

REVIEW ARTICLE

## Augmented Reality and Virtual Reality Simulators in Dentistry: Transforming Education and Clinical Practice

*Dr. Muskan Mittal*<sup>1\*</sup>

<sup>1</sup> BDS, Kamineni Institute of Dental Sciences, Narketpally

\* Author of Correspondence: Dr. Muskan Mittal, BDS, Kamineni Institute of Dental Sciences, Narketpally

Email: muskanmittal155@gmail.com

### KEYWORDS:

Virtual Reality, Augmented Reality, Dental Education, Dental Simulators, Haptic Technology, Clinical Training, Dental Surgery

Received date-18-02-2026

Revised date-22-03-2026

Accepted date-22-03-2026

Published date -24-03-2026

Citation format- Mittal M. Augmented reality and virtual reality simulators in dentistry: Transforming education and clinical practice. *J Dent Innov Med Sci.* 2026;1(1):33–40.

### ABSTRACT

**Background:** The integration of immersive technologies in healthcare education has marked a significant paradigm shift. Dentistry, with its high demands for psychomotor precision and spatial awareness, stands at the forefront of this digital revolution. Traditional training methods face challenges regarding patient safety, ethical constraints, and resource limitations. Augmented Reality (AR) and Virtual Reality (VR) offer transformative solutions to these challenges.

**Objective:** This review aims to comprehensively evaluate the applications, effectiveness, and technological foundations of AR and VR simulators in dentistry. It seeks to analyze benefits for both undergraduate students and practicing clinicians, identifying barriers to adoption and future trends.

**Methods:** A comprehensive literature search was conducted across major medical and dental databases. Studies focusing on haptic fidelity, skill transfer, clinical applications, and educational outcomes were selected for analysis.

**Results:** Findings indicate that VR/AR simulators significantly enhance psychomotor skill acquisition, with studies reporting an increase in student confidence. Technologies such as Simodont and DentSim provide objective feedback and reduce faculty teaching time. However, global adoption remains low (less than 10%), hindered by high costs and infrastructure demands.

**Conclusion:** AR and VR technologies are not merely supplementary tools but are essential for the future of dental training. While economic and technical barriers exist, the long-term ROI and patient safety benefits necessitate their broader integration into dental curricula and clinical practice.

## Introduction

The landscape of dental education and clinical practice is experiencing a profound shift driven by the adoption of augmented reality (AR) and virtual reality (VR), which are increasingly integrated across both training and clinical workflows to enhance educational quality and clinical performance [1]. Historically, dental training relied heavily on the "phantom head" models and the apprenticeship system—methods that, while foundational, present significant limitations in the modern era.

Current challenges in traditional dental training are multifaceted. Educational institutions face rising costs, limited faculty-to-student ratios, and ethical imperatives to minimize patient risk during the learning curve. Dental education aims to lead students through several phases of development, from inexperienced to proficient, ultimately producing a skilled clinician. It typically takes students several years to develop the fine motor skills necessary to be prepared for entry-level dental practice [2]. Developing fine motor skills and tactile discrimination requires prolonged, repetitive practice, a process that is difficult to standardize or objectively assess using conventional methods.

The evolution of simulation technologies has moved rapidly from passive observation to active, immersive participation. Virtual Reality (VR) and Augmented Reality (AR) simulators represent the pinnacle of this evolution, offering standardized, repeatable, and safe environments for skill acquisition. Beyond their established role in preclinical training, these technologies are gaining recognition for their applications in clinical skill enhancement, treatment planning, and continuing professional development, contributing to improved clinical outcomes. Despite the clear advantages, there remains a gap in the widespread adoption and understanding of these technologies, particularly regarding their utility for practicing clinicians beyond the academic setting.

This review provides a comprehensive analysis of AR and VR in dentistry. Unlike previous reviews that focus solely on undergraduate education, this article extends its scope to clinical applications for experienced practitioners, examining how these

tools facilitate complex treatment planning and continuing professional development. The objective is to synthesize current evidence, clarify technological distinctions, and provide a strategic roadmap for implementation.

### Understanding Virtual Reality (VR)

Virtual Reality (VR) refers to a computer-generated simulation of a three-dimensional image or environment that can be interacted within a seemingly real or physical way by a person using special electronic equipment. In dentistry, VR systems typically involve complete sensory immersion [3,4].

The technical components include Head-Mounted Displays (HMDs) that provide stereoscopic vision, motion tracking sensors that capture the user's head and hand movements, and haptic feedback devices. Immersion levels vary significantly:

**Non-immersive:** Desktop-based systems where the user views a 3D environment on a monitor.

**Semi-immersive:** Systems utilizing large projection screens or concave displays to cover a wider field of view.

**Fully immersive:** Environments where the user wears an HMD, completely blocking the physical world and replacing it with the digital simulation.

