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Review article

The virtual assessment in dental education: A narrative review

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Abstract The shift towards virtual assessment in dental education represents a significant advancement over traditional evaluation methods, offering new opportunities for assessing both theoretical knowledge and practical skills. This review examines the use of virtual assessment tools within the context of dental education. A narrative literature review was conducted, analyzing studies published between 2000 and 2024, sourced from PubMed, the Cochrane Library, and Embase. From the initial search, 13 studies were selected for qualitative synthesis. The results indicate that virtual assessments, facilitated by technologies such as computer-based simulations and remote objective structured clinical examinations (OSCEs), have enhanced the accuracy and comprehensiveness of dental student evaluations. These methods allow for more consistent and objective assessments of competencies, addressing some limitations of traditional practical exams. However, the integration of virtual assessments presents challenges, including the need for significant investment in technology, infrastructure, and training for faculty and students. Despite these challenges, the review concludes that virtual assessment has the potential to become a cornerstone of modern dental education, offering a scalable and adaptable solution for evaluating dental competencies in diverse learning environments.

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Introduction

Establishing robust assessment methods for dental education is inherently complex, as it requires objectivity, validity, and fairness. Miller proposed a framework known as Miller's pyramid for assessing clinical competence with a hierarchy of levels. For dental education, we should focus more on assessing the learner's knowledge, competence, and performance. In recent years, virtual assessment has begun to gain traction within the field of dental education, marking a significant shift from traditional evaluation methods. To reach a high level of clinical proficiency, it is essential to master cognitive, psychomotor, and affective competencies. Dental education aims to provide practitioners with comprehensive expertise in these areas. While there are many assessment methods for non-technical skills and knowledge, evaluating technical skills remains challenging for educators. As educational institutions increasingly integrate digital tools such as virtual simulations and online platforms, these technologies offer a more flexible, accessible, and interactive approach to assessing dental students' competencies. This transition allows for more comprehensive evaluations of both theoretical knowledge and practical skills. However, despite its promising potential, virtual assessment is still in its early stages and has yet to be fully developed or explored. Several challenges and unanswered questions remain its effectiveness, reliability, and the extent to which it can replicate the complexities of real-world clinical scenarios.

In contemporary dental education, assessment methods play a crucial role in ensuring that students meet the high standards expected in the profession. Traditionally, these assessments have relied heavily on a combination of written examinations, practical skill assessments, and objective structured clinical examinations (OSCEs).[1,2] Written exams, including multiple-choice questions (MCQs), essays, and short-answer questions, have been a staple in dental education. These exams primarily assess students' understanding of theoretical knowledge, including biomedical sciences, dental materials, and treatment planning.[3] Nevertheless, technical skill holds exceptional significance in dental procedures, standing alongside knowledge and attitude. While written exams effectively test cognitive knowledge, they fall short in evaluating hands-on clinical skills and decision-making abilities,[4] Practical assessments involve students demonstrating their ability to perform specific dental procedures on typodont models or simulators. These skills are assessed in controlled environments, allowing educators to evaluate students' technical proficiency. However, these assessments are often criticized for needing more realism, as they do not fully replicate the complexities and unpredictability of real patient scenarios. Moreover, practical assessments can be logistically challenging and resource-intensive, requiring significant time, equipment, and faculty involvement.[5] Objective structured clinical examinations (OSCEs) are widely regarded as one of the most comprehensive methods for assessing clinical competence. In an OSCE, students rotate through a series of stations where they must perform specific tasks, such as taking a patient history, performing a clinical procedure, or interpreting diagnostic data. Each station is designed to assess different aspects of clinical competence, including communication skills, clinical reasoning, and technical ability.[6] OSCEs provide a more holistic evaluation of a student's readiness for clinical practice.[7] However, they also have limitations, including high costs, logistical complexity, and the potential for examiner bias.[8,9]

With the advancement of digital technology, virtual assessment methods have emerged as a promising innovation in dental education. Virtual assessments leverage computer-based simulations, virtual reality (VR), augmented reality (AR), and online platforms to evaluate students' knowledge and skills in a more dynamic and interactive manner.[10] Integrating virtual assessments into dental education is challenging despite the potential benefits. These include the need for significant investment in technology and infrastructure, a learning curve associated with new technologies, and the necessity to validate virtual assessment methods to ensure reliable and accurate measures of competence. Therefore, this review aims to understand how these virtual technologies can be used for comprehensive, remote assessment of dental competence. Then we discuss virtual assessments' advantages, limitations, and future developments in dental education.

