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Review article

SIMULATIONS IN DENTAL EDUCATION: HISTORY, CURRENT TECHNOLOGIES, AND FUTURE PERSPECTIVES – A REVIEW

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ABSTRACT

Simulation-based training has become an integral component of dental education, evolving from traditional hands-on techniques to virtual reality (VR) and haptic-based systems. This review examines the historical progression, current applications, and emerging advancements in dental simulation technology. Early preclinical training relied on extracted teeth and phantom head models, providing students with basic technical skills. The introduction of VR-based simulators in the early 21st century enhanced training by integrating digital case scenarios and real-time performance feedback. This review underscores the transformative role of VR and haptic simulation in dental education, highlighting both achievements and areas requiring further research and development.

Keywords: dental simulation, dental education, VR simulators, haptic dental training,

BACKGROUND

The implementation of simulation in healthcare has significantly advanced since its initial introduction, when mannequins were first utilized for training in anesthesia. Dentistry, like all healthcare professions, continues to advance and adapt to new techniques and philosophies. Dental education is constantly evolving to prepare students for their future job that encompasses a diverse range of procedures, each necessitating precise, task-specific expertise. Due to the irreversible nature of most dental procedures, students must acquire the necessary skills to deliver safe and effective care during patient treatment. While virtual reality (VR) simulations, including haptic technologies, are increasingly utilized in dental education, they have yet to fully replicate the comprehensive range of case scenarios required for comprehensive student training. [1, 2]

The aim of the article is to review the historical path of simulation in dental tutoring, together with current applications and novel developments in the virtual reality field.

METHODS

Studies were identified using the databases Google Scholar, PubMed, Web of Science. Three researchers (A.B., A.P. and M.M.) used the following keywords for each database: Dental simulation, Phantom head simulation, and Haptic dental training. The search was performed in the timeline December 2024 - January 2025. Inclusion criteria contained studies published between 1998 and 2024, discussing topics regarding the historical trajectory of dental simulation training as well as current applications and types of haptic advancements. Exclusion criteria were non-English written papers, studies that didn't focus on dental simulation education and studies published before 1998.

REVIEW RESULTS

Based on the inclusion and exclusion criteria, information from a total of 14 articles was gathered into a narrative summary by the authors.

Historical development of simulation education in dentistry

Preclinical dental training began with teaching the students on extracted teeth in the early 19th century, until the first phantom head simulator was invented by Oswald Fergus. It was used to teach oral anatomy and physiology. [3] Thanks to them students were able to start replicating clinical manipulation procedures with the help of visual and verbal instructions from utors. [4] These preclinical teaching methods are used nowadays – students are shown teeth models, pictures and videos and are asked to perform a variety of dental manipulations on plastic teeth. [2] They are tutored by a faculty assistant professor and receive feedback on their work after they complete it. [5]

VR-supported dental simulation

Due to the intensive technology development, virtual reality (VR) began to be incorporated in preclinical dental teaching.

The first VR and computer-supported simulators started entering dental universities in Europe and North America at he beginning of the 21st century. [3]

Virtual reality simulators allow the integration of clinical cases in preclinical tutoring. They also facilitate tactile diagnostic skills with haptic technology. There are two main types of VR simulators available. The first group are simulators that combine phantom heads-based simulators on which different dental procedures can be performed with real dental instruments. The second group are haptic-based simulators, on which dental procedures are practiced on a haptic device and virtual models. [2, 6]

Characteristics of the current available VR simulators

DentSim

DentSim was among the pioneering systems enabling a broad range of restorative procedures. Its key benefit lies in merging mannequin-based training with 3D visualizations. This combination enhanced realism by allowing the use of finger stabilization, water spray, and a dental handpiece. Additionally, it utilized infrared technology to show students' preparations on computer screen, providing real-time evaluation and feedback, which is crucial for mastering complex motor skills. [7]

