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# Virtual and Augmented Reality: Changing Horizons in Dentistry

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**ABSTRACT**

Background: Augmented and virtual reality (AR-VR) is a fast developing technology that has been used in the field of medicine for a long time. It has also found its way in dentistry and the preliminary assessments so far have shown promising results. Aim: The presented scoping review was conducted with an aim of identifying the current applications of AR-VR in the field of dental training and education. The paper also highlights the presently available dental simulators, their features and areas of use. Result: It was found that AR-VR is not restricted to teaching of upcoming dentists but also helps practicing physicians to return to basics and refine their skills. Inclusion of haptics provides a realistic experience by simulating the tactile sensations. Instant feedback feature act as a source of motivation to cover the missed bases. Conclusion: AR-VR technology has numerous advantages in dental education and training. However, the currently available systems require imports and are bulky to be transported in difficult terrains. Thereby it is important that indigenous systems be developed that have enhanced feasibility to be used for training of Armed Forces for managing trauma cases encountered in the field.

**Keywords:** Virtual reality; Augmented reality; Dentistry

## 1. INTRODUCTION

Virtual Reality (VR) is a computer-generated environment that provides the user with a sense of realistic environment experience using 3-dimensional (3D) models to interact with. VR has been used in the field of research and medicine since more than 25 years but has received a recent boom with increasing interest of leading application and software companies[1]. Comparatively, augmented reality (AR) is a more recent technology and has been used inter-disciplinarily for treatment and education purposes.[1] In the field of medicine, VR has been used as diagnostic aid, as an assistance before and during surgical procedures, imparting education and training in procedures like laparoscopic surgeries, medical database visualisation, treatment and rehabilitation of patients with autism, phantom limb pain, psychiatric disorders, palliative care for cancer patients etc[2–7]. Adjunctive use of VR as a teaching module has shown improvement in student's learning curve which has further encouraged institutes to adopt the same[5].

In context of dental education, since the introduction of dentistry as a separate subject and specialisation, it has been taught via didactic methods which in recent years have been aided by audio-visual projections. Coming to practical dental skills, a student is required to hone their skills on plaster models, phantom heads and extracted teeth. Though these methods have been successful, they add to monetary constraints for students by reinvestments in plastic teeth and instruments. Also, these modes present with ideal teeth morphology and conditions, restricting teaching to standard preparations which is not always encountered in live patients. The students are also not able to have a practical experience of probable medical emergencies that can be encountered in a dental setup, therefore finding themselves in a fix under clinical situations.

With the plethora of advantages provided by AR-VR technology and introduction of haptic feedback technology, it has thus become necessary that the technology finds its way in regular teaching curriculum[8]. The presented paper is a scoping review of the currently employed applications of AR-VR systems in the field of dentistry for the purpose of student and practitioners training and their practical application at various levels.

## 2. VR AND AR IN THE FIELD OF DENTISTRY

### 2.1 Operative Dentistry and Endodontics

Operative dentistry is regarded as the "bread and butter" of the profession since it involves addressing the most common patient chief complaint of tooth decay and associated pain[9-10]. As a student, one learns the basics by preparing different preparations on typhodonts which is then followed by refining of skills on extracted teeth and live patients. AR-VR technology will help in bridging this gap and make clinical transition a more fruitful experience. Comparing student's knowledge and skills of cavity preparation, Llena *et al.*[11] compared traditional teaching methods with those imparted using AR technology. Although no significant difference was found in the level of knowledge of the two groups, a significant difference was

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seen in terms of the skilled parameters. Students too rated their experience of using AR to be favourable although use of computers was preferred over use of mobiles. In contrast, Quinn *et al.* in their pilot study found that students did not favour the use of VR simulation devices and rather preferred it as an adjunct to conventional teaching methodology[12].

