A Systematic Review and Proposed Model for Integrating Virtual Reality Simulation Tools with Problem-Based Learning Method in Preclinical and Clinical Endodontics and Restorative Dentistry

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ABSTRACT
Background: Recent technological advancement have brought many opportunities for educators to integrate innovative techniques to maximize student learning. Problem-based learning (PBL) remains the cornerstone of teaching in preclinical and clinical dentistry. **Objective:** This study aimed to identify the applicability of virtual reality (VR) tools within the educational framework of PBL, and to propose a model for integrating VR techniques into PBL for dental education. **Methodology:** We conducted a systematic review of the literature. We identified articles between January 2003 and January 2022 by searching five electronic databases (PubMed, Scopus, Cochrane, Ovid MEDLINE, and Ovid OLDMEDLINE). Obtained literatures were examined based on PICO criteria following a preset of inclusion and exclusion principles. **Results:** A total of 17 studies were included in this review based on the search methodology employed. No observational studies directly explored VR in conjunction with PBL in endodontics or restorative dentistry. Studies however discussed either VR or PBL in relation to endodontic and/or restorative dentistry indicating lack of empirical work in this area. Nonetheless, the limited data available demonstrated the need for improvements in the performance levels of students adopting VR-enhanced PBL.
Conclusion: Problem-based learning method can benefit from augmentation with VR and simulation platforms for teaching preclinical dental students a wide variety of clinical procedures, refine their motor skills, thereby minimizing errors on actual patients and promoting more integrated learning. We propose that a learning model integrating VR and PBL is integrated in dental education.
Keywords: Problem-Based Learning, Virtual Reality Simulation, Endodontic, Restorative Dentistry.

INTRODUCTION

Problem-based learning (PBL) has consistently received support for being one of the most effective approaches to teaching in both preclinical and clinical medical and dental education [(1-3)]. Nonetheless, rapid advances in technology continue to influence the landscape of education and training. Educators are regularly exposed to new and innovative methods in facilitating the acquisition of knowledge, as well as sophisticated technology for use in augmenting instruction. While PBL is widely used within institutions where its instructors readily have access to this technology, very little effort has been made in integrating these advanced tools within the PBL curriculum[(4)]. In fact, virtual reality (VR) and simulation technology, which emerged as a result of the surge in scientific advancement, are becoming more common as useful tools for training and assessment in the clinical environment[(2)]. VR systems are one method of simulation, which allows medical professionals and trainees to practice and refine their ability to perform complex clinical procedures[(4)]. VR simulation, in particular, targets the individual's haptic, or tactile perception, sense by providing the individual with computer-generated sensory feedback (visual, auditory, or tactile) as they interact with the simulated environment in real time[(5,6)]. It is likely that VR simulation may be used in conjunction with PBL for medical and dental education, though limited data on the effectiveness of merging these two techniques exist within the current literature[(4)]. Problem-based learning's advantages include active participation in knowledge acquisition and a student-centered approach to learning that is anchored in a realistic setting, as evidenced by its popularity. Learning that takes place through PBL is focused primarily on concepts, rather than a specified amount of acquired knowledge, and draws heavily from the individual's existing knowledge base, which may further enhance concept building. Based upon the use of group discussions, the PBL student is asked to reflect and provide feedback as they tackle each assigned clinical problem, thereby completing the cycle of learning[(7,8)]. Curriculums developed on the foundation of PBL are comprised of the following four crucial elements: (**i**) Requiring students to use their knowledge in a clinical context, (**ii**) Improving students' clinical thinking skills, (**iii**) Advancing students' abilities to undertake self-directed learning, and (**iv**) Increasing students' intrinsic motivation for the subject matter.

Because the PBL technique is mostly centered on group discussion, there are some clear drawbacks to using it for skill acquisition in the clinical competency phase of medical and dental training[(3)]. Indeed, the acquisition and refinement of core clinical skills requires more practice-based experiences. Most training programs rely on an apprenticeship approach for clinical competency training, such that the medical or dental student sees patients under the close supervision

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of a skilled expert. While practical experiences are crucial to the student's development of competence as a practitioner, there are also a number of drawbacks to this apprenticeship approach[7].

