelity haptic device with weighted metal dental handpiece and 6 DOF movement. Electromagnetic tracking device for dental mirror. 3D mouse.
Use external camera	No	No	Yes, Dual CCD IR tracking camera	No	No	No	No—Navigation screen is equipped with a camera for future functionality.
Ergonomic postures	No	No	Yes	No	Yes	Yes (height adjustable)	Yes & height adjustable
Instant feedbacks	No	Yes	Yes	Yes	Yes	Yes	Yes
Exam simulation	Yes	Yes	Yes	No	Yes	Yes	Yes
Wi-fi	No	No	No	No	No	Yes (optional, wired is standard)	Yes (optional use)

Table 1. Cont.

Devices	PerioSim®	Voxel Man	DentSim™	IDEA Simulation	Simodont®	SIMtoCARE	Virteasy Dental ©
Direct transfer of data to programme convenor/tutor	Not available	Not available	Yes Run-time control application enables the instructor to control run-time grades	Yes The software contains a replay mode. Upon completion of a specified task, it can be watched in full by the student or the instructor	Yes The teacher station allows instructor to watch six simulators live at once and record all preparations for evaluation and giving feedback later	Yes Remote viewing of the iPad and simulator view of all simulators simultaneously.	Yes—through Virteasy Assistant.
Teeth used	Animated	Animated	Plastic teeth	Animated	Animated	Animated (virtual reality mixed with reality)	Animated—from micro-CT scans
Right and left operation	Available	Available	Available	Available	Available	Available	Available
Ability to use off campus	Possible	Possible	Not possible	Possible	Not possible	Possible (with additional server)	Yes
Reported real life experience	Tactile sensation is realistic for teeth and not so for gingiva [11].	N/A	Realistic experience using plastic teeth on a real manikin [12].	Tactile sensation still needs to be tuned to simulate a genuine sensation [13].	3D images are realistic. However, the texture of healthy decayed and restored tooth structure still needs improvement [14].	Latest technology with high resolution realistic 3D models in auto stereo and mixed with the real view of the hands and finger support (mixed reality).	The results of this study demonstrate that it is possible to provide reliable and clinically relevant qualitative feedback via a VR dental simulator [15].

Currently, the role of technology-enhanced and simulations-based learning as an essential tool for delivering dental education is acknowledged across the globe. Since the beginning of training, dental practitioners are expected to develop high psychomotor skills to be proficient clinicians. However, technological advancements are required in this field with an aspiration of increasing the learning curve before working on a patient [16]. Simple phantom-head simulators are helpful for psychomotor skills but explorations with hand-eye coordination along with motor skills hold immense importance. In reality, a lot of expenses are required for the maintenance of this system, including waste management and the expensive materials required for teaching students. Phantom-head dental simulators are not working on green dentistry or eco-friendly principles. Hence, incorporation of haptic training devices or virtual reality simulators (VRS) in delivering dental education is effective and provide a feedback mechanism proposed for the refinement of manual dexterity [17]. These devices replicate a real environment for its users, allowing them to touch and feel surrounding structures [18]. Dental operators with the aid of a virtual reality test systems do not only prepare students for dental competencies but also emphasize target appraisal based competencies [19]. Learner skill assessment is mainly accompanied by having a specialist supervisor who observes the procedure with the final result achieved conventionally. However, there is a limitation of human expert assessment. By VR simulators, all of the aspects of the operator's work can be collected and summarized during the simulation activity and further analyzed to provide a more appropriate objective assessment and feedback. Primarily the term *haptic* is also recognized as a *cutting edge technology* [20] and connects an individual with a computer and simultaneously provides tactile feedback. The operator applies divergent forces along the axis and obtains feedback [20]. Figure 3 shows various commercially available dental simulators.



Figure 3. Different type of commercialized simulators in dental education trainings: (A) SIMtoCARE, (B) Model T—Uni Sim, (C) Model L—Uni Sim, (D) Virteasy Dental, and (E) SIMtoCARE.

Consolidation of a haptic device in a training system as part of an undergraduate curriculum permits the users to practice a variety of dental procedures in a virtual 3D environment where they can touch or feel the objects, thereby creating more realistic conditions [21]. In the modern dental era, facilitators have an extensive array of haptic devices for every field of undergraduate dental studies with their pros and cons and

different principles according to their applications. The categorization of dental simulators and their applications according to the dental departments are discussed in Figure 4 [8].