Evaluating the learning curve of students in the clinical procedure of access opening, Suenukarn *et al.*[13] found that using haptic VR, novice fourth year dental students were able to learn and improve the procedure in merely two to three sessions. This was seen to be faster and consistent compared to conventional way of learning and also provided students with bimanual dexterity and force utilisation assessment. Imber *et al.* too supported that the evaluations obtained on virtual simulator are as reliable as those seen on mannequins[14]. In their prototype software design, Sararit *et al*.[15] appraised user acceptability of VR simulator for managing endodontic emergencies. With a few roadblocks brought to the fore by a couple of users, most of the users encouraged the use of the simulator citing its purpose, design, feasibility and usefulness in learning emergency management. Dixon *et al*.[16] showed the application of Virteasy Dental simulator for assessing 2 mm depth cavity on a simulated block of density similar to that of enamel. They concluded that clinically relevant qualitative feedback could be provided by the simulator's use and can help the operator in developing more complex skills.

### 2.2 Tooth Preparation for Prosthetic Crown

After completion of the root canal treatment, most of the restored teeth need to be reinforced by a prosthetic crown to avoid the loss of the remaining tooth structure. Thus, tooth preparation for prosthetic crown is a common procedure that a dentist needs to be versed with. It is important that the preparation has minimal flaws so that the resultant crown has a higher rate of survival and service. Comparatively, maxillary preparations are more difficult that mandibular and the same becomes a challenging task when performed in patients without prior pre-clinical practice[17]. Thus, this calls for use of technological advances that would provide learning dentists with practice and performance evaluation of their preparations before proceeding to clinical work.

Preppr, software developed at the University of Otago, New Zealand has been used to analyse all ceramic tooth preparation for mandibular molar by students with no prior practical knowledge about the same. It showed students performing better than those taught by conventional ways and was proposed to be included as part of dental simulator systems[18].

### 2.3 Maxillofacial Surgery

A good maxillofacial surgeon requires thorough knowledge of structural anatomy and precise and neat movements to produce good surgical results. Getting a first-hand experience on cadavers or patients is not possible for all clinical scenarios and here AR-VR technology can work wonders.

AR is being used as an adjunct in various maxillofacial surgeries like orthognathic surgeries, tumor surgeries, temporomandiular joint (TMJ) motion analysis and foreign body removal, osteotomies, minimally invasive biopsies, prosthetic surgeries and dental implants[19]. In one of the initial studies by Wagner *et al*.[20] head mounted display (HMD) were used by surgeons to visualise the super imposition of bone segment or soft tissue as a real-time overlay. This provided them with increased visual access to perform a smoother surgery. In another study, high fidelity simulators were proposed to help surgeons learn the accurate osteotomy cuts for bilateral sagittal split osteotomy (BSSO)[21]. Pulijala *et al.* developed and validated VR surgery using Oculus Rift and Leap Motion devices for Le Fort I osteotomies wherein the trainee can interact with each armamentarium and know its application[22]. It consisted of a 360° operating room, spherical videos and computer generated 3D models of operating room which were seen as suitable training tools by the surgeons. However, inclusion of haptic force feedback and realistic interaction with 3D instrument models was identified as an area that required further work. Yu *et al.*[23] in their preliminary attempt showcased the advantages of the discussed technology by performing virtually simulated orthognathic surgeries before operating on actual patients. This helped in forecasting the probable patient's esthetic outcomes and surgical success. Ai *et al.*[24] presented a proxy VR system integrated with volumetric rendering for cranial implants to be used with a desktop computer system. However, there isn't any further literature available about the use of the same.