The Geneva System

The Geneva Dental School's Department of Cariology at the University of Geneva has been pioneering the use of 3D computer simulations to teach dental anatomy. Their goal was to assess the benefits of integrating information technology into the curriculum. Currently, they are working on a second-generation virtual reality dental simulator with enhanced tactile features for teaching drilling procedures. [8]

Virtual Education System for Dentistry

The Virtual Education System for Dentistry, developed by the Affiliated Stomatological Hospital of Nanjing Medical University and Suzhou Digital-Health Care Company, is a prosthodontics simulator. It includes the Virtual Learning Network Platform (VLNP) and the Real-time Dental Training and Evaluation System (RDTES). [9] Before hands-on practice, students use the VLNP to study operational instructions, criteria for crown preparation, and watch standard procedure videos. They then perform crown preparations on a phantom head with RDTES guidance, which records and assesses their work based on predefined criteria. Students can compare their results with the standards on a computer screen. [10]

Individual Dental Education Assistant (IDEA)

The Individual Dental Education Assistant (IDEA) is a VR simulator designed to enhance hand flexibility in dental students. It features a handheld pen that mimics a dental turbine and provides force reports, along with simulation software. Unlike other simulators, IDEA focuses on improving proficiency with dental handpieces by having students practice removing virtual materials of various shapes. The system evaluates performance based on drilling speed and accuracy. [11] Researchers have found that IDEA can upgrade students' performance in dental skill tests and help identify those with hand flexibility issues. [12, 13]

The Virtual Reality Dental Training System (VRDTS)

The Virtual Reality Dental Training System (VRDTS), created by Novint Technologies in collaboration with the Harvard School of Dental Medicine, is a VR simulator for cavity preparation. It simulates various dental instruments and materials, allowing for virtual tooth restoration. However, it does not support proper positioning or hand/finger rests, as students hold the interface in the air. [14]

Iowa Dental Surgical Simulator (IDSS)

The Iowa Dental Surgical Simulator (IDSS), developed by the University of Iowa's College of Dentistry, allows students to feel intact enamel, dentine, and carious dentine on a virtual tooth. It includes a computer, monitor, and force report device with custom software. Students use a control stick or an explorer handle to interact with the virtual tooth displayed on the screen, receiving different haptic responses based on the area touched. [15]

PerioSim

PerioSim©, developed by the C. J. Luciano College of Dentistry at the University of Illinois at Chicago, is a dental simulator designed to train periodontal procedures. It is usable for students to exercise diagnostics and treatment of different periodontal diseases by visualizing a 3D virtual human mouth. With the help of virtual instruments, they can experience sensations when touching teeth, gingiva, and tartar. However, the tactile feedback for gingival tissues is not very realistic. [16]

HapTEL system

The HapTEL system, developed by King's College London Dental Institute and Reading University, uses a

haptic unit adapted from a gaming device. It features two screens for viewing a simulated jaw, specialized software for flexible drilling, and a foot pedal to regulate bur speed. Users can replay their procedures and receive feedback on the percentage of carious and hard tissue removed. Scores are stored for monitoring progress, with simulations ranging from simple to complex caries. [17]

VirDenT system

The VirDenT system, developed by the Faculty of Dental Medicine at the University Ovidius of Constanta, Romania, uses virtual and augmented reality to mimic prosthetic and restorative procedures. It includes a virtual drill, teeth, and a patient, with a haptic interface for practicing. Students can follow dental interventions demonstrated by an intelligent tutor and receive real-time feedback. The system graphically and haptically simulates tooth preparation, providing feedback and recording progress for evaluation, similar to the HapTEL system. [18]

Moog Simodont

The Academic Centre for Dentistry Amsterdam (ACTA) has recently installed Moog Simodont dental trainers. These haptic devices allow students to engage in hands-on training for various procedures in a simulated dental setting. Thanks to them trainees can focus on enhancing manual dexterity, performing diagnostic assessments, developing treatment plans, preparing cavities, and practicing crown and bridge restorations. [19, 20]

Dentify

Dentify is a Portuguese VR-invention which helps undergraduate students to improve their manual skills in the field of Operative dentistry. The simulator combines a haptic pen that replicates the form of a dental turbine, VR-glasses and audio effects and creates a customizable environment for the students by including the possibility to work on a single tooth or complete dental arch, zoom-in and indirect vision features, different types of virtual burrs and different difficulty settings. [21]

A summary of all the mentioned above systems' characteristics is presented in Table 1.

