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Review

Simulation training in dental medicine for building professional competence

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Abstract: Simulation training in dental medical eduaction is a modern high-tech approach in providing quality higher education. Simulation training immerses students in realistic scenarios, allowing them to develop both technical and non-technical skills essential for effective patient care. This study highlights key contemporary issues in high-tech simulation training for dental education and consolidates its rationale and benefits. We searched the databases PubMed, Scopus, Web of Science, and ResearchGate. This review includes 36 articles published in English, Russian, and Ukrainian from 2020 to 2024. Non-peer-reviewed papers or those not published in indexed journals were not considered. Simulation training was found to impact integration of theory and practice, training a wide range of psychomotor skills, development of complex clinical competences, cultivating confidence, empathy and patient-oriented care, neuroplasticity of the brain and the cognitive load. Pedagogical benefits and the place of simulation training in the curriculum were also discussed.

Keywords: dental; medical; education; simulation training; brain

1. Introduction

The achievements of contemporary science such as virtual and augmented reality, AI, and haptic technologies create an enjoyable and motivating educational experience and contribute to the development of competent dental practitioners.

Simulation-based learning in dentistry provides many advantages. It involves recreating real-life clinical scenarios through the use of simulators and virtual reality, allowing dental students to improve their practical skills and bridge the gap between theoretical knowledge and clinical practice. This educational approach enables students to practice various procedures in a controlled environment before working with actual patients, facilitating the integration of theory with hands-on experience (Chopchik et al., 2023; Dzhendov and Georgieva, 2022).

This type of learning is particularly important given the challenges faced in real clinical settings, such as reduced patient visits and limited opportunities for practical experience (Veremeenko et al., 2022). Simulation training not only helps students master practical skills but also encourages interdisciplinary collaboration, teamwork, and effective communication with patients. This enhances the quality of dental education and complements real clinical practice.

As the role of simulation in medical education, including dentistry, becomes increasingly important, regulatory authorities are stressing the necessity of skills training laboratories and simulated training modules to enhance student learning and patient safety (Mustilwar et al., 2022). These simulation training technologies offer a

comprehensive, safe, and efficient method of training, ensuring that future dentists are thoroughly prepared for their professional practice.

Current research focuses on positives of simulation traing but there are few studies on the effect of simulation and game-based learning on the neuroplasticity of the brain and cognitive load.

The COVID-19 pandemic enhanced the development and implementation of diferent forms of computer-aided instruction, including simulation training in dental education. Our research covers papers published in pandemic and post-pandemic time in an effort to delineate the contemporary landscape of simulation training, with a particular emphasis on dental education.

This research was made as a part of a project, Digitally Guided Cognition and Cognitive Profiling“ in the frame of a national programme for strategic research and innovation for the development of Medical University of Plovdiv. The project is focused on launching of innovative, effective, and active teaching and leaning methods in dental education by examining the cognitive and memory architecture in dental simulation training by implementation of virtual reality /VR/, augmented reality /AR/ and mixed reality /MR/. Studies have shown the implementation of latest technology like VR and haptic feedback simulators have improved psychomotor skills of students (Mustilwar et al., 2022). These cutting-edge technologies will ensure innovative approach in learning, providing an immersive full-scale scenario experience to learners and new tools for constructing knowledge that lead to improvement of learning content and skills. The present study aims to reveal key up-to-date issues related to high-tech simulation training in dental medical education and to bring together a rationale and benefits of its implementation.

2. Materials and methods

We used the narrative review method (Farrukh and Sajjad, 2023) that allows a broad overview of the topic without a strict methodological framework, as we aimed at considering a variety of literature sources and identify under-researched areas.

We searched the following databases PubMed, Scopus, Web of Science, ResearchGate with keywords “simulation training”, “dental”, “medical”, “education”, “cognitive load”.

Inclusion criteria: This review considers articles published in English, Russian, and Ukrainian between 2020 and 2024. The COVID-19 pandemic significantly affected the educational sector, particularly medical education, highlighting the importance of new technology-enhanced training concepts. This rationale underscores the need for the specified publication period.

Exclusion criteria: Articles that do not meet the inclusion criteria, as well as those that are not peer-reviewed or published in indexed journals or collections, will be excluded from this review.