### 2.4 Dental Implant Placement Surgeries

Dental implants are being increasingly used for rehabilitation of partially and completely edentulous cases. Placing dental implant is a technique sensitive procedure that requires precision training. For successful placement, it is important that the implant is placed in precise location with adequate thickness of bone on all sides to avoid undue implant surface exposure. VR technology has been used as an aid for treatment planning and determining this defined location to provide a smoother and minimally invasive procedure[25-26]. Seipel *et al.*[25] in their initial assessment, investigated the use of a low-cost stereoscopic display system and six degree of freedom in implant placement compared to three degrees of freedom in the virtual world. In a follow up study, treatment planning of the procedure was improved to provide the clinician with six degrees of freedom in real time using computed tomography (CT) images at the voxel level[27]. Kusumoto *et al.*[28] and Ohtani *et al.*[29] individually developed systems wherein they combined the CT images of jaw bone with a VR force feedback haptic device to provide inexperienced training dentists with a real experience by simulating the vibrations and sounds of bone drilling and contra-angled hand-piece. Xiaojun and team[30] proposed a modular software namely Computer Assisted Preoperative Planning for Oral Implant Surgery (CAPPOIS) that aided in pre-operative planning of the procedure. The planned procedure could then be transferred to a haptic feedback device to conduct the same on virtual jawbones before performing the same on patients.

### 2.5 Dental Anesthesia Administration

Inferior alveolar nerve (IAN) block is one of the most commonly used blocks in the field of dentistry and has a high

reported failure rate of 20 per cent - 25 per cent[31]. Causes of block failure can be either anatomical, pathological, pharmacological, physiological or inadequate technique.[32] Anatomical and inadequate technique are two operator related factors that can be improved upon by having a thorough knowledge of the intra- and extra-oral anatomy and repeated practice. AR-VR technology with feedback provision can prove to be advantageous in this aspect. Correa *et al.* evaluated the user feedback of haptic-based VR anesthesia injection training simulator on two different virtual models[32]. Satisfactory training results were obtained however they highlighted the scope of improvement in terms of tactile feedback. Mladenovi *et al*[33] too supported the use of AR simulator for teaching IANB and found significantly better results in the experimental group than the control group who were taught the technique the conventional way. They however did not comment on feedback limitations of the system.

## 3. CURRENTLY AVAILABLE DENTAL VIRTUAL SIMULATOR SYSTEMS

Realising the importance of AR-VR technology in the field of medical and dental sciences, a wide range of commercial dental simulators are now available for the masses (Fig. 1). Some of these systems are being currently used for student training and have presented encouraging results.

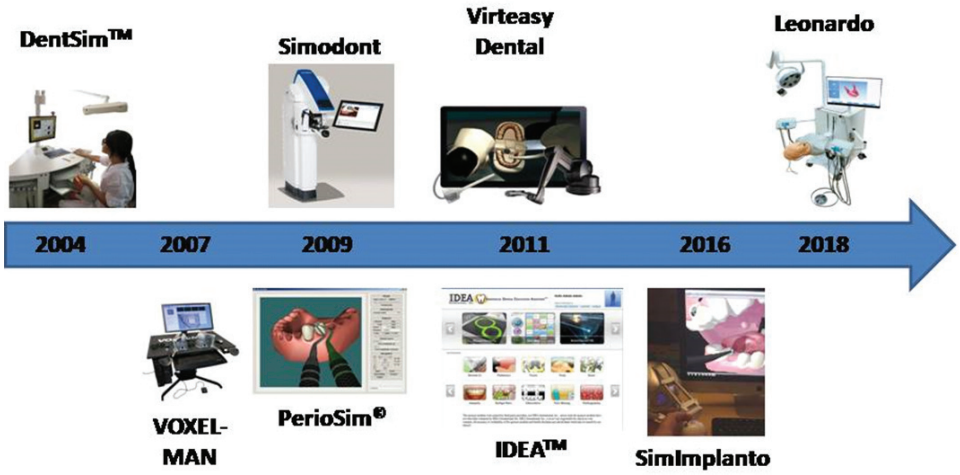


**Figure 1. Dental simulators introduced over the years.**

### 3.1 DentSim™

Introduced in 2004, DentSim™ is one of the first developed dental simulators. It utilises AR which can be integrated with the existing lab mannequin. Movement of student's hand piece during preparation and the typhodont tooth are optically tracked and analysed in real time. The tracked images can be visualised in various angles by the student on computer screen while working on the plastic teeth[34]. Jasinevicius *et al.*[35] found use of the dental simulator to significantly increase the number of preparations and reduce the average time taken by students to complete the same.

