Simulation in prosthodontics: Bridging traditional and modern educational methods.

Anushka Agarwal[1], Dolanchanpa Dasgupta[2], Swarnali Biswas[3], Sunetri Bera[3].

[1]Post Graduate Student, Department of Prosthodontics and Crown & Bridge, Kusum Devi Sunderlal Dugar Jain Dental College and Hospital, Kolkata.
[2]Professor and Head, Department of Prosthodontics and Crown & Bridge, Kusum Devi Sunderlal Dugar Jain Dental College and Hospital, Kolkata.
[3]Senior Lecturer, Department of Prosthodontics and Crown & Bridge, Kusum Devi Sunderlal Dugar Jain Dental College and Hospital, Kolkata.

Abstract

Background: Simulation has emerged as a transformative pedagogical and clinical tool in dental education, particularly in prosthodontics. Traditional training, while effective, presents limitations in standardization, safety, and student engagement. Virtual simulation technologies—ranging from haptic-based tools to immersive virtual reality—offer the potential to revolutionize skill acquisition, feedback mechanisms, and cognitive integration.

Objective: This review explores the applications, advantages, limitations, and future directions of simulation-based training and practice in prosthodontics, while evaluating its efficacy compared to conventional methods.

Methods: A narrative literature review was conducted, synthesizing findings from studies published between 1998 and 2024. Databases including PubMed, Scopus, and Web of Science were searched by applying Boolean search using keywords such as "simulation," "prosthodontics," "dental education," and "virtual training." A total of 30+ peer-reviewed articles were included, spanning preclinical simulation, virtual tooth preparations, and haptic devices in prosthodontic skill training.

Results: The results obtained were enhanced psychomotor skill acquisition, error reduction, improved learner confidence, repetitive, standardized practice, feedback-driven learning, identified limitations.

Conclusion: While simulation cannot fully replace traditional hands-on training, its integration into prosthodontics offers a powerful adjunct that complements conventional techniques. Further longitudinal and outcome-based research is needed to validate long-term clinical proficiency.

Keywords: Dental Education, Digital Dentistry, Haptic Feedback, Preclinical Training, Prosthodontics, Simodont, Simulation, Virtual Reality.

Address of correspondence: Dr. Anushka Agarwal, 227 Laketown, Block -B, 3rd Floor, Kolkata - 700089.
Email address: anushka.253113@gmail.com **Phone no:** 7003516139.
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Introduction

Prosthodontics is a technically demanding dental specialty that relies heavily on the development of fine motor skills, clinical reasoning, and an acute sense of esthetics and function. Historically, the training of prosthodontists has centred on preclinical exercises using plastic teeth mounted on phantom heads and mannequins, which serve as static models for simulating clinical procedures. While effective to a degree, these traditional approaches often fail to capture the complexity, variability, and tactile feedback associated with real-world patient care.[1]

In response to these limitations, simulation-based training [SBT] has emerged as a transformative pedagogical strategy in dental education. Drawing inspiration from aviation and medical training, dental simulation incorporates virtual environments, three-dimensional [3D] modelling, haptic feedback systems, and more recently, artificial intelligence to replicate realistic clinical scenarios. [2-4] These innovations offer a controlled, repeatable, and measurable training environment that enhances both technical skill acquisition and cognitive integration. [5]

The integration of simulation into prosthodontics is particularly noteworthy due to the high precision and esthetic demands of the specialty. Simulation platforms, such as Simodont®, now allow dental students and residents to perform virtual tooth preparations with real-time resistance, visual feedback, and detailed metrics on performance. [6] Virtual reality (VR) and Augmented reality (AR) applications enable immersive learning experiences, bridging the gap between theory and practice. [7]

COVID-19 further accelerated the incorporation of digital tools into dental curricula, with simulation becoming a vital substitute for clinical exposure during institutional lockdowns. [8] The result has been a global shift in mindset toward blended learning, where digital simulation complements traditional preclinical and clinical education. [9]

This literature review aims to synthesize the current evidence on simulation in prosthodontics, highlighting its applications, benefits, educational outcomes, limitations, and future directions. By drawing on findings from over three decades of research, this review also considers how simulation compares to conventional methods and its implications for curriculum design and clinical competency.