For instance, this method of training increases the risk for complications (for dental trainees, this may include damage to tooth structure, pain, trauma to the tooth or other nearby structures, or even actual failure of the procedure) to arise during the procedure performed by a minimally trained student and may prolong the patient's length of treatment[3,4]. Further, the student's own anxiety regarding their skills in performing the procedure on a real patient, while being watched by a supervisor, is likely to contribute significantly to this increased risk[7]. Conversely, patients may not actually be comfortable receiving treatment from a trainee[7].

Virtual reality's capacity to generate a simulated world in which the learner can walk around and manipulate in a realistic manner makes it suitable for bridging the mentioned gaps in PBL's applicability for learning and practicing basic clinical competency abilities. Moreover, studies have demonstrated that the use of virtual learning tools was associated with improvements in knowledge. Retention was also observed to improve with the use of virtual learning, such that average rates of retention increased from 3.8% to 9.8%[6,7]. Further, instruction time was decreased by up to 75% when virtual learning tools were used in conjunction with clinical practice[3-6]. In fact, virtual evaluation tools, based on the principles and practices, may be a good way to evaluate students in terms of their clinical practice after controlling for any extraneous factors that may influence the evaluation (e.g., difficult patients)[8]. However, student-specific factors such as sleep deprivation or anxiety can still exist despite evaluation with VR[6].

The learning advantages of recent VR systems include: **i**) near complete simulation environments for many clinical procedures; **ii**) complex simulation environments by inciting the visual stimuli; and **iii**) ability to refine hand-eye coordination during each specific procedure using visual and tactile feedback. Each of these skills may be taught, by using VR and simulation, in conjunction with PBL to enhance the learning process and improve retention of important clinical concepts through visual and auditory stimulation[2]. On average, most dental students begin to strengthen and fine-tune their haptic sense and perfect hand-eye coordination from the very beginning of their preclinical and clinical training[9]. This is critical for dental training, as the small and difficult to access oral cavity impedes a dentist's ability to analyze the area conveniently. Indeed, the procedures performed within the oral cavity by dentists require a very high degree of precision[9].

AIM OF THE STUDY

The aim of this study is to determine the role of VR in teaching clinical competency skills of dental students and to explore potential ways in which VR techniques may be integrated with PBL method.

As such, literatures on the use of VR tools in combination with PBL specifically within restorative and endodontics preclinical and clinical dental training programs were reviewed. Additionally, findings from these studies on the role of different virtual methods for clinical instruction in dental training programs, in particular, how VR might help improve practice and acquisition of clinical dental skills were combined with findings from studies on the use of PBL among dental training programs, to create a proposed model on the augmentation of PBL using VR simulation for training in dentistry.

METHODOLOGY

The current study was a comprehensive systematic review, aimed at analyzing how different virtual learning methods are being employed within endodontic and restorative dentistry, and the possible role of VR classrooms in augmenting these teaching curriculums. This study specifically explored the role of VR in dental students' educational curriculum teaching methodology and any association with PBL.

For this systematic review, Population, Intervention, Comparator and Outcome (PICO) guidelines were used whenever applicable. PubMed, Scopus, Cochrane, Ovid MEDLINE, Ovid OLDMEDLINE, were searched for articles published in English language from January 2001 to January 2022 using keywords: "Restorative Dentistry AND Virtual Reality," "Endodontic AND Virtual Reality," and "Problem-Based Learning AND Virtual Reality". Titles of studies that matched the search criteria were examined and articles not dealing with endodontic and restorative dentistry were excluded.

Inclusion criteria, for this review, **included**: **i**) article was published within the last fifteen years; **ii**) article is written in English; **iii**) article explores PBL teaching methods for preclinical and clinical teaching; and **iv**) article examines the role of VR in dental education.

Exclusion criteria: discarded all studies published prior to 2001, those not written in English, and any articles that failed to discuss the pre-clinical/clinical teaching curricula.

The abstracts of the remaining articles were read in the second step of screening. Duplicates and off-scope studies were deleted. Full-text articles were read in the final review step to discover pertinent material. Manual searches of the reference lists from each recognized article were used to supplement the search. The final review did not include interim reports, abstracts, letters, short messages, reviews, or textbook chapters.

RESULTS

Articles were selected based on the relevancy of content to the current research topic. The focus was limited to articles that addressed the pre-clinical and clinical aspects of dental education through VR models in areas of restorative dentistry and endodontics. All other methods were excluded. After looking at the titles of all 55 abstracts returned in the search across the various databases and other sources, 4 duplicates were deleted. The abstracts of the remaining 51 articles were examined, and 30 abstracts were deleted after applying the inclusion and exclusion criteria. In addition, 4 further articles were eliminated, leaving 17 articles for the review. Full text articles were referred for validation and quality assessment. Studies were evaluated based on pre- and post-intervention assessment, homogeneity of participants, random allocation, and follow-up and feedback, respectively[10]. A flow diagram of the article's inclusion and exclusion criteria is illustrated in Figure **1**.