### Understanding Augmented Reality (AR)

Augmented Reality (AR) differs fundamentally from VR by keeping the user grounded in the real world. Instead of replacing reality, AR superimposes digital information, such as images, text, or 3D models onto the user's view of the physical world in real-time.

Key differences lie in the visualization: while VR disconnects the user from their surroundings, AR enhances it. In clinical dentistry, AR is particularly valuable for projecting subsurface anatomical structures, such as nerve pathways or tooth roots, directly onto the patient's face or the surgical site via smart glasses or tablet screens [3,5].

### Mixed Reality (MR)

Mixed Reality (MR) represents the convergence of AR and VR, creating a hybrid environment where physical and digital objects co-exist and interact in real-time. In dental education, MR allows a student to work on a

physical mannequin while receiving digital guidance overlays that adapt to their movements, bridging the tactile reality of physical tools with the versatile guidance of digital software [6].

### Haptic Feedback Technology

The success of dental simulators relies heavily on haptic feedback (force feedback). Dentistry is a tactile profession; the resistance felt when a burr touches enamel is distinct from soft caries or pulp tissue. High-fidelity haptic devices must operate at a refresh rate of at least 1 kHz to render smooth, realistic tactile sensations [6,7]. Modern systems employ voxel-based volumetric modeling, assigning density values to different virtual tissues, allowing the simulator to calculate appropriate resistance forces dynamically.

## Current VR/AR Systems in Dentistry

### DentSim System

The DentSim system (DenX Ltd., Israel) was one of the earliest pioneers in this field. It utilizes AR technology combined with infrared tracking to monitor the position of the dental handpiece and the mannequin head in real-time [6]. Students view their work on a monitor that displays their preparation alongside an ideal preparation. The system offers immediate feedback on preparation walls, depth, and smoothness, and also evaluates the student's ergonomic posture.

### Virtual Education System for Dentistry

The Virtual Education System for Dentistry is a prosthodontic training simulator jointly developed by the Affiliated Stomatological Hospital of Nanjing Medical University and Suzhou Digital-health Care Company. It comprises two main components: the Virtual Learning Network Platform (VLNP) and the Real-time Dental Training and Evaluation System (RDTEs). Before entering hands-on training, students first engage with the VLNP, where they study procedural guidelines, predefined crown preparation criteria, and standardized instructional videos.

Subsequently, learners carry out crown preparation exercises on a phantom head while being supported by the RDTEs, which records both the preparation process and final outcomes. Upon completion, the system automatically evaluates student performance using predefined preparation standards, allowing learners to visually compare their own work with ideal reference criteria on a computer interface [7,8].

### Simodont Dental Trainer

The Simodont (Moog Inc., USA) is a high-fidelity VR simulator that emphasizes haptic realism. Unlike DentSim, it does not use a physical mannequin for the tooth itself but projects a 3D virtual tooth. The user holds a haptic stylus that simulates the handpiece. Its "dry" operation eliminates the need for water systems and plastic consumables. The voxel-based modeling allows for the realistic simulation of pathology, such as caries removal and pulp exposure, which are impossible to reset instantly in physical models [7,9].

### PerioSim

PerioSim is a computerized virtual reality-based dental training system that presents a three-dimensional model of the quadrant with adjustable transparency, enabling visualization of teeth, gingiva, bone, and supporting structures. The system integrates immersive 3D graphics with haptic feedback, allowing trainees to experience tactile sensations while using virtual instruments such as a Shepherd's hook explorer for detecting caries-active white spot lesions or a periodontal probe for assessing periodontal pockets, with real-time visualization and recording of applied instrument pressure. A configurable control panel enables customization of instrument selection, tissue transparency, navigation, haptic fidelity, and tremor modulation [10].

### VirTeaSy Dental

The Virteasy Dental system (HRV, Laval, France) is a VR-based haptic interactive simulator designed for dental education and practical training, integrating an avatar patient with a library of virtual dental procedures. It enables users to perform various tasks within a computerized virtual environment and includes a virtual magnification feature offering adjustable zoom from 1× to 20× by modifying the

virtual camera's field of view and distance. Although it does not fully replicate the optical physics of a dental microscope, the system provides a realistic approximation of loupes or microscopic magnification. Virteasy can be used in both immersive VR mode with a headset and semi-immersive mode using a standard monitor, allowing ergonomic positioning around the virtual patient and adjustment of chair height and inclination. To minimize motion sickness in VR mode, magnification is delivered through a secondary static viewing tool, resembling a tablet or microscope display, offering localized magnification and a closer simulation of conventional dental magnification devices [11].