3. Results

We found and retrieved 36 papers meeting the review criteria. They are summarized in **Table 1**.

Table 1. Key findings from the articles included in the review.

No.	Authors/Year/Title/Language	Type of study	Key findings
1.	Abdullah et al. (2023). Simulation's usage in training for dental trauma: An analysis of four splinting methods. English	A comparative cross-sectional study	Simulation exercises in the dental curriculum can significantly improve instruction and learning abilities. The research provided significant learning advantages and captured students' attention, leading to a consensus that such training should be made mandatory.
2.	Arutyunov et al. (2023). Dental simulator based on a robotic complex with an integrated smart jaw. Russian	An original research.	A fully functional anthropomorphic dental robot with integrated modules Smart-Jaw and Smart Teeth and supporting the communicative function through artificial intelligence is the optimal way for increasing practical competence.
3.	Baidarov et al. (2023). Simulation training in medicine: past, present and future. Russian	Review of literature	Simulation training improves performance, teamwork, and communication. New teaching methods enhancing effectiveness are needed.
4.	Cenzon et al. (2022). Use of a simulated virtual training module to improve dental hygiene students' self-reported knowledge, attitudes, and confidence in providing care to children with autism spectrum disorder: A pilot study. English	A pilot study	Experiential learning requires critical thinking and increases students' knowledge, attitudes, perceived confidence and comfort. More investigation of the topic is needed.
5.	Chechina et al. (2022). The attitude of dental students to the impact of simulation training on the quality of practical skills formation. Russian	An original research–survey.	Simulation training forms clinical thinking, increases self-esteem, and facilitates the transition to working with live patients. It is important not only in undergraduate education but also for dental practitioners.
6.	Chopchik et al. (2023). Substantiation of the need to implement simulation training for dental students based on the analysis of the activities of the Stomatological Medical Center at O. Bogomolets National Medical University. Ukrainian	A retrospective study, survey.	Computer-guided practical skills training is an option when patients with suitable diagnoses are unavailable. Simulation enhances the connection between theory, practice, and clinical work.
7.	Chu et al. (2023). Mirror training device improves dental students' performance on virtual simulation dental training system. English	Experimental controlled study.	The study demonstrated that training with a dental mirror device effectively enhances students' skills in indirect vision for dental manipulations and boosts their confidence. A virtual reality dental trainer assessed the performance of students using indirect vision.
8.	de la Hoz Calvo et al. (2022). Low-fidelity handmade simulator for pediatric dentistry simulated scenarios. English	An original study.	A low-cost, low-fidelity simulator allowed for the creation of intraoral cases and direct work on teeth, but the realism of the simulator's face needed improvement. Sophisticated simulators are unnecessary for developing clinical competencies.
9.	Dzhendov and Georgieva (2022). The application of simulators in dental medicine students' training. English	A systematic review.	Dental simulators provide valuable learning opportunities for students to develop and enhance their dental skills in an engaging virtual environment. The virtual patient application allows for the recreation of clinical scenarios in virtual reality, making the learning experience both rewarding and entertaining.
10.	Eng et al. (2020). Doctoral Colloquium—Enhancing Brain Plasticity and Cognition Utilizing Immersive Technology and Virtual Reality Contexts for Gameplay. English	An experimental study, a work-in-progress.	Study 1 shows that cognitively demanding imersive active gameplay increases cognition and neuroplasticity. Study 2 devised an experimental design to reproduce Study 1 in virtual reality to examine whether the findings of enhanced cognition and neuroplasticity generalize across virtual contexts and development.
11.	Gileva et al. (2023). Improving the effectiveness of medical care in dental emergencies using simulation training. Russian	An original study.	Emergency situations within a dental practice, necessitates immediate first aid response. By studying these conditions through simulation lessons using mannequins and feedback-driven simulators, healthcare professionals can be better prepared to react swiftly and effectively, ultimately saving patients' lives.
12.	Hamza et al. (2023). Are simulators paving a new way for continuing education? English	A review.	The use of simulators has improved knowledge retention, boosted clinician confidence, and reduced learning anxiety while making educational resources more accessible. This review highlights the benefits and drawbacks of surgical simulators. Simulated learning is transforming higher education, particularly in healthcare and continuing education in dentistry.