Materials and methods

A narrative review was conducted to provide a comprehensive overview of virtual assessment in dental education. The literature search focused on identifying relevant studies published between 2000 and 2024, emphasizing virtual technologies' use within the context of dental education assessments. A comprehensive literature search was conducted using the keywords "virtual assessment," "dental education," "skill assessment," "online assessment," "remote assessment," and "OSCE" across three databases: PubMed, Embase, and Cochrane Library. Because we would like to focus on the assessment of the level of knows(knowlege), knows how(competence), and shows how(performance) in Miller's pyramid. We excluded the 'workplace-based assessment' and 'Clinical direct observation assessment', which assess the level of does(action) in Miller's pyramid from the literature search.[11] The initial search yielded a total of 172 records, with 102 from PubMed, 52 from Embase, and 18 from Cochrane Library. After removing 37 duplicate records, 135 articles remained for further screening.

The abstracts of these 135 records were reviewed, leading to the exclusion of 67 records due to irrelevance to virtual assessment in dental education. Subsequently, a thorough full-text review was conducted on the remaining 68 articles. Based on the content, 55 articles were further excluded as they did not align with the scope of this review. Consequently, 13 studies met the inclusion criteria and were included in the qualitative synthesis of this review (Fig. 1). These studies provide a foundation for discussing virtual technologies' current applications, effectiveness, and potential future directions in enhancing assessment capabilities within dental education. The details of the articles reviewed are summarized in Table 1., which provides an overview of the methodologies, key findings, and implications of each study.

Results

The development of virtual assessment technology

In the traditional dental education assessment, for example, in Taiwan, the computer-based test (CBT) and the simulated pre-clinical operation skill test (PCOST) are part of the dental objective structured clinical examination (OSCE). The PCOST is designed for clinical practice using manikins, physical typodonts, and instruments in the simulation laboratory.[25] Dental trainees now have access to a full-body patient simulation system known as SIMROID to practice and assess operation skills.[26] Another system called DentSim allows students to work with actual artificial teeth while viewing computer-generated images on a monitor.[12] However, the COVID-19 pandemic necessitated rapidly adopting virtual assessment methods in dental education. With physical distancing measures in place, these technologies offered a compelling alternative by allowing remote yet realistic simulations of clinical scenarios.

The very first development of virtual assessment was building an online platform for remote evaluation. Especially during the COVID-19 pandemic, the global threat and the challenging situation accelerated the adoption of online platforms. While initially driven by necessity, these platforms have demonstrated the potential for long-term use. Online assessments can include interactive case-based scenarios, virtual patient consultations, and even remote OSCEs.[23,27] These platforms allow for greater flexibility, enabling students to be assessed from anywhere with an internet connection. Additionally, online assessments can be standardized and automated, reducing the potential for bias and ensuring consistency across evaluations.[23,24]

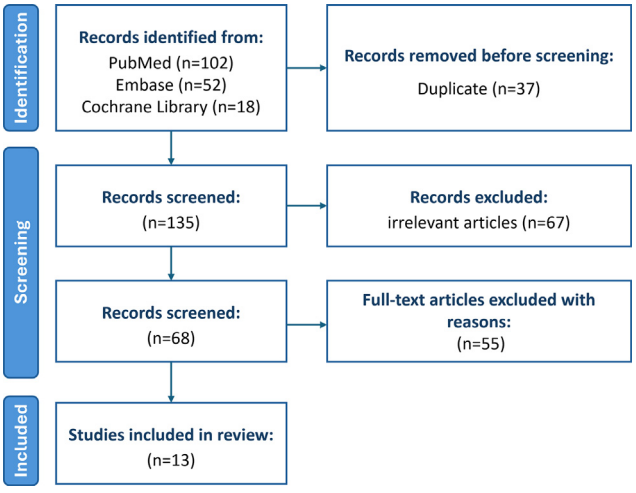

Figure 1 Flow chart of the selection process.

The other important issue for virtual assessment is computer-based simulations, which allow students to practice and be assessed on dental procedures in a virtual environment.[25,28] These simulations can mimic real-life scenarios, allowing students to refine their skills risk-free. For example, virtual patients can present with various dental conditions, requiring students to diagnose, plan treatment, and execute procedures. The software can track students' performance, providing immediate feedback and allowing for repeated practice until competence is achieved.[29] This method addresses traditional practical assessments' limitations by offering a more flexible and scalable solution.

Furthermore, augmented reality (AR) and virtual reality (VR) technologies have significantly advanced dental education by introducing sophisticated skill assessment and feedback methods. These technologies provide realistic and interactive environments that transform procedural and diagnostic dental competencies are evaluated and enhanced. In VR-based assessments, students can perform dental procedures in a fully virtual clinic, interacting with virtual patients and tools as they would in real life. Several virtual dental trainers have recently been developed; some are commercially available. One example is SIMODONT, a major haptic VR dental education device worldwide.[30] AR, conversely, can overlay digital information onto real-world environments, enhancing the realism of practical assessments. For instance, AR can guide students during a procedure, highlighting anatomical structures or suggesting the next step. These technologies enhance the learning experience and provide a more accurate assessment of students' clinical skills.[13,15,16,18–20,31,32]