### HapTEL System

The HapTEL (Haptic Technology Enhanced Learning) system focuses on the ergonomics of dental training. It utilizes a virtual workbench setup that mimics a clinical environment, providing performance analytics that help students refine their hand grip and fulcrum positions. The haptic work-station consists of a haptically-enabled modified dental drill (or in the case of teaching injections to nursing students, a syringe) providing realistic force-feedback to the operator/learner during use within the virtual clinical environment. For the dental students, this environment, which includes a set of teeth in a jaw and the dental drill, is displayed on a 3D dual-screen system viewed by the operator using 3D glasses [12].

### Comparative Analysis

While DentSim provides excellent physical orientation via AR, Simodont offers superior material simulation through VR haptics. HapTEL stands out for its detailed ergonomic feedback and performance analytics. Newer platforms are increasingly integrating cloud-based case libraries, enabling global sharing of training scenarios. The next frontier is AI integration, offering personalized coaching and adaptive feedback based on individual performance data.

### Benefits for Dental Students

The integration of VR simulators offers a risk-free learning environment where mistakes become valuable learning opportunities rather than ethical liabilities. Students can repeat a complex Class I cavity preparation or a crown reduction dozens of times without the cost of plastic teeth or the risk of harming a patient [13,14].

Immediate, objective feedback is perhaps the most significant pedagogical advantage. In traditional settings, feedback is delayed until an instructor is available, and it can be subjective. VR systems provide real-time metrics on angulation, depth, and tissue removal. This immediacy accelerates the learning curve significantly [14,15].

Psychomotor skill development is enhanced through high-repetition practice. Studies have shown an increase in skill confidence among students trained on VR simulators compared to traditional methods. Furthermore, these systems standardize assessment, eliminating instructor bias and providing quantifiable performance metrics that are crucial for accreditation and competency verification [13,16].

### Benefits for Practicing Clinicians

Beyond undergraduate education, AR and VR hold immense value for seasoned practitioners. For complex rehabilitation cases, VR allows for procedural rehearsal. Clinicians can import patient-specific CBCT and MRI data to create a "digital twin" of the patient's jaw. This enables the rehearsal of implant placement or orthognathic surgery in a virtual environment before the actual operation, reducing surgical time and complications [17].

Continuing professional development (CPD) becomes more accessible. Clinicians can maintain skills for infrequently performed procedures, such as complex apicoectomies or zygomatic implants, via simulation modules without traveling to training centers. VR also serves as a powerful patient communication tool. Visualizing the treatment outcome in 3D helps patients understand the procedure, thereby improving informed consent and treatment acceptance. Additionally, VR distraction therapy is a proven non-pharmacological method for managing dental anxiety in patients during procedures.

## Applications Across Dental Specialities

**Prosthodontics:** Practice using Virtual reality-based interactive simulation (VRIS) can significantly improve learning outcomes in prosthodontic education. Its key benefits include real-time feedback, reduced procedural time, enhanced learner confidence and motivation, faster development of clinical skills, improved performance metrics, and greater overall engagement in the learning process [18].

**Oral Surgery:** Integrating virtual reality (VR) into Oral and Maxillofacial Surgery (OMFS) and Oral Surgery (OS) training enhances surgical skill acquisition and anatomical knowledge, particularly benefiting undergraduate students and those in their specialization phase. 12 articles collectively highlight the transformative impact of VR on dental surgical training, not only improving the realism of simulated surgical environments but also refining the skills of surgical trainees [19].

**Endodontics:** Pre-surgical practice in a virtual environment using the 3D computerized model generated from the original CBCT image data improved endodontic microsurgery performance [20].

**Periodontics:** Since periodontics relies heavily on tactile feedback for diagnosis and surgery, integrating haptic technology is essential for creating authentic simulators. Research conducted at the University of Illinois Chicago (UIC) College of Dentistry has confirmed the effectiveness of a haptics-based virtual reality platform for training in this field [21].

**Orthodontics:** To achieve precise dental alignment and occlusion, it is essential to position brackets, wires, and appliances accurately. By incorporating force feedback, this platform enables students to practice within an authentic simulated setting. This integration significantly lowers both the financial expenses and the time required for dental clinical training [22,23].

**Pediatric Dentistry:** VR headsets are primarily used as distraction tools to reduce anxiety and pain perception in young patients during treatment [24].