Table 1. (*Continued*).

No.	Authors/Year/Title/Language	Type of study	Key findings
13.	Hu et al. (2022). A critical review of simulation-based medical education: An advanced opportunity for next generation of medical education. English	A critical review.	High-quality simulation-based medical education serves as a valuable tool to enhance training quality and bolster trainees' confidence. It can also reduce the risk of medical errors in practice and promote patient safety. The specific needs for each simulation will be determined through a careful and comprehensive analysis of simulation performance.
14.	Kaskova et al. (2022). Modern aspects of the practical training of future dentists. Ukrainian	An original research–survey.	Simulation training is valuable in developing practical skills through repeated practice opportunities. Additionally, it cultivates clinical reasoning among prospective dentists. None of the respondents indicated any adverse effects on the educational process stemming from the inclusion of simulation classes.
15.	Kim et al. (2023). Conformer-based dental AI patient clinical diagnosis simulation. English	An original study.	The study highlights the integration of standardized patients in dental clinical education through the application of deep learning. AI-driven Standardized Patients (SP) offer realistic patient interactions that enable students to refine their clinical skills. Utilizing AI patients in SP simulations can significantly improve the constrained clinical diagnostic training environment, which often arises from challenges related to environment, cost, and recruitment.
16.	Knox (2023). Game-based learning design optimized for cognitive load. In: Reimagining Education: Studies and Stories for Effective Learning in an Evolving Digital Environment. English	A chapter.	It highlights the importance of designing educational games that minimize cognitive load, referencing Sweller's principles for optimal educational technology design.
17.	Kober et al. (2020). Game-based learning environments affect frontal brain activity. English	An original study.	The study explored the effects of game-based learning environments on brain activity and user experience, finding that game elements can enhance emotional and reward processing in the brain. Increased brain activation was observed in areas associated with emotion, reward, and attention during the game-based task.
18.	Kweki et al. (2023). The impact of simulation-based training in cardiovascular medicine: A systematic review. English	A systematic review.	Simulation tutoring complements traditional training methods. Despite negatives related to availability and cost, there is evidence that it offers many advantages compared to traditional teaching methods. Virtual reality education should be integrated with real-life teaching with a variaty of educational scenarios.
19.	Lee and Duffy (2021). Use of simulation technology in transportation training: A systematic literature review. English	A systematic literature review.	The effectiveness of simulator training is influenced by the quality of both the equipment and the instruction. Simulation schemes can be developed to stimulate brain activity.
20.	Maimon et al. (2022). Continuous monitoring of mental load during virtual simulator training for laparoscopic surgery reflects laparoscopic dexterity: A comparative study using a novel wireless device. English	A comparative study.	The study explores the relationship between cognitive load, skill acquisition, and brain activity, indicating that simulators may influence neuroplasticity by facilitating learning and adaptation. The use of simulators in skill acquisition implies potential neuroplastic changes as learners adapt to new tasks and improve their performance over time. This is suggested by the concept of "offline gains," where performance improvements occur with repeated practice.
21.	Marsden et al. (2022). Improving dental student confidence through the use of simulated patient cases. English	An original study.	Student confidence improved after completing simulated patient cases, and students reported that the learning support provided was beneficial to their development. This learning intervention has the potential to enhance student self-efficacy, cultivate contextual competency, and promote reflective practice.
22.	Mustilwar et al. (2022). Skill and simulation lab in dentistry—a futuristic era. English	A descriptive study.	The research emphasizes the futuristic aspect of dental training simulation labs, suggesting that they are integral to the evolution of dental education and practice.

Table 1. (*Continued*).