VR are crucial in simulating dental procedures, allowing educators to assess students' practical skills in a controlled yet realistic setting. As detailed by Suebnukarn et al.,[19] VR simulators provide an immersive platform where students can engage in complex dental procedures such as cavity preparations and root canals. These simulators are equipped with sensors that track every tool's movement and decision. They are analyzed against best practices to provide detailed feedback on the student's performance, enhancing their procedural skills. Additionally, Collaco et al. discuss the impact of immersive VR technologies on dental training, emphasizing how these systems improve skill accuracy and confidence, particularly during anesthesia administration.[13]

Besides, we should emphasize that VR feedback goes beyond simple corrections. These systems offer real-time corrections and provide visual or auditory cues to help students adjust their techniques during and after the procedure. For example, VR training platforms with haptic feedback can alert students to deviations from the optimal drill path or when excessive force is applied, enabling them

Table 1 Comparative analysis of selected studies.

Authors (Publish year)	Subject (study population/ country)	Methods (study design/groups/ number of subjects)	Assessment content	Assessment methods	Results (main findings)	Conclusion (suggestions)	Remarks
Baechle et al.[12] (2022)	First-year dental students, Virginia Commonwealth University School of Dentistry, United States	**Study design:** Retrospective observational study. **Groups:** 11 cohorts of first-year dental students (2012 –2022). **Number of subjects:** 1072 students for Class I preparation and 986 students for Class II preparation.	Class I occlusal preparation on a mandibular molar (#19-O). Class II mesioocclusal preparation on a maxillary first molar (#14-MO).	**Computer -based assessment** Data was extracted from the DentSim™ advanced simulation software. Measures collected included practice session metrics (total number of sessions, average scores, time spent preparing and self-evaluating) and exam session metrics (time spent preparing, self-evaluating, and exam scores).	Significant improvement in exam scores was observed compared to practice scores for both Class I and Class II preparations. Higher exam scores were linked to better average practice scores and effective self-assessment during exams, particularly in Class I. In Class II, more practice attempts also contributed to better exam scores.	Deliberate and repetitive practice using advanced dental simulation, combined with self-assessment, is effective in improving exam performance and psychomotor skill development in dental students. Further research is needed to confirm these skills' translation into clinical settings and their impact on patient care.	The study underscores the value of simulation in dental education and calls for more research to validate the clinical applicability of skills acquired through such training. Limitations include variations in faculty involvement and inconsistent use of optional practice hours.
Suebnukarn et al.[18] (2009)	20 participants: 10 fourth-year dental students (novices) and 10 prosthodontics experts, Thailand	**Study design**: Comparative study between novice and expert performance **Groups**: Two groups—Novices and Experts **Number of subjects**: 20 participants (10 novices, 10 experts)	The study involved using a haptic VR system for crown preparation. The VR system provided force feedback and recorded process measures such as task completion time (T), force used (F), and angulations (A) of the bur during each step of the crown preparation.	**VR assessment** The performance was assessed based on both process measures (T, F, A) and outcome measures (O). Process measures included the time taken to complete the task, the force applied in different directions, and the angulations of the instrument. The outcome measure was evaluated by an expert using a scoring system based on the depth, inclination, and smoothness of the preparation.	Experts performed significantly better than novices, with shorter task completion times, more consistent and appropriate force application, and more accurate angulations. The outcome scores were also significantly higher for experts, demonstrating that the VR system can effectively distinguish between novice and expert performance.	The study concluded that the haptic VR system is capable of objectively measuring and distinguishing the skill levels between novices and experts. The process and outcome measures provided by the system are effective in evaluating clinical skill proficiency and can be used to develop objective scoring criteria for dental education.	This study highlights the importance of incorporating both process and outcome measures in the evaluation of clinical skills using VR systems. The ability to capture detailed kinematic data and provide real-time feedback makes this approach highly valuable for dental training. Future work may focus on expanding the system's capabilities to cover a wider range of dental procedures and

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Table 1 (*continued*)