The extensive review of the database failed to return any article linking PBL directly with VR learning tools. As such, very few studies were included in this review (7 studies). Table **1** provides an overview of the studies included in the analysis in terms of study design, sample characteristics, and model construction (which accounts for potential bias factors), as well as a report of the results. These articles exhibited considerable variation in all aspects from the statistical test to interpretation of analysis scores.

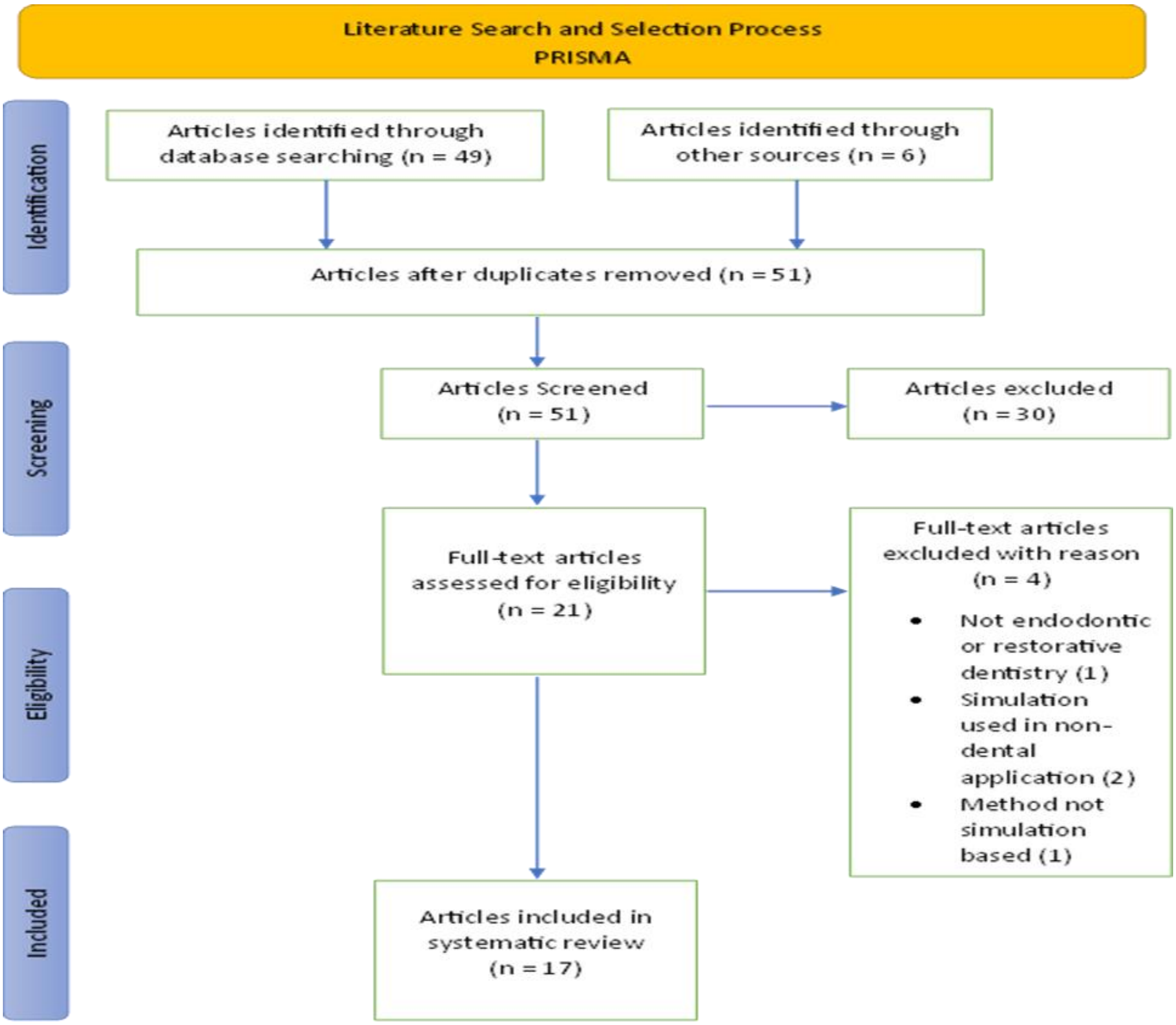

Figure (1): Flow Diagram of Literature Search

Table (1): Systematic Review of Studies and Key Findings

Study Title	Year Published	Authors	Study Design	Sample Characteristics	Criteria	Results
A study comparing the effectiveness of conventional training and VR simulation in the skills acquisition of junior dental students	2003	Quinn F, Keogh P, McDonald A [8]	Case-Control Group 1**:** Conventional phantom heads and teeth with Instructor for 21hrs Group 2: Conventional phantom heads and teeth for 16hrs with 1hr training for simulation units and 4hr with VR with real time feedback and access to Instructor for technical expertise; no access to evaluation options in software Group 3: Conventional phantom heads and teeth for 16hrs with 1hr training for simulation units and 4hr with VR and Instructor for technical expertise only; feedback and evaluation provided by units' software	32 second-year dental students participated in the study.	Criteria for cavity evaluation is based on best practices	After initial independent scoring, the two examiners discussed any notable differences until an agreed score was reached. Once the codes were broken, non-parametric analyses were performed on the data. Wilcoxon Tests for the semi quantitative scores indicated significant differences between the VR and conventional training groups for outline form, depth and smoothness but not for retention or cavity margin angulation at p <0.05 level, with the VR group receiving the higher, i.e., worse scores. Cavity margin angulation approached significance with a p-value of 0.0536. The results indicated that VR-based skills acquisition is unsuitable for use as the sole method of feedback and evaluation for novice students.
Effect of augmented visual feedback from a virtual reality simulation system on manual dexterity training	2005	Wierinck E, Puttemans V, Van Steenberghe [7]	Case Control All participants had 1 hour of introduction and received a manual guide with information on the performance criteria. The no-FB group practiced under normal vision conditions in the absence of any augmented FB. The FB group received real-time FB (KP) and preparation evaluation (KR) from the CTS. During these training sessions, participants had access to the same instructor but	42 first-year dental students participated in the study.	Four analysis errors (outline shape, depth, floor smoothness and wall inclination) and two critical errors (pulp exposure and damage to adjacent teeth) were selected as assessment criteria.	