No.	Authors/Year/Title/Language	Type of study	Key findings
23.	Nahum and Bavelier (2020). Video games as rich environments to foster brain plasticity. English	A chapter	The chapter emphasizes the importance of attentional control and reward processing in enhancing brain plasticity. These mechanisms are crucial for neuroplasticity and can be effectively harnessed through video games. Video games are highlighted as potent tools for driving brain plasticity. They can integrate neurofeedback seamlessly, which may lead to broad and generalized cognitive benefits.
24.	Nöttgen H, Czappa F, Wolf F. 2022. Accelerating brain simulations with the fast multipole method. English	An original study.	The study refers to neuronal networks, synaptogenesis, and brain mapping, emphasizing the importance of connectivity in understanding brain functions. It discusses cortical simulations involving a large number of neurons and synapses, highlighting advancements in neural simulation tools like NEST.
25.	Nurunnabi et al. (2024). Simulation based teaching and learning in clinical education. English	A review.	Simulation in medical education helps students practice important skills like communication, teamwork, and medical procedures safely, without any risk to real patients or staff. The paper acknowledges that no educational tool is universally effective for everyone, highlighting the importance of well-designed simulation programs to maximize their educational benefits.
26.	Ostafiichuk et al. (2022). Use of pedagogical technologies in future dentists' training course. Ukrainian	A review.	Simulation learning technologies and case-based approaches enhance skills, foster personal growth, and improve self-directed learning while enabling effective processing of information. They also establish quality expectations for specialists, who must demonstrate optimal behavior in various situations. Simulation training allows for accurate replication of critical clinical scenarios, tailoring the learning experience to each student's needs.
27.	Patel et al. (2024). The impact of an aging simulation program for dental students in two community dental clinics. English	An original research.	The aging simulation significantly increased dental students' awareness of aging-related limitations, particularly regarding visual and hearing impairments. These interventions, particularly those focused on empathy, are effective in improving healthcare students' attitudes towards older adults.
28.	Ranauta et al. (2023). The integration of haptic training into the QMUL dental curriculum. English	An original research.	The pandemic challenged dental education, leading to the integration of haptic virtual simulators to ensure effective training . A structured framework for simulation-based dental education was developed, influenced by instructional design theory, to improve educational outcomes in pregraduate training.
29.	Sevcenko et al. (2021). Measuring cognitive load using in-game metrics of a serious simulation game. English	An original research.	Cognitive load is crucial in adaptive learning environments, where an optimal level can enhance training effectiveness. EEG data and machine learning can classify cognitive load, leading to improved learning outcomes.
30.	Sevcenko et al. (2022). Neural correlates of cognitive load while playing an emergency simulation game: A functional near-infrared spectroscopy (fNIRS) study. English	An original research.	The paper introduces a new method for assessing cognitive load using fNIRS in combination with the time-based resource-sharing (TBRS) model. This approach is applied in a realistic emergency simulation game, which is a novel application of these techniques . The research provides insights into the dynamics of cognitive load by identifying specific time slots that are critical for measuring cognitive load.
31.	Slaidina et al. (2023). Patient-specific virtual simulation in the clinical training for prosthetic dentistry. English	An original research.	Patient-specific virtual simulation is an engaging and informative learning experience that can be applied for training before actual work in the clinic provided a good technical performance.
32.	Strub (2024). Do we feel the same emotions in simulation as with a real patient? A pilot study among dental students. English	A pilot study.	Simulation is used to train dental students in difficult emotional situations. The results showed that there was almost no difference between the emotions experienced in simulation and in clinical practice. Simulation training could improve emotional intelligence and empathy in undergraduates up to the level of postgraduates.

Table 1. (*Continued*).

No.	Authors/Year/Title/Language	Type of study	Key findings
33.	Uppgaard et al. (2023). The effect of smartphone filming on student confidence in dental anesthesia techniques: A randomized trial. English	A randomized trial.	Incorporating video reviews can be a beneficial teaching method in dental education, warranting further exploration to enhance student performance and confidence.
34.	Veremeenko et al. (2022). Simulation training as a significant factor in the process of preparing dentists for further practical activity. English	An original study.	Effective simulation training requires modern dental instruments, equipment, and materials, in addition to phantoms. Incorporating native drugs for "preparation" and virtual training is also crucial to enhance the range of practiced skills. Training in a specialized simulation center fosters not just individual skill development but also interdisciplinary collaboration, teamwork, professional behavior, and communication. This approach is designed to complement, rather than replace, the training stages in Russian universities, ultimately improving practical skills mastery.
35.	Watz et al. (2023). Precision learning through data intelligence. English	A review.	The paper presents architecture for storing human performance data, emphasizing the importance of a common format with metadata for effective analysis. It explores the use of competency-based assessments to inform proficiency-based training, which helps in managing learning goals and improving training efficiency.
36.	Wu et al. (2024). Situational simulation teaching effectively improves dental students' non-operational clinical competency and objective structured clinical examination performance. English	An original research.	Introducing a situational simulation course can result in notable advancements in students' non-operational clinical competencies as well as their performance on final assessments. The authors suggest the incorporation of simulation-based clinical teaching in undergraduate training programs to enhance key skills, particularly in communication and cognitive processing.