**Dental Implantology:** Offering better learning retention than standard methods, MR-training provides an efficient and user-friendly platform for teaching dental implant placement to students [25].

## Barriers To Adoption

Despite the clear advantages of VR-haptic trainers, they are utilized in fewer than 20% of the world's 1,000+ dental schools. This limited adoption is primarily due to three interconnected factors: the high initial capital and faculty investment required, the significant time needed for experts to develop evidence-based curricula, and the costly space requirements for simulation labs. Furthermore, the lack of widespread, cross-border validation research creates skepticism regarding their efficacy. To overcome these hurdles and maximize the technology's impact, standardized global practices and rigorous research are essential to prove its educational value [26].

## Economic Considerations

According to Strategic Market Research, the worldwide market for dental simulators is set for significant expansion. Valued at USD 1.8 billion in 2024, it is forecasted to reach USD 2.78 billion by 2030, reflecting a steady 7.5% CAGR [27]. This upward trend is primarily fueled by rapid technological innovation and a rising global need for advanced professional training and dental education tools. While the upfront cost is high, the Return on Investment (ROI) can typically be realized within 3-5 years. This is achieved through the elimination of consumable materials (plastic teeth, burs, impression materials) and a massive reduction in faculty supervision time. Furthermore, the risk mitigation and liability reduction offered by better-trained graduates provide intangible but significant economic value.

## Future Directions

The future of dental simulation lies in the convergence of technologies. Artificial Intelligence (AI) will drive personalized learning algorithms that adapt simulation difficulty based on student performance. The "Metaverse" promises collaborative learning platforms where students from different continents can observe and participate in complex surgeries in a shared virtual space.

Advanced haptic systems with thermal feedback and improved soft tissue modeling (simulating bleeding

and swelling) are in development. The convergence of Robotics and VR will allow for seamless transitions where a surgeon trains on a robot-assisted simulator that perfectly mimics the robotic surgical system used in the clinic. 5G connectivity will further enable cloud-based, low-latency streaming of high-fidelity simulations.

### Limitations of Current Technology

Current limitations focus on fidelity. While hard tissue simulation is advanced, soft tissue haptics often lack the realistic "give" and elasticity of real gingiva or tongue tissue. Visual resolution limitations can sometimes obscure fine details. Motion sickness (cybersickness) remains a side effect for a subset of users in fully immersive VR environments. Ethical concerns regarding data privacy for patient-specific models and the potential over-reliance on technology at the expense of manual intuition must also be addressed [26].

### Recommendations for Implementation

Institutions should conduct comprehensive needs assessments before acquisition. A phased implementation, starting with pilot programs, allows for faculty adaptation and technical troubleshooting. Faculty development is crucial; educators must be competent not just in dentistry but in the operation of the simulators. Curriculum mapping ensures that VR modules align with specific learning objectives rather than being used as novelties. Continuous evaluation frameworks should be established to measure the effectiveness of the technology on student outcomes.

### Conclusion

Augmented and Virtual Reality simulators represent a fundamental evolution in dental competency acquisition. The evidence is compelling: these technologies increase confidence, reduce faculty workload and provide a safe, standardized training environment [3,5]. While barriers such as cost and faculty training are substantial, they are surmountable with strategic planning and are outweighed by the long-term benefits.

With adoption currently hovering around less than 10% in many regions, there is an urgent need for dental institutions to accelerate integration. The

question is no longer whether to adopt these technologies, but how quickly. As AI and robotics converge with VR, the distinction between simulation and practice will blur, ultimately benefiting the most important stakeholder: the patient.

### References

1. Lin PY, Chen TC, Lin CJ, Chang WJ, Chen JH. The use of augmented reality (AR) and virtual reality (VR) in dental surgery education and practice: a narrative review. *J Dent Sci.* 2024;19(Suppl):S91-S101.
2. Suebnukarn S, Phatthanasathiankul N, Sombatweroje S, Rhienmora P, Haddawy P. Process and outcome measures of expert/novice performance on a haptic virtual reality system. *J Dent.* 2009;37(9):658-665.
3. Albuha Al-Mussawi RM, Farid F. Computer-based technologies in dentistry: types and applications. *J Dent (Shiraz).* 2016;17(3):215-222.
4. Moussa R, Alghazaly A, Althagafi N, Eshky R, Borzangy S. Effectiveness of virtual reality and interactive simulators on dental education outcomes: a systematic review. *Eur J Dent.* 2022;16(1):14-31.
5. Farronato M, Maspero C, Lanteri V, Fama A, Ferrario VF, Farronato G. Current state of the art in the use of augmented reality in dentistry: a systematic review of the literature. *BMC Oral Health.* 2019;19(1):135.
6. Li Y et al. Mixed reality and haptic-based dental simulator for tooth preparation: research, development, and preliminary evaluation. *JMIR Serious Games.* 2022;10(1):e30653.
7. Li Y et al. The current situation and future prospects of simulators in dental education. *J*