Performance analyses revealed an overall trend towards significant improvement with training for the experimental groups. The FB group obtained the highest scores. It scored better for floor depth *(p< 0.001)*, whilst the no- FB group was best for floor smoothness *(p<0.005)*. The transfer test on a traditional unit revealed no significant differences between the training groups. Consequently, drilling experience on a VR system under the condition of frequently provided FB and

Study Title	Year Published	Authors	Study Design	Sample Characteristics	Criteria	Results
			only for technical advice. The control group (CO) performed all test sessions without participating in any training program.			lack of any tutorial input was considered to be not beneficial to learning.
Effect of tutorial input in addition to augmented feedback on manual dexterity training and its retention	2006	Wierinck E, Puttemans V, Swinnen S [9]	Case Control Subjects were randomly assigned to one of two training groups, the feedback (FB) or feedback-plus (FB+) group, or to a non- training control (CO) group, each consisting of 12 subjects. The training groups differed from each other with respect to the feedback provided. The same real-time simulator feedback and evaluation information was available for both groups, but the FB+ group received extra tutorial input to enrich the simulator feedback. The latter consisted of 10 min of expert advice on one or two specific evaluation issues.	36 first-year dental students participated in the study.	All cavity preparations were evaluated and graded by the VR system, using four evaluation parameters (outline shape, floor depth, floor smoothness and wall inclination) as assessment criteria.	Performance analyses revealed an overall trend towards significant improvement with practice for the training groups ($p<0.001$). Cavity preparation experience on a VR system under the condition of frequently provided feedback supplemented with expert input was most beneficial to long time learning
Augmented Kinematic Feedback from Haptic VR for Dental Skill Acquisition	2010	Suebnukarn S, Haddawy P, Rhienmora P[2]	Case Control Three experimental conditions that received augmented kinematic feedback (F, M, FM) and one control condition that did not (KR-only).	32 sixth-year dental students participated in the study.	The augmented kinematic feedback variables examined involved force utilization (F) and mirror views (M). Six evaluation parameters (visibility of the canal orifices, four axial walls, and pulpal floor).	The results showed that the augmented kinematic feedback groups had larger mean performance scores than the KR-only group in Day 1 of the acquisition and retention sessions (ANOVA, $p<0.05$). The apparent differences among feedback groups were not significant in Day 2 of the acquisition session (ANOVA, $p>0.05$). The trends in acquisition and retention sessions suggest that the augmented kinematic feedback can enhance the performance earlier in the skill acquisition and retention sessions.