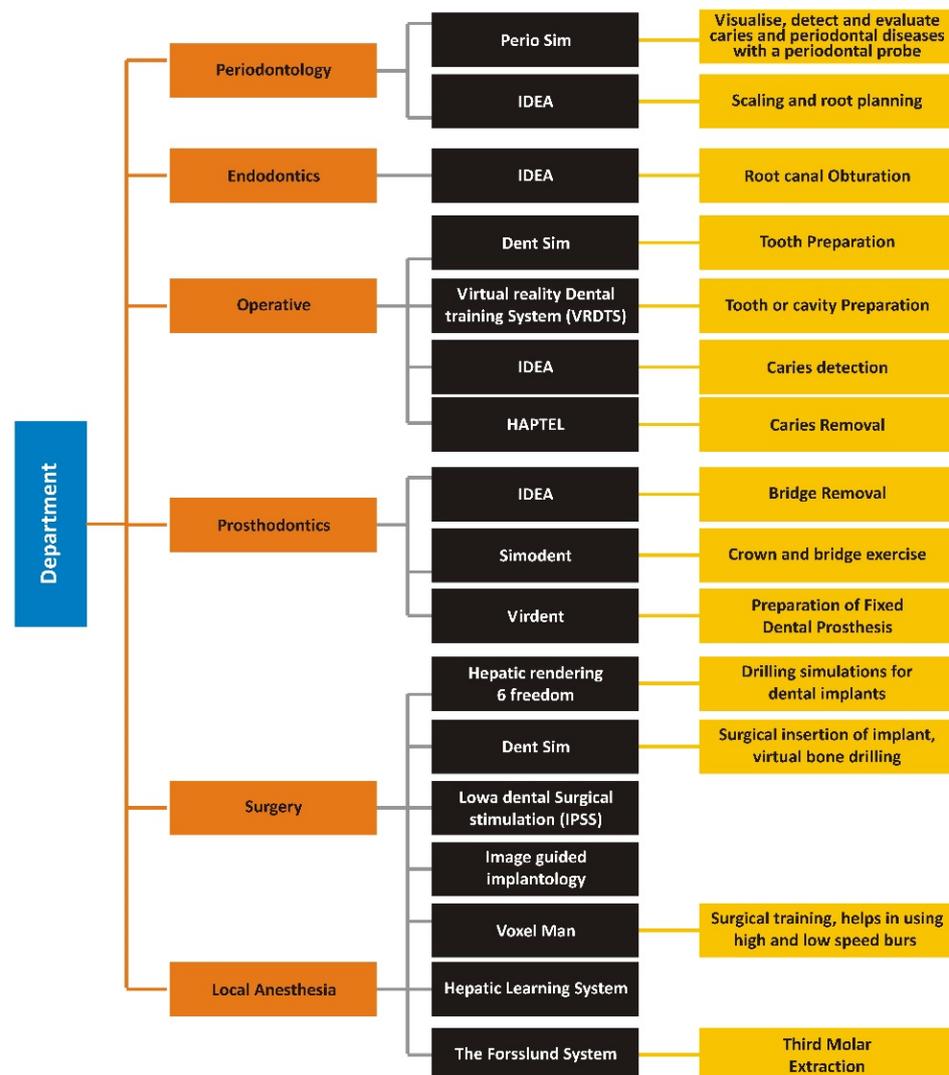


Figure 4. Classification of simulators based on their application in dental departments.

2. Virtual Reality in Periodontology (Gum Diseases)

To understand the practicality for the utilization of a virtual reality simulator, it is essential to seek the foundations of diagnosing periodontal disease. Periodontal disease as newly classified as, “a chronic multifactorial inflammatory disease associated with dysbiotic plaque biofilms and characterized by progressive destruction of the tooth-supporting apparatus” [22]. The initial characteristics include loss of periodontal tissue support and bone loss, which may be assessed radiographically by the appearance of periodontal pocketing along with gingival bleeding. Other features include the presence of plaque/calculus and gingival inflammation. The biomarkers of periodontal probing pocket depth (PPD) and percentage bleeding on probing (BoP) are important parameters in classifying the disease and are dependent on the skills of a dentist.