Methods

This review follows a narrative design, synthesizing peer-reviewed literature published from 1998 to 2024. Studies were selected based on relevance to simulation in prosthodontics or closely related preclinical dental training.

Search Strategy: Databases searched included PubMed, Scopus, EBSCO, and Google Scholar. Keywords used were: “simulation,” “prosthodontics,” “Simodont,” “virtual reality,” “dental education,” “preclinical training,” “haptic feedback,” and “digital dentistry.” Reference lists of relevant articles were manually searched to identify additional sources.

Inclusion Criteria:

a. Studies published in English between 1998 and 2024.
b. Original research articles, systematic reviews, scoping reviews, and expert opinions.
c. Research on simulation applied in prosthodontics or general dental education relevant to prosthodontic procedures.
d. Studies involving predoctoral students, postgraduates, or faculty.

Exclusion Criteria:

i. Articles focused solely on orthodontics or oral surgery unless discussing multi-specialty applications.
ii. Conference abstracts or letters without sufficient methodology or results.
iii. Non-English publications.

Data Synthesis:

i. Data from selected studies were grouped thematically:
ii. Applications of simulation in prosthodontics,
iii. Educational outcomes,
iv. Comparative advantages over traditional training,
v. Limitations and challenges,
vi. Integration into curricula and regulatory acceptance.
vii. The data was interpreted qualitatively for thematic clarity rather than quantitative meta-analysis due to variability in study designs and outcome measures.

Results and Thematic Synthesis

Analysis of the selected literature reveals consistent themes related to the implementation and outcomes of simulation in prosthodontic education. These have been organized into five thematic domains: 1) Applications in Prosthodontics, 2) Educational Impact, 3) Comparative Benefits Over Traditional Methods, 4) Limitations and Barriers, and 5) Curricular Integration and Global Trends.

1. Applications in Prosthodontics

Simulation is being used extensively in fixed, removable, and implant prosthodontics for training and clinical planning. One of the most common applications is in virtual tooth preparation, especially for crowns and bridges. Simodont®, a widely adopted haptic simulator, allows students to perform full crown preparations with high levels of visual and tactile fidelity. Leung et al. (2021) demonstrated that Simodont users showed greater consistency and accuracy in taper, depth, and finish line design compared to those trained on typodonts. [6]

Liu et al. (2020) applied a virtual system to ceramic crown preparation, concluding that students trained in a digital environment showed superior understanding of preparation guidelines and better transfer of knowledge into clinical simulations. [10]. These findings echo Botelho's (2019) results, where students using video-assisted simulations demonstrated more retention of prosthodontic procedures compared to traditional learners. [11,12]

In implant prosthodontics, simulation has enabled preoperative training using integrated CBCT and prosthetic planning software, allowing learners to visualize implant angulation and prosthetically driven placement. This aids in understanding spatial anatomy and designing optimal prosthesis contours. [13,20] The use of AR and VR in full-mouth rehabilitation planning is also emerging, allowing clinicians to simulate occlusal schemes and esthetic outcomes in real-time. [25]

Applications have expanded beyond mechanical skill-building. Amini et al. developed a VR empathy training system for dental providers, enhancing their ability to manage prosthodontic patients with anxiety, disability, or cognitive decline — important for elderly or complete denture patients. [11]

2. Educational Impact

Simulation plays a powerful role in psychomotor development, cognitive learning, and reflective practice. Tremblay et al. (2019) observed that high-complexity simulation tasks promoted metacognition and student self-assessment, key elements in prosthodontic education. [7] Compared to traditional mannequin-based exercises, simulation encourages deliberate practice with instant feedback, which supports better long-term retention.