### 3.2 Voxel-Man

Voxel-Man simulator was first introduced for middle ear virtual surgery which was later adapted for dental surgeries and includes carious lesions in various configurations[36-37]. The simulator has microtomographically replicated real teeth and a force feedback enabled dental handpiece that allows students to work on their manual dexterity and improve problem solving skills. The device has high fidelity that differentiates in tactile sensations of enamel, dentin, pulp and carious tissue, giving a real-life experience. All the models and instruments are visualised on a high resolution 3D screen with access to a variety of high and low speed burs controlled via a foot pedal. With the help of virtual dental mirror, the tooth can be viewed from all sides, magnified and be visualised in cross-sectional images. Automatic skill assessment feature evaluates the work done by student comparing it with a predefined standard as a reference preparation. Thus, students are able to get an instant feedback on their work. As a pilot test model, Pohlenz *et al.*[36] checked the simulator's applicability as an additional learning modality and was highly recommended by students (92.7 %). In another study by Sternberg *et al*[38] simulator was utilised for performing apicectomies comparing 2 trainee groups in preservation of vital structures while performing the procedure in pig cadaver model. Group that received prior training on simulator showed better performance than group directly performing on cadaver models.

### 3.3 PerioSim© Force Feedback Dental Simulator

PerioSim©, developed by Luciano at the University of Illinois,[39-40] is a mannequin based haptic VR simulator designed for training and performance evaluation of students, hygienists and practicing dentists in periodontal probing and white spot caries detection. Its hardware components consist of PHANToM™ Desktop haptic device and a compact personal computer. The system allows the user to interact with 3D human mouth on computer screen while working with haptic device to have a lifelike interaction with teeth and gingiva. Students can view the clinical scenario from various angulations and work with various instrument positioning. In a study by Steinberg *et al.*[41] establishing the evidence-of-concept for using PerioSim© as teaching aid, stated that images were more realistic for teeth and instruments than for gingiva. Also, tactile sensations were more pragmatic for teeth than for gingiva. With these improvements incorporated in future, PerioSim© was seen as a useful modality to be integrated as teaching aid and evaluating student's skills.

### 3.4 Simodont® Dental Trainer

Nissin Simodont® is a haptics technology dental trainer by Moog Industrial Group, Amsterdam with courseware development by Academic Centre for Dentistry in Amsterdam[42]. Its hardware consists of a touch panel for user interaction, a 3D display viewer, projectors for stereo vision, a virtual mirror, handpiece gimbal and foot pedal. It provides with features of height adjustment and hand and finger rest for user comfort.

To enhance student learning, the courseware can be modified by teachers to provide already present or customised cases and build patient specific exercises. Based on student performance reports can be created and exact student work can also be reviewed.

Tested by Bakr *et al.*[43] at Griffith University, Australia, Simodont® was found as a useful supplementary teaching tool by teaching staff but had technical limitations of hardware and software. Checking the efficacy of the trainer in a randomised control trial, Al-Saud *et al.* concluded that combination of instructor guidelines and feedback from trainer showed better performance compared to either method used alone and thus advocated its use as an adjunct[44]. Checking the simulators applicability for pre-clinical paediatric dentistry training, Zafar *et al.*[45] presented that the simulator can be adequately used as an adjunct for dental training.

### 3.5 BoneNavi System

Developed by Ohtani *et al.*[29] in Japan, BoneNavi is a computer-aided implant surgery support system. The system combines the use of CT images of jawbones and a VR force feedback device to simulate implant placement and surgical guide development for implant placement. These CT images are used for individualised treatment planning and it practice before carrying out the actual procedure on patient. At present, no literature providing its validation has been reported.