Study Title	Year Published	Authors	Study Design	Sample Characteristics	Criteria	Results
Virtual Reality: An effective tool for teaching root canal anatomy to undergraduate dental students: A preliminary study	2020	Reymus M, Liebermann A, Diegritz C [14]	Case Control A questionnaire was designed to assess the ability undergraduate dental students in preclinical training to detect all anatomic aspects of the replica teeth as well as their understanding of the underlying root canal anatomy.	42 third-year undergraduate dental students in preclinical training participated in the study.	Three separate technologies were used in the investigation: two-dimensional radiography, CBCT scanning, and virtual reality simulation. McNemar's and Binominal tests were used to analyze the data.	VR has considerable advantages over three-dimensional reconstructions and two-dimensional radiographs when teaching root canal anatomy ($P < 0.001$)
Contribution of Haptic Simulation to Analogic Training Environment in Restorative Dentistry	2020	Vincent M, Joseph D, Amory C, Paoli N, Ambrosini P, Mortier É, Tran N [13]	Case Control Two groups were used. Group 1 (n=45) was assigned to cavity preparations on a haptic simulator and group 2 (n=43) was assigned to conventional practical work on plastic analogue teeth.	88 first-year undergraduate dental students in preclinical training enrolled and randomly defined.	Data were analyzed using non-parametric Friedman statistical tests with Dunn's correction at α=0.05 for multiple paired comparison and non-parametric Kruskal-Wallis statistical tests with Dunn's correction at α=0.05 for multiple unpaired comparison.	VR has considerable advantages over three-dimensional reconstructions and two-dimensional radiographs when teaching root canal anatomy ($P < 0.001$)
Augmented Reality and Virtual Reality in Dentistry: Highlights from the Current Research	2022	Fahim S, Maqsood A, Das G, Ahmed N, Saquib S, Lal A, Khan A, Alam M [16]	Case Control Subjects were randomly assigned to one of two training groups, the traditional teaching methods vs the AR. Questionnaires were designed to evaluate knowledge and skills, with the administration of a satisfaction questionnaire for those using AR.	41 dental students participated in the study.	AR cavity models were developed with computers and mobile devices. The Mann-Whitney U-test, Wilcoxon test and the chi-square test were used to compare the qualitative parameters of the cavity designs between the groups.	Between the two groups, there were no discernible variations in the degree of knowledge prior to, immediately following, or six months after teaching ($P>.05$). However, the students considered the AR approaches to be a helpful tool that favored knowledge and skill acquisition.

DISCUSSION

The ability to rebuild defective tooth structure is one of the most significant talents for dentists. Undergraduate dental courses place a strong emphasis on this skill. Despite the recent shift toward minimally invasive and adhesive dentistry, the primary goals of undergraduate dental education are to teach students how to (**i**) detect dental caries and remove pathological tissue, when necessary, (**ii**) prepare cavities using well-established geometrical principles, and (**iii**) place restorative materials in a proper and predictable manner. Students must practice in laboratories before undertaking operations work on real patients to achieve these goals. This can be accomplished by using simulated circumstances that allow students to practice frequently while receiving feedback[10-13].

The present study sought to undergo a complete review of the literature assessing the efficacy of VR tools to augment PBL methodology used in preclinical and clinical endodontics as well as restorative dentistry. Results from database searches highlight the alarming shortage of studies examining the use of VR teaching methods with PBL method. Although more work is clearly necessary, there are a small number of studies using VR methods that we were able to examine as part of this review[3]. Overall, findings from this review of the literature suggest that augmenting VR methods for dental education may help improve student's performance on outcome measures of clinical competency in addition to the use of standard evaluation and feedback methods. Conclusions regarding the use of VR specifically within PBL curricula cannot be drawn at this time due to a lack of studies in this area. While PBL has been a dominant method for training medical and dental students, several limitations exist in terms of this modality's ability to train students most effectively in the required clinical competencies. More recent studies are now exploring potential technological advances, such as computer assisted learning and VR simulation, to augment classroom instruction. Nonetheless, there is a lack of integration in terms of these different teaching models. Indeed, it was hypothesized that amalgamating these two modalities would result in a rich and improved learning environment and enhanced outcomes[8].