4. Discussion

After careful consideration and content analysis, the following key issues were identified:

4.1. Integration of theory and practice

Simulation learning enhances dental students' education by providing hands-on experiences that help them master essential skills while reinforcing theoretical knowledge (Kaskova et al., 2022). Research indicates that simulated trauma education improves students' perceptions and learning outcomes, with most students agreeing that it positively impacts their education (Abdullah et al., 2023). The use of surgical simulators in continuing education courses has demonstrated benefits such as improved knowledge retention, increased confidence, easier access to educational resources, and reduced anxiety about learning. This transformation is significant for healthcare academic institutions and offers great potential for dental education (Hamza et al., 2023).

Simulation learning plays a vital role in enhancing the clinical skills of dental students by offering a realistic environment to practice various procedures. Studies show that simulation technologies, including dental simulators, virtual reality simulators, and haptic technology, enable students to develop their practical skills and confidence when treating patients (Chu et al., 2023; Dzhendov and Georgieva, 2022; Kaskova et al., 2022). These technologies allow students to apply their

theoretical knowledge in a practical setting, which leads to better integration of preclinical and clinical learning (Chechina et al., 2022; Chopchik et al., 2023).

Furthermore, simulation training in dental education significantly enhances students' decision-making skills by providing a realistic environment for practicing clinical scenarios. This training effectively bridges the gap between theoretical knowledge and practical application (Dzhendov and Georgieva, 2022; Kaskova et al., 2022). The rapid advancement of technologies, including virtual reality in dental education—such as various advanced simulators like DentSim and the Geneva System—highlights the importance of simulation in aligning theoretical knowledge with practical skills, ultimately preparing students for real patient interactions (Dzhendov and Georgieva, 2022).

4.2. Training a wide range of psychomotor skills

Dental students can enhance various skills through simulation training. The incorporation of simulation technologies in dental education—such as phantoms, manikins, and virtual simulators—provides an effective environment for students to practice and refine a wide range of psychomotor skills, improving the quality of their education (Chechina et al., 2022; Dzhendov and Georgieva, 2022; Kaskova et al., 2022; Veremeenko et al., 2022).

These tools enable repeated practice of specific dental procedures, leading to better skill mastery and the development of clinical thinking (Hamza et al., 2023). Simulation training allows students to improve their practical skills in areas such as mirror perception, operational techniques, spatial awareness, and the nuances of dental surgery, alongside mastering dental manipulations and integrating clinical reasoning (Chu et al., 2023; Marsden et al., 2022).

This type of training is particularly essential when access to real clinical practice is limited, providing a beneficial alternative for students to acquire and refine fundamental clinical skills. By practicing on simulators and in phantom centers equipped with modern tools and materials, students can develop a comprehensive range of skills in a safe and controlled environment, enhancing their ability to manage dental trauma and deliver effective treatments (Veremeenko et al., 2022).

Simulation training often involves the use of mannequins and simulators with feedback mechanisms to prepare students for emergency conditions like anaphylactic shock and clinical death, ensuring they can respond swiftly and correctly in critical situations (Gileva et al., 2023). The latest innovations include anthropomorphic robots like the Promobot-Ct, which are equipped with specialized sensors and actuators to create a fully functional training experience, enhancing practical competencies and communication skills through artificial intelligence (Arutyunov et al., 2023). High-fidelity simulators that accurately mimic real clinical situations are crucial, as they allow trainees to practice invasive and non-invasive procedures repeatedly without risking patient safety, thereby reducing medical errors and increasing patient satisfaction (Hu et al., 2022).

4.3. Development of complex clinical competences

Simulation training should focus on developing not only technical skills but also essential competencies such as communication, problem-solving, teamwork, leadership, and management skills (Nurunnabi et al., 2024).