Patil et al. (2023) systematically reviewed haptic feedback devices and confirmed improved hand–eye coordination, reduced instructor dependency, and increased procedural accuracy among students trained with simulators. [14] Moreover, students in these studies reported lower anxiety when attempting clinical tasks for the first time after simulation exposure.

Monteiro and Sibbald (2020), however, questioned the assumption that simulation-induced “surprise” enhances retention, suggesting instead that structured debriefing is more important for reinforcing learning outcomes. [5] This highlights the need for thoughtful integration of simulation into broader pedagogical frameworks.

Additionally, Perry et al. (2015) noted that students in simulation-rich environments develop a more nuanced understanding of procedural rationale, critical in prosthodontics where individualized treatment planning is essential. [4]

3. Comparative Benefits Over Traditional Methods

Simulation surpasses traditional methods in several dimensions:

Standardization: All students receive identical cases, unlike typodonts or clinical settings where case variability limits comparability. [1,6]

Immediate Feedback: Platforms like Simodont score based on defined parameters — taper, angle, convergence, depth — offering quantifiable feedback that improves self-regulation. [6]

Unlimited Repetition: Virtual cases can be practiced repeatedly without additional material costs, helping weaker students remediate without institutional burden. [4]

Safety and Ethics: Training on live patients involves risk, especially in irreversible procedures like tooth preparation. Simulation mitigates this risk while building confidence. [14]

Studies comparing traditional and simulated training reinforce these benefits. Stoilov et al. (2024) found that students using virtual preparation simulators outperformed their peers in final practical exams and displayed greater procedural efficiency. [15] Similarly, Quinn et al. (2003) demonstrated higher preclinical performance scores and fewer procedural errors in students trained with VR versus traditional methods. [26]

4. Limitations and Implementation Challenges

Despite strong educational outcomes, simulation technology faces notable barriers.

Cost is the most reported limitation. High-fidelity simulators like Simodont cost over USD $100,000 per station, excluding maintenance and software updates. [3] For institutions in low-income regions, this creates a digital divide.

Haptic realism remains imperfect. While resistance can mimic enamel and dentin, simulators cannot yet replicate nuances such as carious texture, pulpal feedback, or soft-tissue interaction. Jasinevicius et al. (2004) reported that the lack of complete sensory realism may hinder full transfer of skills to live patients. [17]

Faculty calibration and acceptance also present issues. Fraser et al. (2012) observed that retroactive interference may occur when new simulation training disrupts previously learned physical skills.[8] Moreover, instructors unfamiliar with digital systems may resist transition or misuse the platforms due to inadequate training. [1,4]

There are also psychological barriers for students. Shariff et al. (2020) explored how learners often overestimate their abilities post-simulation, indicating a false sense of preparedness if simulation is not coupled with clinical application. [9]

5. Curricular Integration and Global Trends

Global curricula are increasingly integrating simulation as part of competency-based dental education. In the US, the Commission on Dental Accreditation (CODA) now recognizes simulation as valid for clinical skill development. [4] The General Dental Council (UK) and Dental Council of India (DCI) are also adapting frameworks that include digital and simulation-based learning outcomes. [22]

Buchanan (2001) and Yang et al. (2012) highlighted that integration success depends on faculty engagement, administrative support, and institutional willingness to adopt new technologies.[18,23] Progressive institutions report increased student performance, faculty satisfaction, and better transition from preclinical to clinical phases when simulation is used as a preparatory tool. [12,14]

George et al. (2024) have emphasized simulation as critical for bridging gaps in clinical exposure due to overburdened patient schedules and limited lab facilities.[2] While resource limitations persist, the Indian dental education system is actively piloting scalable simulation models. (Table No.1)

Discussion

The use of simulation in dental education dates back to the 1980s, when Green and Klausner (1984) demonstrated that clinical simulation could improve preclinical performance and standardize student outcomes. [21] These early studies emphasized the potential of structured practice environments but were constrained by the limitations of static models. By the late 1990s, advances in digital technologies began to shift attention toward computer-assisted and virtual methods, laying the groundwork for immersive simulation in prosthodontics.