### 3.6 Virteasy Dental

Virteasy Dental is a haptic simulator developed by HRV (Changé, France) in collaboration of multiple institutes one of which is the University of Sheffield[46]. It simulates a completely virtual environment which consists of a virtual patient to work upon in a virtual room. It includes teaching modules related to restorations, edodontics, prosthodontics, and implantology along with operator's assessment. The editor feature of the simulator enables the user to themselves import the intra-oral scans and create the desired pathology to work upon. The simulator has shown positive results in terms of providing clinically relevant qualitative feedback[16].

## 4. INDIVIDUAL DENTAL EDUCATION ASSISTANT™ (IDEA)

Making its first appearance in 2011, IDEA is a prototype software, initially developed for cavity preparation, that can be installed on any computer system[47]. Equipped with a stylus having six degrees of freedom, it utilises a PHANTOM® haptic device (SensAble Technologies, Inc®) to simulate realism. The system also provides access to preinstalled modules for other procedures namely, ManualDexterity™, Scaling & Root-Planning™, OralMed™ and PreDenTouch™. The procedure of cavity preparation is done on geometric 3D shapes instead of actual images of the tooth. Installed feedback system measures time taken for the task, removal of desired amount of tissue and deviation from the desired activity[48]. In the initial evaluation of the simulator done by Gal *et al.* it was concluded that the software has much potential to be used both, by professionals as well as learning students[47]. However, it required further improvement concerning sensation simulation and required further inputs, from educators as well as students for its further enhancement.

### 4.1 SimImplanto

Introduced in 2016 by Pires *et al.*, SimImplanto is a keyboard controlled Falcon haptic device that simulated oral rehabilitation of edentulous maxillary and or mandiblar space using implants[49]. 3D jaw models were obtained by scanned dental casts while CT scans were used to simulate various bone densities for implant placement and drilling resistance. No further data could be found in literature that can further comment on the simulator's efficacy and applications.

### 4.2 Leonardo

Distributed by GEOTAR media, Russia, Leonardo dental simulator is a mannequin based simulator which tracks interventions on teeth models in real time and gives a comprehensive feedback of all procedures[50-51]. The training capability of the simulator includes history taking and anesthesia selection specific to a patient and also has the scope for customisation. The system tracks the total time taken for a procedure along with effective times, amount of healthy tissue removed and excess movements during the procedure. It uses Polhemus electromagnetic motion tracking technology to provide real time feedback and used real dental equipment equipped with tiny micro sensors™. At a time, the system can precisely track 6 sensors simultaneously and provide with instant feedback.

### 4.3 SimEx Computerised Dental Simulator (CDS-100)

A proprietary product by EPED Inc., CDS-100 combines dental simulation and evaluation in a virtual 3D environment.[52] It aids in providing training to the learning dentists and can be used by practitioners to develop upon their skills. The simulator provides instant feedback and has the features of recording operating procedures that can be viewed at the users or evaluator's will. The use of the simulator looks promising; however, there is no documented literature available that supports its use.

## 5. CONCLUSION

The few studies that have utilised the AR-VR technology in the field of dentistry have shown promising results for the future use of the technology. The currently available simulators too have presented positive user feedback however they all present scope for improvements. With increasing shift of the dental fraternity towards implant-based rehabilitation of the missing tooth/ teeth, it is important that the practicing dentist be thoroughly versed with the procedure and its probable complications during the procedure. This would be further advantageous if the training is instilled during the teaching years which currently takes a back seat due to lack of confidence gained from working on acrylic models which fail to simulate the clinical scenario. Incorporation of AR-VR technology in Armed Forces will help train the surgeons on perspective

trauma cases which will help them in better handling of the actual cases in the field.

Thus it is imperative that resources be put into development of AR-VR technology in the field of dentistry that are not only successful in providing real-life experience but are also handy enough to be used by students and dentists in difficult terrains, who find it difficult to visit the cities for the state-of-the-art learning.

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