Authors (Publish year)	Subject (study population/ country)	Methods (study design/groups/ number of subjects)	Assessment content	Assessment methods	Results (main findings)	Conclusion (suggestions)	Remarks
							integrating more advanced feedback mechanisms.
Rhienmora et al.[15] (2010)	Dental students and experienced dentists, Thailand	**Study design**: Developmental and validation study **Groups**: 5 dental students (novices) and 5 experienced dentists (experts) evaluated the simulator. **Number of subjects**: 10 (5 novices, 5 experts)	The study developed a VR dental simulator incorporating haptic feedback for tooth preparation. The system allows users to practice and be assessed on their tooth cutting and exploration techniques.	**VR assessment** Performance assessment was conducted using hidden Markov Models (HMMs) to classify users as novices or experts based on their interactions with the simulator. Data collected included force, time, position, and orientation of the virtual tool. Feedback was provided on the realism of the tooth surface exploration and cutting process.	The VR simulator was able to classify user performance with 100 % accuracy between novice and expert operators. Feedback from users indicated that the simulator provided a realistic experience, though some users noted areas for improvement, such as surface roughness and force consistency.	The VR dental simulator successfully integrates realistic haptic feedback and performance assessment, making it a viable tool for dental training. The study suggests that with further development, such simulators could play a crucial role in the education and assessment of dental procedures.	This study highlights the potential of VR simulators not only for skill training but also for providing objective assessments through advanced methods like HMMs. The ability to differentiate between novices and experts with high accuracy demonstrates the simulator's value as an educational tool. However, the study also acknowledges the need for further refinement of the system's haptic feedback and user interface for broader application.
Rhienmora et al.[16] (2011)	Dental students and experienced dentists, Thailand	**Study design**: Developmental and validation study **Groups**: 5 dental students (novices) and 5 experienced dentists (experts) participated in the evaluation. **Number of subjects**: 10 participants	The study developed a VR dental simulator with haptic feedback for practicing crown preparation. The system incorporates objective skill assessment and feedback generation using hidden Markov Models (HMMs) to classify users' skills as novice or expert	**VR assessment** The VR simulator recorded data on tool position, orientation, and applied force during the crown preparation. The performance was assessed using HMMs, which classified the user's performance level as either novice or expert. Feedback	The HMM-based assessment was able to correctly classify all participants as either novices or experts with 100 % accuracy. The feedback provided by the simulator was rated as highly acceptable by expert evaluators, with an average acceptability	The study concluded that the VR dental simulator with objective skill assessment and feedback is an effective tool for training dental students. The system's ability to accurately assess performance and provide feedback	This study highlights the use of advanced machine learning techniques (HMMs) for objective skill assessment in dental education, demonstrating the potential of VR simulators to provide high-quality, individualized training. The study

			based on their tool handling, force application, and movement during the procedure.	was generated based on deviations from expert performance.	score of 4.154 out of 5.	comparable to that of human tutors suggests its potential as a supplement to traditional training methods.	also suggests that expanding the simulator's capabilities to cover more complex dental procedures could further enhance its educational value.
Suebnukarn et al.[19] (2011)	Fourth-year dental students, Thailand	**Study design**: Prospective randomized controlled and blinded trial **Groups**: Two groups—group 1 (experimental): 16 students trained using micro-CT tooth models with a haptic VR simulator; group 2 (control): 16 students trained using conventional methods with extracted teeth in a phantom head. **Number of subjects**: 32 students (16 per group)	The study focused on the training of access cavity preparation for endodontic treatment. The haptic VR simulator was integrated with microcomputed tomography (micro-CT) tooth models, providing a realistic 3D visualization and tactile feedback that simulates the cutting of enamel, dentine, and pulp.	**VR assessment** Procedural errors were the primary outcome measure, assessed by a blinded expert. Secondary outcome measures included the amount of tooth mass removed and task completion time. Error scores were based on a four-point scale evaluating cavity extension and wall quality. Statistical analyses were conducted using the Wilcoxon test for pre- and post-training comparisons, and the Mann—Whitney test for comparisons between groups.	Both the VR and conventional groups showed significant improvements in error scores after training ($P < 0.05$). However, there was no significant difference in error score reduction between the two groups ($P > 0.05$). The VR group significantly reduced the amount of hard tissue removed during post-training ($P < 0.05$), whereas no significant difference was observed in the phantom head group. Task completion time did not significantly differ between the groups.	The study concluded that training with a haptic VR simulator and micro-CT tooth models is as effective as conventional training methods in reducing procedural errors in endodontic access cavity preparation. Additionally, the VR group demonstrated better conservation of tooth structure, suggesting the potential of VR technology to enhance minimally invasive practices.	This study highlights the potential of VR technology in providing a realistic and effective training environment for dental procedures. The ability of the VR system to help students reduce tooth mass loss is particularly noteworthy, indicating that such technology could be beneficial for teaching minimally invasive techniques. Further research could explore the long-term impact of VR training on clinical outcomes.
Suebnukarn et al.[20] (2014)	34 participants: 14 novices, 14 intermediates, and 6 experts in endodontics, Thailand	**Study design**: Validation study with benchmarking **Groups**: Three groups—novices (14), intermediates (14), and experts (6) **Number of subjects**: 34 participants	Participants used the haptic VR dental simulator to perform endodontic cavity preparation tasks at three levels of difficulty (easy, medium, hard). Each participant completed 10 trials	**VR assessment** The simulator recorded the path length of the virtual instrument and the error scores for each trial. Error scores were based on a four-point scale evaluating various aspects of	The error scores at the easy and medium levels successfully distinguished between experts, intermediates, and novices, particularly in the early trials. However, by the end of the training, the	The study established the construct validity of the haptic VR dental simulator, demonstrating its ability to differentiate between skill levels. Expert error scores and path length were	This study is critical in demonstrating that the haptic VR dental simulator can effectively distinguish between novice and expert performance, particularly in early training phases. The use of path length as