Virtual reality has the potential to revolutionize dentistry education from both an economic and practical aspect. The use of cadavers or synthetic recreations (silicone or plastic models) in dentistry schools and postgraduate courses is the current gold standard for studying head and neck anatomy. Unlike cadavers and synthetic recreations, VR is reusable, making it more cost-effective. They can also improve anatomical structural visualization, resulting in a better comprehension of dental features. Additionally, implementing these new technological ways may increase students' enthusiasm and interest in learning. In this era of COVID-19, the use of virtual simulators in professional education programs might allow students to fine-tune their clinical abilities without risking injuring a patient during the learning process and, more importantly, without risking infection[12,14].

Dental practitioners, dental technicians, patients, and the interdisciplinary team can all benefit from these modern tools. Through a complete virtual simulation, the practitioner can show patients the projected clinical outcomes. The virtual simulator may provide direct feedback to the student, allowing them to enhance their clinical abilities more quickly and safely. Several VR projects in medical education have been detailed, with most of them playing a constructive role in the learning process. Students and residents both praised the VR approach for teaching anatomy. Another study in which students were exposed to simulated head trauma found that employing VR in teaching root canal anatomy had a favorable didactic effect[15]. Although VR may help dental students study more effectively, more information about their learning philosophies is needed[12,13].

Though, the development and practice of dentistry have been significantly impacted by numerous recent technological developments. Some of the most difficult and taxing specialties in dentistry still include endodontics and restorative dentistry. To be a skilled clinician, one must have the necessary knowledge and clinical abilities to treat disorders including dental caries, pulpitis, and dental abscesses[16]. Because they alter the patient experience, augmented reality (AR) and virtual reality (VR) are increasingly popular in the practice of modern dentistry. Different scientific sectors have benefited from the use of AR and VR, but their application in dentistry has not yet been fully investigated, and traditional dental practices are still widely used[16,17].

While data from this literature review generally supports the use of VR simulation within dental education, more work is necessary to further evaluate the feasibility and usability of this model, particularly in PBL programs. Given the paucity of literature in this specific area, a model for integrating VR techniques within a PBL curriculum is proposed and delineated below, in hopes that it will serve as a springboard for future studies.

PROPOSED MODEL FOR PBL-VR LEARNING

There are four critical features of a VR system: **1**) the VR system must be flexible in that it can produce a variety of simulations; **2**) the VR system must effectively give the student a sense of presence within the simulated environment; **3**) the student must be able to exert control over elements of the simulated environment by interacting with it; and **4**) the student must receive feedback from the VR system[(4,6)]. The use of VR enhanced PBL is not restricted to routine cases that students typically study while in dental school. The flexibility of VR technology allows for the ability to produce cases that force students to work through unexpected situations. The proposed model for PBL-VR learning is outlined below.

Phase I: Instructional Phase

Students are given a lecture and simultaneous video demonstration of the endodontic procedure with virtual aids and tools, through which they experience a nearly authentic simulation of the clinical scenario and procedures. Computer-assisted simulators are used for real time tactile feedback using 3D graphics and image processing. Students are asked to follow the process with the lecturer as they proceed through the lecture[(9)]. Students are then shown different scenarios where the errors they make on the simulator are revealed to them as a clinical error, including its causes, its reasons, and how to prevent or correct it. The operator can view any cut made in the tooth or any filing action carried out through different angulations provided. The software is designed to give detailed feedback on all steps, thereby allowing the student to understand his areas of improvement. The evaluation scores can be obtained at the end of the session for student and evaluator[(9)].

A complete understanding of the anatomy of a root canal is vital to proper treatment of a root canal infection. Failing to detect atypical root canals and extra roots are among the main causes of failed root canals therapy. Furthermore, since human molars exhibit a high degree of variation in the number of roots and root canals[(14)], it is vital that students learn the anatomy of a root canal and gain experience in working with aberrant anatomies. As with the previous example of the VR enhanced PBL, each student would use VR technology, and all students would be involved in the same simulated environment. Students would share the same presence which is a crucial aspect of VR. In the shared simulated environment, students would be introduced to a patient and would obtain the following case history: 42 years old healthy male patient came to the clinic after experiencing a toothache in the right posterior maxilla for five days. The patient revealed that for the past two months the same tooth has been extremely sensitive to hot and cold stimuli. At this point students would need to discuss the relevant case facts as a group and decide on a course of action. Thus, the problem is open-ended, as VR technology allows students to perform a wide range of diagnostic tests and procedures. However, for the purposes of this paper, only one course of action will be outlined. The cases can be made more realistic, thereby improving PBL through integration of medical and dental records and x-rays and examination notes. Students can be asked to input their diagnosis and treatment plan to allow better integration of all factors and steps of treatment. The use of shared haptic technology would allow one student to perform the physical examination, yet all students would receive the tactile feedback.