The measurement of these parameters involves the use of a periodontal probes [23]. These instruments require careful probing of the gingival sulcus around six areas per tooth with a standard pressure of 0.25 Newton (N) to chart the pockets. The probing pressure required to measure peri-implant disease is further reduced to 0.15 N [24]. Thus, motor skills and tactile perception of the gingival sulcus by the dentist are paramount in

aiding diagnosis of diseases. Furthermore, the removal of plaque/calculus by mechanical or ultra-sonic means also involves operator variability. The removal of calculus during non-surgical periodontal therapy also requires the operator to be alert with his perceptions of sub-gingival plaque or calculus. Traditional interventions allowed for the utilization of models or animal heads for the development of periodontal skills such as tissue handling and flap surgeries. However, in the modern era, various studies have reported success in using a virtual reality-based computer system. In Table 2, a detailed description of the reported studies is mentioned. A haptic virtual reality simulator system (PerioSim[®]) was introduced by Steinberg et al. in 2007, the idea of which was taken from another audio-visual reality simulator called DentiSim [25]. PerioSim[®] introduced the haptic “touch to feel” sensation by having a stylus to interact with a physical dental model which is then portrayed visually in 3D. The result of the study indicated that it increased the students’ tactile ability (although the representation of gingiva could not be registered into the system and some limitations were observed). Similarly, Koesnikov et al. introduced a haptic feedback system which registered pressure and pathway demonstrations [26]. Although it improved the tactile perceptions of its users, the accurate reconstruction of gingiva could not be registered into the system. Furthermore, Yamaguchi et al. also proposed a haptic feedback virtual reality system which was specifically designed for periodontology [27]. It involved the simulation of probing skills and caries removal. The results obtained from his study indicated remarkable improvement in students’ perception and tactile ability to replicate performances, but the system could not fully replicate the environment of a clinical setting or cutting instrument. The major advantage which was seen as being common in all the aforementioned studies was the improved tactile perception and ability of a student to detect and appreciate the anatomical considerations. Another advantage was that these virtual reality systems were less time consuming than conventional training classes. Considering that drawbacks in delivering pristine education can sometimes occur due to tight schedules and lower strength of professional faculty available, these systems can prove to be useful as they do not require more training staff and are self-explanatory in their use. Despite all the benefits of this technology, the major drawback is the cost-effectiveness of the devices. Considering that majority of the devices have been unable to reproduce the accurate 3D models of soft tissue owing to the morphology of the soft tissue itself, teaching hospitals in developing countries are unable to use this technology.

Table 2. Applications of virtual reality (VR) simulation in periodontology.

Author	Scope	Sample Size	Main Findings	Conclusion	Future Recommendations	Limitations
Yamag Uchi et al. [27]	Caries removal and periodontal probing skills were assessed, using haptic virtual reality simulator.	Caries removal: 7 Periodontal pocket probing task: 26	Significantly higher training scores were obtained after the first training session.	In-contrast to a conventional stimulator, a VR simulator can be used for multiple purposes and can be utilized as a training tool for efficient evaluation within a short period of time.	Scores for cutting should also be incorporated for future training evaluations	The simulator failed to replicate an exact clinical environment, use of hand instruments, electric engine and tools with cutting properties should be incorporated. Moreover, for a more realistic approach, soft tissues and face models should be developed.
Steinberg et al. [25]	Perio-sim was developed, using haptic technology and VR graphics	30	Highly realistic graphics were formed for teeth in contrast to the gingiva. However, Periosim [®] can serve well to evaluate basic skills	Periosim [®] can be a valuable tool to develop tactile skills in students	A significantly greater realistic touch for gingiva and the addition of a sound system is highly recommended. A six-degree freedom unit should be established. Furthermore, students trained with Periosim [®] should be contrasted with learners, trained with conventional methods to evaluate the efficiency of the system.	Few defects in terms of stiffness and deformability were observed in graphs, thus the exact difference between the tooth and gingiva couldn't be evaluated. Collision with the lateral aspect of the device couldn't be evaluated due to the "three-degree freedom" nature of the system.
Koesni kov et al. [26]	Development of a haptic simulator for investigation of sensorimotor skills	30	Models, demonstrating force and position pathways were developed along with a haptic playback system	The simulator proved to be a useful tool as it could record the procedure performed by the facilitator while the trainees could easily follow the force and position pathways formed by the teacher.	For future investigations more complex features for a more realistic approach needs to be incorporated such as gingival tactile feel.	The gingival tactile feel could not be evaluated. The system lacked complex effects.
Wang et al. [28]	Development of iDental simulator for quantitative and qualitative analysis	29	The simulator was able to sustain construct validity, thus differentiating students from experts	Bimanual coordination could be practiced using this haptic feedback system and the results could be evaluated quantitatively and qualitatively.	3-DOF model designed, led to penetration of probe into the gingiva and tooth thus incorporation of a 6DOF model would give more reliable results.	Users gave rough readings at points where the occlusion was serious such as central lingual point of the tooth.