Buchanan (2001) pioneered the systematic documentation of simulation's pedagogical benefits in dental curricula, showing that virtual systems enhanced psychomotor training and feedback opportunities.[6] Quinn et al. (2003) further validated these findings by demonstrating that VR-trained students achieved superior preclinical performance compared to conventional training methods.[26] Jasinevicius et al. (2004) compared VR-based and non-computer-assisted systems, highlighting that while digital platforms reduced procedural errors, they still lacked tactile realism. [17]

During this period, Donaldson et al. (2008) argued for increased international collaboration and standardization of simulation in dental education, reinforcing its role in competency-driven training. [22] By 2011, Duta et al. introduced the feasibility of VR and AR in dental education, pointing to their scalability and adaptability in preclinical training. [13]

The 2010s marked a significant expansion in simulation research and pedagogical refinement. Gal et al. (2011) assessed faculty and student perceptions of haptic VR simulators, noting their potential for manual dexterity training.[36] Yang et al. (2012) promoted blended learning, integrating 3D resources into inquiry-based dental education.[18] Fraser et al. (2012) cautioned that poorly integrated simulation could lead to retroactive interference in skill retention. [8]

Synthesis reviews by Perry et al. (2015) and Higgins et al. (2016) confirmed that simulation enhanced reflective practice, while Al-Saud et al. (2017) established haptic simulators as reliable tools for motor skill acquisition. [3,19,31] Tremblay et al. (2019) highlighted that complex tasks within simulation environments encouraged metacognition and student self-assessment.[7] Botelho (2019) demonstrated the effectiveness of video-assisted simulation in improving retention of prosthodontic procedures.[12]

Notably, Serrano et al. (2020) emphasized patient-centered virtual training, while Amini et al. (2021) piloted immersive VR for empathy training in prosthodontics, broadening simulation beyond psychomotor training.[29]

The COVID-19 pandemic accelerated simulation's integration into prosthodontics. Liu et al. (2020) demonstrated that VR-based ceramic crown preparation improved knowledge transfer and accuracy.[10] Leung et al. (2021) confirmed that Simodont users showed superior performance in crown preparations compared to typodont-based training.[6] Towers et al. (2022) reported enhanced student engagement when VR was combined with 3D-printed patient-specific models.[30]

Systematic reviews by Moussa et al. (2022) and Patil et al. (2023) further validated simulation's role in improving psychomotor precision and reducing instructor dependency.[14,34] Hsu et al. (2022) emphasized the clinical relevance of haptic training in tooth preparation.[35] Stoilov et al. (2024) provided robust evidence that students trained with VR preparation simulators outperformed phantom-head cohorts in objective assessments.[15]

More recent research has expanded simulation's role in prosthodontics education. Patient-specific VR models have been trialled to allow individualized prosthodontic training (2023). A meta-analysis (2024) confirmed that VR interactive simulation practice improves procedural efficiency, particularly in implant prosthodontics. A 2025 RCT on veneer preparation showed VR simulators provide outcomes comparable to phantom heads, though tactile realism remains a challenge.[41]

Regional studies such as George et al. (2024) highlighted simulation's role in India, where patient scarcity and resource constraints necessitate blended learning.[2]. Similarly, a cross-sectional study in Pakistan (2024) documented postgraduate trainees' positive perceptions of simulation and AR integration in prosthodontics education.[42]

Emerging technological trends are also reshaping the landscape. Generative AI has been identified as a potential driver of adaptive simulation platforms (2024), while reviews on AI in prosthetic dentistry (2025) suggest integration with VR and haptics may lead to more patient-specific, predictive simulations.