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Table 1 (*continued*)

Authors (Publish year)	Subject (study population/ country)	Methods (study design/groups/ number of subjects)	Assessment content	Assessment methods	Results (main findings)	Conclusion (suggestions)	Remarks
			for each difficulty level.	cavity preparation, including extension and wall quality. The outcomes were assessed by an expert who was blinded to the participants' group.	error scores among the groups were no longer significantly different. The path length measure was able to distinguish performance differences between groups at the hard level of training, where error scores did not.	used to define benchmarking criteria for optimal performance, which could be used to set standards for training and assessment in dental education.	an additional measure for assessing performance in more difficult tasks is a valuable finding, suggesting that this measure could be incorporated into more comprehensive assessment systems. The study also emphasizes the potential of using expert benchmarking to set standardized performance criteria in dental education.
Dixon et al.[14] (2020)	Dental students, University of Sheffield and Cardiff University, United Kingdom	**Study design**: Validation study **Groups**: 12 clinical teachers assessed cavity preparations performed on a VR simulator. **Number of subjects**: 12 clinical teachers	A cavity preparation exercise was created on a VR dental simulator, where students prepared a cavity of 2 mm depth with maximum undercut following a straight-line template. The simulator provided qualitative feedback based on predefined assessment criteria.	**VR assessment** Assessment criteria included smoothness, ability to follow the outline, undercut, depth, and floor flatness. Feedback was compared between the VR simulator's assessment and clinical teachers' evaluations of 3D-printed models of the cavity preparations.	The inter-rater reliability (IRR) between clinical teachers varied, with κfree values ranging from 0.15 to 0.58, and percentage agreement ranging from 57.58 % to 78.79 %. The VR simulator showed a mean agreement of 70.83 % with clinical teachers' assessments, demonstrating that VR simulators can provide reliable and clinically relevant qualitative feedback.	The study demonstrated that VR dental simulators could reliably provide valid and meaningful qualitative feedback that is comparable to feedback from clinical educators. It suggests that this approach could be extended to a broader range of dental skills exercises.	This study is significant in establishing the concurrent validity of VR simulators for providing qualitative feedback, a step forward in integrating VR into dental education. However, the study's limitation is that it focused on a single, simple exercise. Further research is suggested to validate this approach across more complex dental procedures.
Collaco et al.[13] (2021)	163 clinical dental students, University of São	**Study design**: Experimental study **Groups**: Four groups	Students trained on a VR dental simulator for administering	**VR assessment** Technical skills were evaluated based on	Students in the immersive groups demonstrated more	Immersive VR simulation with haptic feedback	This study underscores the importance of

	Paulo, Brazil	with varying combinations of immersive and non-immersive training and haptic feedback (Full immersive with feedback on, non-immersive with feedback on, immersive with feedback off, non-immersive with feedback off) **Number of subjects**: 163 students divided into four groups (Full immersive: 42, non-immersive with feedback on: 40, immersive with feedback off: 41, non-immersive with feedback off: 40)	anesthesia to the inferior alveolar nerve. The simulator included haptic feedback and immersive virtual reality with a head-mounted display (HMD).	needle insertion accuracy, angle, depth, and task execution time. A machine learning model was also used to classify student performance based on needle insertion point coordinates. Subjective feedback was collected via questionnaires on syringe handling and simulator sickness.	accurate and faster performance in administering anesthesia compared to the non-immersive groups. The machine learning method showed an accuracy of 84 % in classifying student performance. Students reported higher realism in syringe handling with haptic feedback.	significantly improves technical skills in dental anesthesia. The use of machine learning for automatic evaluation is effective and could be integrated into VR training programs to enhance skill acquisition and assessment.	combining immersive VR with haptic feedback in dental education. The use of machine learning for automatic evaluation is a noteworthy innovation, providing objective assessment and immediate feedback to students. The study also suggests that immersive VR may offer a more realistic and effective training environment, potentially leading to better clinical outcomes.
Yin et al.[17] (2021)	30 fifth-year dental students, Thammasat University, Thailand	**Study design**: Randomized controlled trial with pre-test/post-test design **Groups**: Three groups—group 1 (G1): Trained with VR simulator without feedback; group 2 (G2): Trained with VR simulator with video-based formative feedback; group 3 (G3): Trained in traditional laboratory setting without VR simulator. **Number of subjects**: 30 students (10 per group)	The study focused on the access opening procedure for endodontic root canal treatment using a VR simulator. The simulator provided video-based formative feedback highlighting procedural errors such as undercuts, overcuts, and perforations. The feedback was designed to correlate specific procedural actions with resulting errors.	**VR assessment** The simulator's assessment included kinematic data analysis (e.g., handpiece position, force applied, orientation) and error identification (e.g., undercuts, overcuts, perforations). The effectiveness of the feedback system was measured through pre- and post-training scores evaluated by two blinded experts, and learning gains were calculated based on improvements.	The group that received video-based formative feedback (G2) showed significantly higher learning gains compared to both the group trained without feedback (G1) and the group trained in a traditional setting (G3). The feedback system was found to be effective in improving procedural accuracy and reducing errors.	The study concluded that video-based formative feedback in VR simulations significantly enhances learning outcomes in dental surgical skill training. The feedback system can serve as a valuable supplemental resource in dental education, particularly for students in the early stages of skill development.	This study emphasizes the importance of detailed, procedural feedback in skill acquisition and highlights the effectiveness of integrating advanced feedback systems within VR simulators. The ability to visually correlate procedural errors with specific actions offers a powerful tool for enhancing technical skills in dental education. Further research could expand the feedback system's capabilities to address more