3. Virtual Reality (VR) Simulation in Restorative Dentistry (Dental Caries Management)

A preeminent emerging trend to train students for operative procedures and the development of psychomotor skills is the use of virtual reality in dental education [16,29]. Restorative dentistry revolves replacing a diseased part of tooth structure followed by restoration, thus developing restorative competency by practicing standard geometrical features for cavity preparation followed by proper placement of restorative materials. This forms an integral part of training inspiring dentists. The role of VR simulators is essential in the restorative dentistry since it is incorporated in the undergraduate curriculum much earlier in contrast to other preclinical courses [29]. Conventional restorative training involved the use of manikins that helped in positioning and mimicked the general anatomy. However, the difference in mechanical properties of plastic teeth in contrast to real ones along with changes in hardness due to carious lesions could not be simulated in conventional manikins [27]. The emergence of computer-assisted simulations revolutionized undergraduate dental training [18,30].

Virtual reality (VR) in restorative dentistry and endodontics offers the prospect of creating a digital environment for its users to perform various exercises such as cavity preparation (by providing multiple magnified images), caries evacuation, and light-curing techniques [31]. Additional features such as simulation fidelity integrated the simulation device with the proposed learning objectives. “Real-time feedback” allowed students to practice independently and gave a standardized assessment of their work [16,30]. For individual evaluation, the feature also allowed the recording of the training session [32]. Validity and follow up studies reported significant improvements in novice dental students trained with VR technology. Quinn *et al.* conducted a study to compare conventional training with virtual reality simulation among dental students in terms of outline, cavity depth, and smoothness, retention, and angulation of margins [33]. Students trained with VR simulators performed better when evaluated for cavity shape, depth, and smoothness while the results for retention and margin angulation were the same among both study groups. Jasinevicius *et al.* in another novel study concluded that students can be trained five times more promptly in contrast to traditional exercising [18]. Other preliminary studies are listed in Table 3. Therefore, there is a need to integrate VR simulation-based learning in the curriculum, as this would empower students with an option of self-learning which could instantly be evaluated thus saving the instructor’s time. These studies showed that the VR simulation improved the handling skills and help in transferring skills in clinical practice. Recently, the reliability and clinically relevant assessment via virtual reality has been proven by Jonathan *et al.* [15] on the commercially available VIRTEASY Dental[®]. In this study, assessment criteria for cavity preparation are optimized and qualitative analysis was conducted. The finding of the study provides a detailed proof of concept for validating the assessment carried out by VR dental simulators.

Table 3. Application of virtual reality (VR) simulation education in the restorative dentistry and endodontics.