Table 1. Dental simulators characteristics.

Simulator	Technical characteristics	Strengths
DentSim [7]	Mannequin-based + 3D visualizations; infrared tracking; use of real instruments; real-time evaluation	Realism, integration of hand stabilization, water spray, dental handpiece, immediate feedback
Geneva System [8]	3D computer simulation for anatomy; tactile features for drilling	Integrate information technology into curriculum; improved tactile realism
Virtual Education System for Dentistry [9,10]	VLNP for theory + RDTES for phantom head crown preparation; records/assesses work	Blends theory and practice; standard criteria-based feedback
IDEA [11, 12, 13]	VR simulator with handheld pen that mimicks dental turbine; force reports; simulation software	Improves handpiece proficiency; identifies hand flexibility issues
VRDTS [14]	Simulates dental instruments/materials for cavity preparation; virtual restoration	Enables virtual cavity preparation and restoration
IDSS [15]	Simulates sound enamel, sound dentine, carious dentine; haptic feedback	Differentiates tissue textures; diagnostic and preparations training
PerioSim [16]	3D virtual human mouth; tactile sensations for teeth, gingiva, tartar	Periodontal diagnostic & treatment training
HapTEL [17]	Haptic unit adapted from gaming device; dual screens; flexible drilling; foot pedal	Feedback on tissue removal; tracks progress
VirDenT [18]	Virtual + augmented reality; haptic drill; intelligent tutor feedback	Real-time feedback; simulates prosthetic & restorative procedures
Moog Simodont [19, 20]	Haptic devices for full dental procedure simulation	Wide range of training (diagnostics, treatment planning, operative training)
Dentify [21]	Haptic pen + VR glasses + audio; customizable difficulty; indirect vision	Immersive; adjustable to skill level; variety of settings

Advantages of Dental Simulators

When compared with conventional phantom heads, computerized simulators express advantages by providing students a better learning environment, because they are able to gain theoretical knowledge. [9] They also keep records of the training process, allow tracking of the students' progress, and give feedback and work evaluations. [2, 22]

Disadvantages of Dental Simulators

Currently, 3D displays in dental simulators often rely on 3D glasses, which can alter the color of oral tissues and cause vertigo or nausea. [23] These glasses also reduce image resolution, affecting the precision needed for dental operations. Researchers need to develop higher-resolution 3D displays to improve VR immersiveness. [24]

A stable finger rest is crucial for precise dental operations due to the small intraoral space. Without it, accidental injuries may occur. Training should include the use of finger rests for better simulation. [25]

Force feedback in simulators is not sufficiently realistic. Dentists rely on different force feedback from various oral tissues to guide their procedures, so high-fidelity force feedback is essential. [26]

Simulating soft tissue deformation, such as the tongue and facial tissues, is also lacking. Accurate deformation requires a physical model based on properties like density and elasticity. [27]

Training content in many dental simulators is insufficient. They often lack varying difficulty levels, making it hard to assess students' progress. A more comprehensive and structured training curriculum is needed. [28]

CONCLUSION

Simulation technologies in the dental field are constantly evolving. By using such methods in dental education, we can enhance the quality of preclinical training, which will ensure better clinical performance of the students. Although dental simulation systems have many advantages, they cannot fully replicate the real dental procedures. However, by combining theoretical, simulation and real training, we can achieve thorough and substantial dental education.

Abbreviations:

VR - virtual reality
IDEA - Individual Dental Education Assistant
VLNP - Virtual Learning Network Platform
RDTES - Real-time Dental Training and Evaluation System
VRDTS - The Virtual Reality Dental Training System
IDSS - The Iowa Dental Surgical Simulator
ACTA - The Academic Centre for Dentistry Amsterdam

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