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Table 1 (*continued*)

Authors (Publish year)	Subject (study population/ country)	Methods (study design/groups/ number of subjects)	Assessment content	Assessment methods	Results (main findings)	Conclusion (suggestions)	Remarks
							complex errors and procedures.
Osnes et al.[21] (2021)	112 first-year dental students and 17 clinical practitioners, United Kingdom	**Study design:** Comparative study evaluating the construct validity of a haptic caries simulation. **Groups:** First-year dental students and experienced clinical practitioners. **Number of subjects:** 112 students, 17 clinicians	Performance in removing caries using a haptic simulation exercise.	**VR assessment** Participants performed a caries removal exercise on a virtual block, and their precision in removing carious tissue without damaging healthy tissue was measured. The exercise involved using a haptic dental simulator, Simodont, and performance was analyzed based on precision scores and the amount of material removed.	Clinicians were more precise than students in removing caries, with significantly higher precision scores and better performance in removing caries at the amelodentinal junction (ADJ). Both groups removed similar amounts of deep caries, but clinicians removed more enamel and overall carious material without excessive damage to healthy tissue.	The haptic caries simulation can effectively distinguish between novice and experienced clinicians, making it a useful tool in dental education to identify students needing additional support in mastering caries removal.	The study supports the use of haptic simulation as a valuable educational tool in dental training, though the variability in clinician performance and the study's limitations (e.g., imbalance in group sizes and lack of detailed participant background) suggest further research is needed to fully validate this approach.
Pang et al.[22] (2024)	50 dental and dental technology students, Chongqing Medical University, China	**Study design**: Development and pilot study of a virtual interprofessional OSCE (viOSCE) framework **Groups**: 32 students participated in the pilot, divided into dental and dental technology students. **Number of subjects**: 50 students recruited, 32 completed the pilot.	The viOSCE included 7 collaborative examination stations, combining both synchronous and asynchronous tasks, such as fixed prosthodontics, removable prosthodontics, and clinical diagnostics. The stations used a variety of virtual technologies, including a virtual standardized patient (VSP) with haptic feedback and	**VR assessment** The viOSCE utilized scoring rubrics created by a panel of experts, who evaluated both the process and outcomes of the students' performances. The examination included both machine-generated and examiner scores. Correlation analyses were conducted to validate the consistency and reliability of the	The viOSCE was effective in assessing interprofessional education (IPE) outcomes, demonstrating significant improvements in teamwork and collaboration skills among the students. The study found a significant correlation between machine-generated and examiner scores, confirming the reliability of the	The viOSCE framework is a viable tool for objectively assessing the outcomes of IPE and promoting interprofessional collaborative practice (IPCP) among dental and dental technology students. The study suggests expanding the use of viOSCE in dental education and refining the framework to better accommodate the	This study is notable for integrating advanced virtual technologies into the OSCE framework, offering a comprehensive approach to assessing both individual and team-based competencies. The combination of subjective and objective data provides a robust evaluation of student performance, and the study highlights the