Author	Year	Scope	Sample Size	Main Findings	Conclusion	Future Recommendations	Limitations
Desmond [34]	2008	Quantitative measurement of the length of the root canal using VR	7	A novel method for the measurement of the length of a root canal was introduced, which was safer in terms of radiation and gave more accurate results in contrast to traditional X-ray method.	Measurements using VR technology gave results for complex cases and was proved to be economical and more accurate as compared to classical methods.	For future studies, a more realistic environment such as a phantom head or real patients is preferred as compared to the separate teeth used in this experiment. Collaborative work with peer discussions is highly recommended. The calibration process can be improved in future studies by performing usability analysis	Separate teeth on an optical bench were used, thus a realistic environment could not be provided.
Suebnuakarn [35]	2010	kinematic information concerned with movement was investigated using VR	32	Increased performance in skills and retention sessions was observed.	The system proposed had the ability to record student's performance related to kinematic data.	A more realistic environment should be provided and transfer of motor skills from a virtual setting to the patient would serve well in a patient's interest.	In the present study, a computer screen was the only mode of interaction available between the virtual tooth and tool, thus visual hand alignment with the simulated tool would be an advantage for future research.
Toosi [36]	2015	Virtual jaw model was obtained from CT data of a live patient and VR simulator was utilized for root canal treatment.	Not mentioned	K-files from the internal tooth surface could be haptically simulated. Beam deflection model was utilized to simulate K-file deflection. Marching cube's methodology visualized bone removal. Furthermore, to solve the beam model, Runge-Kutta's method was used	A VR method was proposed, which used Phantom haptic models to clean internal tooth surface using simulated K-files to bur enamel and dentin.	Need of more work on this technology for expanding more endodontic procedures via this system.	N/A
Suebnuakarn [37]	2014	Skills were assessed using VR simulator	34	Fortified on quantitative analysis, a competency criterion was proposed which proved that with repeated practice on simulators, students can augment their skills	VR simulator can be used as an invaluable tool for training dental students and differentiate the capabilities of expert practitioners with students.	The model should also evaluate the learning capabilities of students in a real clinical environment.	The model lacked a more realistic approach.
Suebnuakarn [38]	2010	Assessment of endodontic skills	20	Improved skills in post-trained students were observed in terms of force pattern and coordination.	Haptic VR technology used in the study, proved that students learnt faster and had a better knowledge related to force and bimanual dexterity.	Transferability knowledge from VR setting to the clinical environment would be beneficial for future research purposes.	Students were not accessed in a proper clinical setting; thus, the exact transferability knowledge could not be evaluated.

Table 3. Cont.

Author	Year	Scope	Sample Size	Main Findings	Conclusion	Future Recommendations	Limitations
Suebnuakarn [35]	2011	To minimize access preparation errors, micro-CT tooth models were utilized to investigate the effectiveness of VR simulators.	32	Equivalent results to reduce procedural errors was observed when VR simulators were compared with phantom heads.	Micro-CT models of teeth along with VR simulators is a valuable tool for skill development in endodontics.	Skills of VR operators should also be evaluated in a clinical setting.	Skills acquired, were not evaluated in a clinical setting.
Reymus [39]	2020	An economical method using VR technology was used to teach third-year operative students.	42	VR simulators were reported to be equally good in contrast to CBCT and more beneficial as compared to radiography for detection of anatomical features of root canals.	Integration of VR simulators was highly appreciated	The performance of students after each technique should be evaluated in a randomized manner. Students should be divided into groups and to reduce biasness, the investigator should ensure that they don't have any prior knowledge	Student's performance after each method would have given a better evaluation of each proposed method.
Wang [40]	2016	For exploration and diagnosis of carious lesions, an approach was introduced using 6DOF haptic interaction.	5	Stable simulation of varying levels of decay was possible using this approach.	The proposed method simulated different tissues, depth and surface roughness of caries and can be used to train dental students for their motor skills. Students were able to prepare a cavity and use correct instruments during each phase. Secondly, they were able to learn the clinical protocols for treating a lesion and preserving healthy tissues.	Evaluation of skill transfer from the simulation to a real clinical setting would be an advantage.	The study lacked evaluation in a real clinical setting.
Cecilie Osnes [41]	2017	Moog Simodont Dental trainer was developed to teach caries removal and cavity design to dental students.		A novel, caries simulation approach was introduced, students were able to practice caries removal, predominantly its tactile and cognitive aspects in a safe environment.		Evaluation of construct validity and investigate caries algorithm. Secondly precise, simulation of the probe is important.	The simulator was not able to simulate a dental probe, thus correct movements for identifying caries could not be evaluated.

4. Virtual Reality in Maxillo-Facial Surgery

Advancements in simulation-based education allowed learners to practice and opened opportunities for professionals to plan a wide array of surgical procedures. Its applications vary from evaluating accuracy for orthognathic surgery [42], obtaining a perfect match of virtual planes for jaw reconstruction [43], to correct placement of dental implants by guiding its direction and proximity with other important structures [44]. Virtual planning of implants has revolutionized implant dentistry as it has the potential for treating complex cases in immunocompromised patients with least invasive surgical procedure. Dynamic navigation or static guide approaches are utilized to transfer 3D virtual planning onto the surgical field [45]. Dynamic navigation has an advantage over the latter technique as it aids in adjusting the implant's direction in a flexible manner using virtual planning. Established on the virtual designing, static transfer of plan involves fabrication of surgical guide followed by the use of CAD/CAM for implant insertion. In accordance with the type of support (such as dental, mucosal, or bony support), numerous types of surgical guides are accessible to obtain an exceptional accuracy [46].