The use of modern technologies in simulation training enhances practical skills while also promoting interdisciplinary learning, clinical and critical thinking, teamwork, and patient communication. This comprehensive approach is essential for educating future dentists (Veremeenko et al., 2022). Engaging with simulated patient cases can boost students' confidence, self-efficacy, contextual competence, and reflective practice, ultimately enhancing their overall skill set and readiness for real-world clinical scenarios (Kaskova et al., 2022). These simulation-based methods not only help students connect theoretical knowledge with clinical practice but also foster the development of self-efficacy, contextual competence, and reflective skills, preparing them for real patient interactions (Cenzon et al., 2022).

The creation of specialized simulators, such as the pediatric dental simulator developed at the Universidad Europea de Madrid, enables students to diagnose and treat complex cases, thereby improving their clinical competence and communication skills (Abdullah et al., 2023). The integration of AI-driven Standardized Patients (SP) using deep learning models like the Conformer can provide realistic patient interactions, helping students develop clinical performance skills without the high costs associated with hiring actors (Kim et al., 2023).

4.4. Cultivating confidence

Simulation training serves as an effective bridge between theoretical knowledge and practical application, thereby enhancing students' confidence in working with real patients (Hamza et al., 2023). This type of training is particularly important for dental students, as it provides them with hands-on experience in a controlled environment. Research has demonstrated that simulated patient cases and individualized video examinations recorded on smartphones significantly boost students' confidence when performing various dental procedures, including local anesthesia techniques (Dzhendov and Georgieva, 2022; Marsden et al., 2022). By using simulators, students can practice different dental procedures repeatedly, which leads to greater confidence in their skills and improved mastery of techniques (Marsden et al., 2022; Veremeenko et al., 2022). The COVID-19 pandemic highlighted the importance of simulation-based learning, especially in pediatric dentistry, where modified simulators allowed students to practice both diagnosis and treatment, significantly improving their self-perceived clinical competence (de la Hoz Calvo et al., 2022). Furthermore, the use of simulated patient case-based scenarios in e-portfolio workbooks and 3D printed teeth exercises has been shown to increase student confidence and support their learning, suggesting a positive correlation between simulation training and student self-efficacy (Marsden et al., 2022).

4.5. Empathy and patient-oriented care

Simulation experiences, such as aging simulations, enhance empathy and awareness of patient limitations, leading to improved patient-provider relationships and treatment outcomes. Aging simulation programs increase empathy and awareness among dental students regarding the challenges faced by elderly patients. This experience encourages students to modify their clinical practices to better accommodate patients with age-related limitations, thereby improving patient-provider relationships (Patel et al., 2024).

This increased empathy and understanding can lead to more patient-centered care, which is a critical component of effective clinical decision-making (Patel et al., 2024).

Simulation training elicits emotions similar to those experienced in real clinical settings, which is crucial for effective learning and decision-making. Dental students report feeling a range of emotions during simulations, which helps them prepare for the emotional aspects of patient care and decision-making in actual practice (Strub, 2024).

Dental simulation training can significantly enhance the preparedness and confidence of dental students in real patient scenarios. The use of patient-specific virtual simulations, such as those developed with the Simodont Dental Trainer, allows students to practice on actual patient cases in a virtual environment before performing real procedures, which students found more engaging and informative compared to standard tasks, despite some technical limitations (Anda et al., 2023).

Simulated virtual learning interventions effectively enhance dental hygiene students' knowledge, attitudes, and confidence in providing care for children with autism spectrum disorder (Cenzon et al., 2022; Uppgaard et al., 2023).