			computer-aided design (CAD) systems.	assessment.	virtual tools used in the examination. However, some challenges, such as technical issues and varying levels of student motivation, were noted.	diverse needs of students.	potential for viOSCE to become a standard part of dental education assessments. Future research should focus on increasing the sample size and further refining the assessment tools to enhance reliability and user experience.
Donn et al.[23] (2021)	Three final-year dental students (1 male, 2 female) from the University of glasgow, United Kingdom	**Study design**: Pilot study **Groups**: Single group of three students participating in a virtual OSCE (VOSCE) **Number of subjects**: 3 students	The study involved the implementation of a virtual objective structured clinical Examination (VOSCE) using the zoom platform. The VOSCE included 10 stations adapted from a traditional OSCE format, covering various dental disciplines. Due to the limitations of the online format, manual clinical procedures could not be assessed, and the focus was on diagnostic, interpretative, and treatment planning skills.	**Remote assessment** The assessment was carried out using dual marking for each question by two examiners. Feedback was provided post-examination to gauge the acceptability and effectiveness of the VOSCE format. The effectiveness of the VOSCE was evaluated based on student and staff feedback, technical issues encountered, and the overall smoothness of the examination process.	The VOSCE was found to be an effective alternative to traditional OSCEs during the COVID-19 pandemic. The students and staff responded positively to the new format, with the examination reflecting the 'live' situation effectively. However, the study noted challenges such as technical disruptions and the inability to assess manual clinical skills.	The VOSCE format was successful in maintaining the integrity of clinical assessments during the pandemic. The study suggests that while the VOSCE could be a viable alternative in exceptional circumstances, it may not completely replace traditional OSCEs due to the limitations in assessing manual skills. Further research is recommended to refine the process and explore its applicability on a larger scale.	This study is particularly relevant given the context of the COVID-19 pandemic, highlighting the adaptability of dental education to unprecedented challenges. The use of zoom and virtual breakout rooms for the VOSCE provided a feasible solution for continuing assessments under social distancing measures. However, the study also emphasizes the importance of addressing technical issues and the limitations of virtual assessments for manual skills, suggesting a hybrid approach for future assessments.

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Table 1 (*continued*)

Authors (Publish year)	Subject (study population/ country)	Methods (study design/groups/ number of subjects)	Assessment content	Assessment methods	Results (main findings)	Conclusion (suggestions)	Remarks
Donn et al.[24] (2023)	72 third-year dental students and 31 staff members, University of glasgow, United Kingdom	**Study design**: Qualitative study using focus groups **Groups**: Five focus groups involving 24 participants—14 students and 10 staff members—were conducted to explore perceptions and experiences related to the virtual OSCE (VOSCE). **Number of subjects**: 72 students sat the VOSCE; 24 participants in the focus groups (14 students, 10 staff)	The VOSCE comprised four stations adapted from traditional OSCEs, focusing on assessing clinical knowledge and decision-making skills rather than practical skills. Zoom breakout rooms were used as virtual stations, with staff acting as standardized patients and examiners.	**Remote assessment** The VOSCE employed dual marking by examiners for each station, with the assessments focusing on diagnostic and communication skills. The study also utilized online standard setting using the Modified Angoff method to ensure fairness. Feedback was gathered through post-examination focus groups.	The VOSCE was generally well-received, with both staff and students finding it a fair and effective alternative during the pandemic. Thematic analysis revealed six key themes: Preconceptions, preparation, process, fairness, comparison with traditional OSCE, and potential improvements. The main challenges included IT issues and the limitation in assessing hands-on skills.	The study concluded that the VOSCE is a valuable and fair assessment tool under pandemic conditions, though it cannot fully replace traditional OSCEs, especially for practical skills. It suggested a hybrid approach combining VOSCE with face-to-face assessments in the future.	This study provides important insights into the adaptability of dental education to unprecedented circumstances, such as the COVID-19 pandemic. It highlights the strengths and limitations of VOSCE as a tool for clinical assessment and suggests possible improvements for future implementation, including better IT support and more comprehensive station design to cover a broader range of skills.

Abbreviations: VR, virtual reality.

to adjust their methods on the spot. This prompt feedback helps students refine their techniques in real time; recording and rating the procedure in the post-training assessment will significantly enhance the learning process. Suebnukarn et al. validates the use of VR in dental education by showing how haptic feedback can differentiate between novice and expert performances, thereby illustrating the direct application of VR for skill assessment and feedback generation.[18]

Virtual reality technologies in virtual objective structured clinical examinations

Incorporating virtual reality (VR) technologies into objective structured clinical examinations (OSCEs) is revolutionizing the approach to assessments in dental education. These technologies improve the accuracy and realism of OSCEs, providing more thorough and unbiased assessments of students' abilities. VR are increasingly used in OSCEs to simulate real-life scenarios and clinical interactions more accurately. For instance, Donn et al. discuss the application of VR in creating realistic clinical environments during the COVID-19 pandemic, allowing students to demonstrate their skills in a controlled setting that closely mimics actual dental practice scenarios.[23] This approach not only improves the realism of the assessments but also ensures that students are tested under uniform conditions, enhancing the objectivity of the evaluations.

The COVID-19 pandemic presented unique challenges to traditional educational and assessment methods, increasing the use of remote and virtual technologies in healthcare education. Augmented reality and virtual reality technologies played a crucial role in facilitating dental education assessments, primarily through improved virtual OSCEs, ensuring the ongoing integrity of the educational process.