- Med Internet Res. 2021;23(4):e23635.
8. Fu Y et al. Assessment and evaluation of online education and virtual simulation technology in dental education: a cross-sectional survey. *BMC Med Educ.* 2024;24(1):191.
  9. Leung ALS, Yeung C, Chu S, Wong AWY, Yu OY, Chu CH. Use of computer simulation in dental training with special reference to Simodont. *Dent J (Basel).* 2021;9:125.
  10. Chaudhari N, Thakare G. Periosim: haptic-based 3D virtual reality teaching and training simulator in dentistry: a review. *Int J Adv Res Dev.* 2018;3(4):40-42.
  11. Pasqualini D, Carpegna G, Alovisi M, Berutti E, Chogle S. Virtual reality and haptic simulation in modern microsurgical endodontics: case report and proof of concept. *Int Endod J.* 2025 Apr 19.
  12. San Diego JP, Cox MJ, Quinn BFA, Newton JT, Banerjee A, Woolford M. Researching haptics in higher education: the complexity of developing haptics virtual learning systems and evaluating its impact on students' learning. *Comput Educ.* 2012;59(1):156-166.
  13. Dută M, Amariei CI, Bogdan CM, Popovici DM, Ionescu N, Nuca CI. An overview of virtual and augmented reality in dental education. *Oral Health Dent Manag.* 2011;10(1):42-49.
  14. Al-Saud LM et al. Feedback and motor skill acquisition using a haptic dental simulator. *Eur J Dent Educ.* 2016;21(4):240-247.
  15. Rhiemora P, Haddawy P, Khanal P, Suebnukarn S, Dailey MN. A virtual reality simulator for teaching and evaluating dental procedures. *Methods Inf Med.* 2010;49(4):396-405.
  16. Huang TK, Yang CH, Hsieh YH, Wang JC, Hung CC. Augmented reality (AR) and virtual reality (VR) applied in dentistry. *Kaohsiung J Med Sci.* 2018;34(4):243-248.
  17. Mai HN et al. Effectiveness of virtual reality interactive simulation practice in prosthodontic education: a systematic review and meta-analysis. *Eur J Dent Educ.* 2025;29(3):594-607.
  18. Bjelovucic R, Wolff J, Nørholt SE, Pauwels R, Taneja P. Effectiveness of mixed reality in oral surgery training: a systematic review. *Sensors.* 2025;25(13):3945.
  19. Suebnukarn S, Rhiemora P, Haddawy P. The use of cone-beam computed tomography and virtual reality simulation for pre-surgical practice in endodontic microsurgery. *Int Endod J.* 2012;45(7):627-632.
  20. Luciano C, Banerjee P, DeFanti T. Haptics-based virtual reality periodontal training simulator. *Virtual Real.* 2009;13(2):69-85.
  21. Ströbele DA, Othman A, Meier MA, Aboulazm K, von See C. Augmented reality in orthodontics for bracket placement using conventional mobile devices: technical note. *J World Fed Orthod.* 2023;12(6):280-283.
  22. Ye F, Liu L, Yan B, Zhao X, Hao A. Orthodontic simulation system with force feedback for training complete bracket placement procedures. *Virtual Real Intell Hardw.* 2021;3(4):261-273.

23. Eijlers R et al. Systematic review and meta-analysis of virtual reality in pediatrics: effects on pain and anxiety. *Anesth Analg.* 2019;129(5):1344-1353.
24. Wang X et al. The impact of mixed reality training method on novice trainees of dental implants: an in vitro study. *BMC Oral Health.* 2025;25(1):1379.
25. Felszeghy S et al. Benefits and challenges of the integration of haptics-enhanced virtual reality training within dental curricula. *J Dent Educ.* 2024 Jul;89(7):1070-1083.
26. Felszeghy S et al. Benefits and challenges of the integration of haptics-enhanced virtual reality training within dental curricula. *J Dent Educ.* 2024 Jul;89(7):1070-1083.
27. Strategic Market Research. Dental simulator market: global analysis and forecast 2024-2030 [Internet]. New York (NY): Strategic Market Research; 2025 Nov [cited 2026 Feb 13]. Available from: [www.strategicmarketresearch.co](http://www.strategicmarketresearch.co)