4.6. Place of simulation training in the curriculum

Dental simulation training is integrated at various stages within the dental curriculum to enhance the practical skills of students. In the United Kingdom, a dental school has embedded haptic training into their undergraduate curriculum, utilizing a structured framework based on deliberate practice to improve education outcomes (Ranauta et al., 2023). Similarly, at the Faculty of Dentistry, students engage in patient-specific virtual simulation training using intraoral scanners and the Simodont Dental Trainer before actual teeth preparation, which is particularly emphasized in the prosthetic dentistry curriculum (Anda et al., 2023). In Russia, simulation training is conducted in specially equipped centers rather than traditional departments, focusing on both individual skills and interdisciplinary training, thereby complementing real clinical practice without replacing it (Veremeenko et al., 2022). At the Poltava State Medical University, simulation technologies are widely used in the Department of Children's Therapeutic Dentistry, where students from the second to fifth courses practice in a simulation class equipped with phantoms, mannequins, and virtual simulators. This approach has been positively received by students, who believe it significantly enhances their practical skills and clinical thinking, which are crucial for their future work (Kaskova et al., 2022). Integration of simulation training across different stages of the dental curriculum, from early undergraduate years to

specialized courses, underscores its importance in providing a safe and effective environment for students to develop and refine their practical skills before transitioning to real patient care. Simulation training should be integrated into the medical curriculum at all levels, from specialty training to residency and continuing postgraduate education, as it significantly improves performance, teamwork, and communication among future physicians (Baidarov et al., 2023).

4.7. Impact on neuroplasticity of the brain and the cognitive load

Simulation training and game-based learning have been found to have positive effects on neuroplasticity of the brain and cognitive load in students. Game-based learning, which integrates video game play into the learning experience, has been shown to motivate and engage learners of all ages, providing real-world situations for learning and opportunities for practice and trial and error. The gaming educational technology needs redesign to optimize cognitive load (Knox, 2023). Simulation activities, such as emergency simulation games, have been used to induce different levels of cognitive load and measure cognitive load using functional near-infrared spectroscopy (fNIRS) (Sevcenko et al., 2022). These studies have demonstrated that knowledge of task structure and specific time slots can be used to measure cognitive load and adapt the learning environment in real-time (Sevcenko et al., 2021). Simulation training has been shown to impact cognitive load and neuroplasticity of the brain, as measured by EEG markers, in medical students and interns performing laparoscopic tasks (Maimon et al., 2022).

Game-based learning environments, which include game elements such as narratives and virtual incentives, have been shown to increase brain activation in areas associated with emotion, reward processing, and attention. This suggests that game-based learning environments are more rewarding, emotionally engaging, and attentionally stimulating, leading to more efficient learning (Kober et al., 2020). Immersive virtual experiences, particularly those involving physically active and cognitively demanding gameplay, have been found to increase cognition and neuroplasticity, as well as the building of new brain connections (Eng et al., 2020). Video game play, especially when combined with attentional control and reward processing, has also been shown to have a positive impact on brain plasticity (Nahum and Bavelier, 2020). According to Kober et al. (2020) adding game elements to a learning task leads to stronger activation of brain areas. Prefrontal brain areas are more activated in the game-based version compared to the non-game-based version. The authors found that participants rated the game-based version as more attractive, novel, and stimulating but less efficient than the non-game-based version.

There is limited information available on the use of simulation training in the formation of new neural connections in the brain. The papers by Lee and Duffy (2021) and Nöttgen et al. (2022) propose simulation schemes and methods for brain stimulations, but they focus on the accuracy and efficiency of the simulations rather than the formation of new neural connections. Both simulation training and game-based learning have the potential to influence cognitive load and neuroplasticity in students but, based on the reviewed papers, there is no direct evidence or information

on how simulation training affects the formation of new neural connections in the brain.

4.8. Pedagogical benefits

Simulation training is essential for enhancing accuracy, as it provides a platform for focused skill development and assessment, which leads to improved job performance. By integrating precision teaching methods into simulation-based interventions such as defining target skills, monitoring progress, and making informed training decisions (Watz et al., 2023) learners can achieve accurate and rapid responses.

Medical education programs utilizing simulation are being developed to boost engagement and improve health outcomes, particularly in procedures where precision is crucial. The interactive nature of simulation training allows learners to make mistakes in a safe environment, learn from these experiences, and refine their decision-making processes. Modern pedagogical technologies, including simulation learning and case technologies, are employed to foster clinical thinking, professional competence, and the ability to handle various clinical scenarios effectively (Ostafiichuk et al., 2022).

Simulation-based training should include a variety of scenarios to provide comprehensive skill development and ensure early skill transfer while maintaining patient safety (Kweki et al., 2023).