Students would also be able to see and hear the simulated patient. Students would learn that the tooth was not mobile and that the periodontal probing and the clinical attachment level were in normal range. At this point, students would replicate the pain reported by exposing the tooth to both high and low temperatures (pulp sensibility test). Students would also conduct electronic pulp stimulation and would learn the resulting test response, and would then discuss the results, plot a course of radiographs, and ultimately diagnose the patient with symptomatic irreversible pulpitis. In the end, students would determine that endodontic treatment is indicated. Since the initial radiographs did not reveal any abnormalities in the anatomy of the canal, the students proceed under the pretense of a normal anatomy. One student anesthetizes the area, sets up rubber dam isolation, and establishes an endodontic access cavity. When the student performing the procedure conducts a clinical examination with an endodontic explorer, there are two canal openings in each of the distobuccal, mesiobuccal, and palatal roots. At this instant, students would work as a group to review the anatomy and plot a course of action. The ability of the VR enhanced PBL to allow students to work slowly, carefully, and repeatedly as they encounter this anatomical abnormality. Students are in control of the environment, and they are constantly receiving tactile, visual, and auditory feedback from the system.

Phase II: Tooth Models Training

In the tooth model training stage, students are given access to VR tools to help their practice on both the artificial or natural extracted teeth and VR tools at the same time. The VR tools will give a simulation round, followed by actual tooth cutting practice experience, which will give them a closer look and deeper understanding of the different clinical procedures. The natural teeth are used as in the traditional methods of preclinical practice for students.

Students can be hooked up to the simulator to carry out their dental procedure while seeking help from the tool. Through the use of search options and feedback, students can learn to gauge their hand movements, which is recorded in the software connected to the dental practice model[9]. This allows the student to transfer the skills learned on the simulator to real life, while receiving feedback from the simulator on the quality of work by developing smoothness and finesse in the process. Students can get another set of feedback and evaluations based on their real performance on the teeth, thereby further improving their motor and tactile skills. To further improve the learning process, the teeth can be placed on manikins used for dental practice and can be given a personality. The student will interact and behave in the same manner as he would with a true patient. The system will generate some answers based on the questions posed by the student while obtaining history and will give feedback on the process of history taking, steps of diagnosis and treatment planning[4,7,9]. The patient can be given complexities of age, medical conditions, and anxiety of different levels to promote management of cases among students. Unlike paper-based cases and the clinical treatment, the proposed model gives students the opportunity to experiment with multiple courses of action and to repeatedly practice their skills. Technology, therefore, facilitates students' ability to develop novel solutions and to gain comfort with their psychomotor skills before working on actual patients. Furthermore, the discussion and shared haptics allow the group to build each other's knowledge and technical skills. This example highlights how the VR enhanced PBL can act in synergy to facilitate students' knowledge, psychomotor skills, interpersonal skills, self-confidence, and motivation.

Phase III: True clinical practice

Students can now be asked to carry out the dental procedures on real patients and to receive their physical evaluation on clinical environment to be assessed by the instructors. This is to validate the number of errors made and to verify the improvement areas. The students by this stage must have mastered many major procedures and will only be refining their skills on the patients, thereby reducing margins of error.

CONCLUSIONS

The current review demonstrates that, while there has been progress in developing VR simulation tools in preclinical and clinical dental practices, there has been less effort to integrate VR simulation tools with popular and established learning method such as PBL. Employing simulation tactics, particularly in terms of saving faculty time and allowing students to repeat attempts to mastery at their own pace are main advantageous consequence, additionally, the use of PBL augmented VR will reduce dental phobia, which is frequently encountered by young patients, and will lower the clinical errors during the learning phase. Further research of a well-controlled trial and long-term follow-up studies is needed before VR simulation can be used as a mainstream mode of instruction and, in particular, for student assessment.

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