Amidst restrictions on physical gatherings, AR and VR facilitated the seamless transition to remote assessments, allowing evaluators and students to engage in a standardized, immersive examination environment without geographical constraints. For example, studies by Donn et al. demonstrated how virtual OSCEs could simulate detailed clinical settings and patient interactions, thereby maintaining rigorous assessment standards and replicating the pressures and demands of real-life clinical situations.[23] This virtual approach preserved the educational progression during lockdowns and showcased the potential for broader adoption of virtual assessments in post-pandemic scenarios.

The success of virtual OSCEs during the pandemic has shown several benefits. These include conducting assessments in a controlled, bias-free environment less dependent on physical locations. This has implications for the future of dental education, suggesting a shift towards more flexible and accessible assessment formats. These formats can adapt to various disruptions, enhance global accessibility, and potentially reduce costs associated with traditional face-to-face examinations.

By integrating these technologies into their standard operating procedures, educational institutions can better prepare for future disruptions and continue offering high-quality, standardized educational experiences regardless of external circumstances.

Benefits and challenges

AR and VR in OSCEs offer several advantages. These technologies can improve assessment accuracy and increase student engagement. Educational institutions can use AR and VR to develop diverse and complex scenarios that assess a broader range of student skills and responses. Furthermore, these technologies provide immediate feedback to students, which is essential for learning and improvement.

However, challenges are associated with integrating these technologies into OSCEs. One major challenge is the AR and VR equipment cost and the need for specialized training for students and faculty. There are also technical issues related to the reliability and consistency of the technology, which can affect the fairness and accuracy of the assessments.[14] Donn et al. further elaborates on these challenges, noting that while the potential benefits are significant, the practical implementation of VR and AR in OSCEs during the COVID-19 pandemic required careful planning and resources to ensure that the technology enhances rather than complicates the assessment process.[24]

Discussion

Virtual assessment technologies have become an essential tool in dental education, particularly in response to the challenges brought by the COVID-19 pandemic. These technologies, including computer-based simulations, AR, and VR, offer scalable and realistic alternatives to traditional assessment methods, enhancing the evaluation of both theoretical knowledge and practical skills. While the advantages, such as improved accuracy and objectivity, are evident, the integration of these technologies faces challenges, including high costs, technical limitations, and the need for comprehensive training.[33]

One of the primary technological barriers is the hardware limitations associated with AR and VR systems. These technologies require sophisticated and often expensive equipment, such as high-quality headsets, sensors, and computers capable of processing complex simulations. Due to their high costs, these technologies can be less accessible for many educational institutions. Additionally, the maintenance and updating of this hardware can further strain budgets, particularly in resource-limited settings. Software reliability is a significant challenge in developing AR and VR applications. It requires high-level programming expertise and ongoing support to address bugs and software updates. The complexity of these systems can lead to technical glitches that disrupt the learning process and detract from the educational experience instead of enhancing it.[33,34]

Beyond technological issues, educational barriers exist to adopting AR and VR in dental education. One major issue is the resistance to change within some educational environments. Traditional teaching methods are deeply entrenched in many institutions, and educators and administrators may hesitate to adopt new technologies due to unfamiliarity or skepticism regarding their efficacy. Additionally, training educators to use these technologies effectively takes time and effort. Proper training ensures

instructors are comfortable and proficient in leveraging AR and VR tools to enhance their teaching. Without adequate training, the potential educational benefits of these technologies may not be fully realized.[22]

The adoption of AR and VR technologies also depends on the availability of quality content tailored to specific educational needs in dentistry. Developing this content is time-consuming and requires significant investment, which can deter many institutions from considering implementing these technologies. Moreover, there are concerns about the scalability of AR and VR solutions. While they can be highly effective in small-scale or pilot studies, expanding these programs to accommodate larger student populations requires careful planning, significant resources, and robust technological infrastructure.[35]

As AR and VR technologies continue to evolve, their role in dental education is expected to expand, with advancements in artificial intelligence (AI) playing a crucial role in this progression. AI has the potential to significantly improve the realism and instructional quality of AR and VR platforms. For instance, AI-driven real-time analysis of student performance can provide adaptive feedback, identify errors, and predict challenges, resulting in a more focused and efficient learning experience.[36] Moreover, machine learning models contribute to making AR and VR systems more intuitive and responsive to individual learning styles and needs. By analyzing large datasets on user interactions, these models can continuously refine training modules, enhancing their effectiveness and sophistication.[37]

The integration of AI and haptic technology, though still in its early stages, holds tremendous potential to transform dental education. As haptic simulators evolve towards greater realism,[38,39] the adaptability of AI paves the way for personalized feedback and the handling of complex clinical scenarios,[37] creating a groundbreaking training paradigm for future dentists. Moving forward, research should prioritize the development of more cost-effective virtual assessment tools and evaluate their long-term effects on clinical performance. Educational institutions are encouraged to incorporate these technologies into their curricula, supported by comprehensive faculty training programs to ensure effective implementation.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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