Formerly, accessibility of computer programs enabled its users to determine the position of dental implant [47,48] but these programs lacked the potential to give the bone drilling feel to its users [49]. However, initiation of virtual reality simulation (VRS) in the training programs offered opportunities and enabled its users to have a perception of touch along with sight [50]. The system proved to be beneficial for evaluating intimate details of the procedures performed and therefore imparts a rigorous assessment [51]. The haptic devices used in the VRS allows its users to detect the texture of the surrounding soft tissues or bone handling drill, consequently preparing them for real case scenarios [52]. Similarly, orthognathic surgery involving the use of navigation in a virtual environment gave remarkable accuracy in patients. Preoperative simulations comprising of navigation system were utilized to perform the surgeries which included fractures, TMJ ankylosis, cleft lip repair [53], fibrous dysplasia, mandibular hypertrophy, and tumors [54,55].

Literature mentions the significance of virtual reality simulation for the standardization of dental education and need of more studies to optimize the value, assessment method, student feedback, and mechanism of integration in dental curriculum. Numerous methods have been proposed to motivate students towards self-learning thus reducing the faculty time and ameliorating their training skills. Various simulators have been introduced including VOXEL-MAN[®] simulators, which enabled its users to self-assess themselves, validate their training, and represent a safe, realistic, non-destructive, easily accessible surgical anatomy for junior's resident. It is also low cost. Along with their skill refinement, the majority emphasized the training of technical skills. However, there exists a gap in these simulator models in terms of non-technical skills, thus creating problems for its users while working in stressful environments such as operation theatres. In Table 4, discussion of the reported studies on the applications of VR-based simulators for the oral and maxillofacial surgery.

Table 4. Application of virtual reality simulation (VRS) in oral and maxillofacial surgery.

Authors	Year	Scope	Sample Size	Main Findings	Conclusion	Recommendations	Limitations
Heiland [56]	2004	Establishment of a simulator which provided realistic haptic manifestation of structures and with its haptic sensation ability could simulate bone reduction.	40	A sagittal, coronal and axial drilling route was accessible during the procedure.	The system opened possibilities for realistic simulations of complex structures.	Incorporation of soft tissue simulations. Inclusion of other complicated procedures such as molar impactions. Incorporation of CBCT technology for the investigation of oral pathologies	The system lacked a realistic approach
Ioannou [57]	2015	Investigating the effects of integrating VR technology in surgical training in contrast to ovine jaws.	14	Performance of trainees was improved after being trained by the simulator. The 6-DoF haptic system introduced simulated tooth extraction with a variety of force-displacement forms and proved to be a valuable tool for training students to identify the pattern of force applied and correct posture of the tool used.	Comparison of both techniques utilized gave the same results, however, they did not simulate with a real clinical environment. The simulator gave promising results to train dental students for coordinated force and motion skills.	Effects of VR on different parameters would be an advantage, using larger sample size and longer time period. Incorporation of torque feedback in the system to create a more realistic environment.	Accuracy of simulator's drilling algorithm was questionable. The system lacked a realistic touch. Moreover, the magnitude and stiffness of the system were not appropriate, thus sudden changes could not be simulated.
Wang [58]	2015	A haptic simulation model was proposed to train dental students for tooth extractions		When the two groups were compared, the simulator trained group gave equally good results and proved to be a beneficial tool for implant training.	Simulator trained 3rd-year dental students gave a better performance in contrast to students who were not trained before.		
Joseph [59]	2014	Determine the effectiveness of a simulator for evaluating gestural abilities for implant surgery.	60			Evaluation of more complex cases	Simulator lacked the ability to simulate complex situations.