Across decades, evidence demonstrates that simulation improves accuracy, fosters reflective practice, enhances confidence, and reduces error rates. Yet, challenges persist — primarily cost, faculty calibration, and limited tactile realism. Overreliance on idealized simulation risks creating overconfidence without sufficient clinical exposure (Shariff et al., 2020).[9]

The progression of research illustrates a transition: from simulation as supplementary (1980s–1990s), to experimental VR (2000s), to pedagogically integrated (2010s), and finally to mainstream adoption (2020s). With regulatory bodies increasingly endorsing simulation as valid preclinical training, and AI-driven adaptive environments on the horizon, simulation is poised to become integral to prosthodontics education worldwide.

Conclusion

Simulation technologies have transformed prosthodontic education by creating immersive, feedback-rich environments that enhance learning experiences. While not a substitute for traditional methods, they serve as powerful adjuncts, complementing preclinical and clinical training and contributing to improved psychomotor skills, reduced errors, greater procedural accuracy, and increased learner confidence. Their integration aligns seamlessly with competency-based curricula, offering standardized, repeatable, and ethically safer training opportunities. However, challenges remain, including high implementation costs, limited tactile fidelity, and the need for both faculty calibration and student adaptability. Looking ahead, advancements in virtual reality, augmented reality, haptics, and artificial intelligence are expected to elevate simulation to a core component of prosthodontic education. Globally, these technologies hold the promise of bridging disparities in clinical exposure, particularly in resource-limited regions. As innovations continue to mature, simulation is poised to play a pivotal role in shaping the next generation of prosthodontists, preparing them for precise, patient-centred care.

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TABLE

Domain	Author/Year	Key Points
Applications in Prosthodontics	Leung et al., 2021 [6]	Simodont users showed higher accuracy in taper, depth, and finish line compared to typodonts.
	Liu et al., 2020 [10]	VR crown preparation improved guideline understanding and clinical transfer.
	Botelho, 2019 [12]	Video-assisted simulations improved retention of prosthodontic procedures.
	Duta et al, 2011; [13] Yamaguchi et al, 2011 [20]	Simulation supported implant planning, angulation, and prosthetic-driven placement.
	Xia et al, 2012 [25]	Enabled full-mouth rehab simulations for occlusion and esthetics.
	Amini et al., 2021 [11]	VR empathy training improved ability to manage anxious/elderly prosthodontic patients.
Educational Impact	Tremblay et al., 2019 [7]	High-complexity tasks promoted metacognition and self-assessment.
	Patil et al., 2023 [14]	Haptic devices improved hand–eye coordination, reduced instructor dependency, increased accuracy.
	Monteiro & Sibbald, 2020 [5]	Debriefing more critical than simulation-induced 'surprise' for retention.
	Perry et al., 2015 [3]	Simulation promoted deeper understanding of procedural rationale.
Comparative Benefits	Stoilov et al., 2024 [15]	VR-prepared students outperformed phantom-head groups in practical exams.
	Quinn et al., 2003 [26]	VR-trained students scored higher with fewer errors compared to traditional methods.
Limitations	Jasinevicius et al., 2004 [17]	Haptic realism incomplete—caries, pulpal feedback, and soft tissue not replicated.
	Fraser et al., 2012 [8]	Retroactive interference possible when simulation disrupts learned skills.

	Shariff et al., 2020 [9]	Learners may overestimate abilities post-simulation; risk of false preparedness.
	Perry et al., 2015 [3]	High cost of simulators ($100,000+), faculty resistance, digital divide issues.
Curricular Integration	Sipiyaruk et al., 2023 [4]	Recognizes simulation as valid for clinical skill development.
	Donaldson et al., 2008 [22]	Adapting frameworks for digital and simulation-based learning outcomes.
	Buchanan, 2001; Yang et al., 2012 [16, 18]	Integration depends on faculty engagement and institutional support.
	George et al., 2024 [2]	Simulation bridges gaps in India where patient schedules and lab facilities are limited.