5. Virtual Reality Simulation (VRS) in Prosthodontics (Crown & Fixed Partial Denture)

Prosthetic dentistry is a diverse domain offering specialized procedures for the replacement of missing teeth or facial structures. Fixed prosthesis involves cementation of crowns or bridges, while removable prosthesis includes complete or partial dentures. Substantial loss of tooth or bone necessitates the need for a complex prosthodontic procedure with minimum damage to other surrounding tissues. Therefore, a dynamic treatment approach is required. Morphological features, functional problems, and esthetics are some of the essential parameters which need comprehensive care by a prosthodontist for lucrative occlusal reconstruction and simultaneously use them to make a coherent procedure plan [60].

The complexity of prosthetic procedures requires significant precision, and therefore the concept of creating digital clinical scenarios is extremely beneficial (especially during undergraduate programs). Experimental trials using virtual reality simulators such as *IDEA* for bridge removal or *DentSim*TM® for crown and bridge exercises demonstrated significant improvement in the scores of students in various clinical applications of prosthodontics [12,13,61]. The virtual reality simulators introduced enabled students to keep a record of their progress while simultaneously viewing their cases, thereby offering promising results during the training process. Another salient feature of the system was its ability to produce sound alerts if the user errs during the procedure (for instance, cutting an adjacent sound tooth), thereby providing instant feedback and evaluating their performance. This feedback evaluation eventually curtails the load on teaching assistants and offered the potential not merely for students but also for a specialist to ameliorate their clinical skills [62]. Fenney et al. proposed that virtual reality dental simulation increased student's curiosity and eagerness to learn [63] while the obstacles regarding the conventional dental training programs were discussed by Esser et al., who spotlighted the significance of VRS in undergraduate dental education [64].

Established on student scores and preparation time, Kikuchi et al. evaluated the skills acquired using *Dentsim*TM for porcelain fused to metal crown preparation. The virtual reality simulator was incorporated with a real-time image processor which enabled learners to look and evaluate their preparations on a monitor. His findings suggest that the VRS system improved the crown preparation skills of students and reduced the procedural time in contrast to other groups [62]. In another educational study investigated and compared the differences in clinical skills of experts while the experimental group constituted students who were trained by Phantom Omni haptic system (SensAble Inc., Silicon Valley, CA, USA), the two groups were eventually graded by an expert. The calculation of scores was based on three parameters which included the time taken to perform the crown preparation, the force used, and the bur angulation. His findings suggest that the VRS used had the ability to differentiate between novice and experts [61]. Other experimental studies are summarized in Table 5. After over-viewing, they reported that studies on the quality of crown preparation were good when instructed by VR dental simulators and were less time consuming as well. Student can easily revise the exercise many times (as per the needs of their course).

Table 5. Application of virtual reality simulation (VRS) in prosthodontics.

Authors	Year	Scope	Sample Size	Main Findings	Conclusion	Recommendations	Limitations
Kikuchi et al. [62]	2012	Access and compare the influence of VRS (Dentsim™) on student's crown (porcelain fused to metal (PFM)) preparation skills with and without instructor's feedback.	43	A non-significant difference between the two groups was obtained when the students of the two groups were evaluated for their crown preparation skills.	Students trained with VRS gave the same results when compared with the group of students trained by the instructor, therefore the presence of an instructor does not matter and can be substituted with virtual simulators. Secondly, VRS was less time-consuming.	DentSim proved to be an effective virtual simulator for PFM crown preparation.	Instructors did not provide feedback contents since the evaluation criteria were not given any consideration.
Suebnuakarn et al. [61]	2009	Compared the performance scores for crown preparation between experts and novices using VR simulation with force feedback.	20	Haptic VR system with force feedback can be used to differentiate the performance learners and experts.	The investigated parameters which include force, time and instrument angulation correctly evaluated the clinical skills between the two groups.	Incorporation of VR in dental education would allow standardized evaluation of clinical performance.	The clinical parameters evaluated did not provide immediate feedback, therefore for future research, techniques involving artificial intelligence models are highly recommended.
Rhienmora et al. [65]	2010	An intelligent tutor demonstrates dental procedures, therefore allowing students to learn and practice the procedures in a virtual training environment. The training module used has an ability to record and replay the procedures, thus allowing students to correctly follow the steps for crown cutting and reproduce the procedure.		The accuracy of the performance assessment was found to have 100% accuracy.	The virtual reality simulator was able to simulate realistic tooth surface and cutting.	A wide assortment of training strategies can be incorporated in the curriculum using this VR simulator, therefore creating opportunities to differentiate between the performance of the operator as a novice or expert.	In a few scenarios, the tooth surface was found to be too rough, therefore force shading algorithm along with its variants needs further investigations. Students faced navigation troubles in the new virtual environment. The system presented in this study was not able to simulate complex dental procedures which
G. Ben-Gal [13]	2012	Evaluation of manual dexterity, using a haptic simulator (IDEA), Testing parameters included: completion time, number of successful trials, accuracy and scores	106	High reliability of the simulator was observed for all the parameters and consistent results were obtained. Scores for human-based judgement were lower in contrast to the results of this study.	For the parameters tested, the simulator proved to be a valuable tool for assessment, however, the simulator was not able to accurately differentiate between the performances students are trained, dental practitioners.	To increase the sensitivity of the system, adaptations to increase the validity would be helpful to increase the differentiation capacity.	The system lacked the capacity to differentiate between the experts and learners.
I. R. de Boer [66]	2015	The difference in the performance of students, working in two types of the virtual environment (2D and 3D) was evaluated using Simodont dental trainer	124	Students trained in 3D environment performed significantly better in contrast to those working in 2D.	In a virtual training environment, 3D vision proved to be a valuable tool and first choice of preference for the majority of students.	Point of view of experienced professionals should also be considered.	The study did not investigate the results of experts and no comparison of results between novice and experts was drawn.

6. Significance of Technology Enhanced Simulation Education in Dentistry

VR creates an opportunity for practitioners to practice safe dentistry in a virtually realistic environment along with providing constant feedback. Dental simulators impersonate anatomical structures along with re-creating all the tactile sensations. In recent years, studies have signified positive repercussions of VR and simulators for patients by paving a way to view a panorama of a different world. This facilitates the calming down of apprehensive patients and has manifested positive outcomes by eliminating their sense of fear or pain. Consequently, further advance treatment could be scheduled. The evolution of technology in the modern world has made VR simulation-based teaching an integral part of learning for both undergraduate and post-graduate students. Moreover, in the COVID-19 era where social distancing is a necessity, dental training should be practiced in a way to protect students. Therefore, institutes should emphasize the significance of simulators. Haptic machines offer students the opportunity to practice a diverse range of clinical skills in a safe environment and augment their confidence before shifting to patients (which has also served well in patients' interests) [8]. Granting that present simulators lack the competency to challenge traditional dental training for some clinical fields, they still carry immense importance and studies have documented their effectiveness. However, further exploration is essential to ameliorate force feedback and video transmission ability of simulators. To facilitate dental students to practice various clinical procedures independently, it is definitely recommended to combine simulators with 5G and cloud computing technology [15,16]. Therefore, this review aims to persuade researchers to further investigate in this field while assuring trainers the significance of VR in dental training.

7. Conclusions

A paucity of standardization in the dental education system globally acts as a stumbling block in producing the finest dental practitioners. The aim of incorporating these novel technologies such as virtual and haptic simulator in dental education is to guide and help student development through different levels from beginners to competent experts. Therefore, expert clinicians can be trained by a continuous practice which improves their skills in various procedures such as tooth preparation, cavity preparation, periodontal diagnosis, prosthetic fabrication and surgical procedures such as implant placement by increasing their ability of tactile sensation with feedback mechanism before proceeding to work in patient's oral cavity. Another objective of replacing traditional phantom head-based training with VR is to reduce the material waste and cost spending on it. VR simulation labs do not require additional water sewerage pipelines or monthly maintenance which cost a lot to dental institutes and stakeholders. It has been proven that VR based dental education provides the good transfer of psychomotor skills to students while evaluating patients and managing clinical situations.

Based on standard practices for delivering dental education, various limitations exist which needs to be addressed. In essence, a limited number of studies have investigated the definite impact of incorporating the dental virtual reality simulators in the curriculum due to low educational standards, unclear scoring mechanisms, problems integrating this technology in dental curricula, and student or teacher feedback mechanisms. The models investigated in randomized studies so far have essentially focused on technical skills, therefore creating a gap in practicing of the non-technical skills. Thus, there is a need to bridge this gap in modern simulations.

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