Implementing a situational simulation course can lead to significant improvements in students' non-operational clinical competency and final test performance. The authors suggest implementing SSC teaching in pregraduate training to improve communication and cognitive skills (Wu et al., 2024).

The integration of skill and simulation laboratories within dental education programs is essential and should be mandated by regulatory bodies. This approach is vital for cultivating dental practitioners who possess strong clinical competencies. The implementation of such facilities will not only enhance hands-on training but also ensure that graduates are adequately prepared to meet the complexities of real-world dental practice (Mustilwar et al., 2022).

5. Conclusion

Simulation training complements traditional education by providing students with valuable opportunities to improve their practical skills and readiness for real-world dental practice. The use of simulators, phantoms, and virtual reality technologies enables students to practice dental procedures repeatedly, which helps increase their confidence and competence in applying theoretical knowledge to real-life situations.

Exposure to simulated patient cases boosts learners' confidence and self-efficacy, facilitating the development of contextual competence and reflective practice. This enhances their decision-making skills in clinical settings. Simulation centers equipped with modern tools and materials allow students to develop interdisciplinary skills, teamwork, and effective communication with patients. These

experiences complement clinical training and significantly improve the practical skills essential for future dentists.

In addition to the potential for future developments in simulation learning for dental education, there is an emerging area that has not been thoroughly explored: the impact of simulation and game-based learning on students' neuroplasticity and cognitive load. Research in this field is currently very limited.

Educators must carefully design simulation scenarios to ensure they are conducive to learning while still challenging students to develop both technical and non-technical skills effectively.

5.1. Research limitations

The limitations of this research are primarily attributed to the chosen research methodology. The absence of a standardized approach in narrative reviews can lead to potential biases, diminish the reproducibility of the findings, and result in an incomplete representation of the existing literature. We have undertaken rigorous measures to mitigate these adverse effects as much as possible.

5.2. Implications for future research

Comprehensive investigations to better understand how simulation and game-based learning environments may influence neural adaptability and the cognitive demands placed on learners in dental training programs are needed. Also, additional attention is needed on issues related to the effective integration of simulation learning into the curriculum, as well as the connection of simulation learning with modern learning and teaching theories.

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References

Abdullah, S., Malik, A. A., Rashid, M. W., et al. (2023). Simulation's usage in training for dental trauma. International Journal of Health Sciences, 7(S1), 128–134. https://doi.org/10.53730/ijhs.v7ns1.14163

Arutyunov, S. D., Yuzhakov, A. A., Kharakh, Y. N., et al. (2023). Dental simulator based on a robotic complex with an integrated smart jaw. Russian Journal of Dentistry, 27(1), 63–70. https://doi.org/10.17816/dent115139

Baidarov, A. A., Vronsky, A. S., Lazarkov, P. V., et al. (2024). Simulation training in medicine: past, present and future. Perm Medical Journal, 40(6), 53–60. https://doi.org/10.17816/pmj40653-60

Cenzon, K. F., Bruhn, A. M., Claiborne, D. M., et al. (2022). Use of a simulated virtual training module to improve dental hygiene students' self-reported knowledge, attitudes, and confidence in providing care to children with autism spectrum disorder: A pilot study. Journal of Dental Hygiene.

Chechina, I. N., Dmitriyenko, N. Y., Zejbert, A. Y., et al. (2022). The attitude of dental students to the impact of simulation training on the quality of practical skills formation. Virtual Technologies in Medicine, 1(1): 16-19. https://doi.org/10.46594/2687-0037_2022_1_1418

Chopchik, V., Kaniura, O., Bidenko, N., et al. (2023). Substantiation of the need to implement simulation training for dental students based on the analysis of the activities of the Stomatological Medical Center at O. Bogomolets National Medical University. Ukrainian Scientific Medical Youth Journal, 136(1): 7-13. https://doi.org/10.32345/USMYJ.1(136).2023.7-13

Chu, F., Zheng, J., Wang, Q., et al. (2023). Mirror training device improves dental students' performance on virtual simulation dental training system. BMC Medical Education, 23(1). https://doi.org/10.1186/s12909-023-04300-6

de la Hoz Calvo, A., Bartolomé Villar, B., Torres Moreta, L., et al. (2022). Low-fidelity handmade simulator for pediatric dentistry simulated scenarios. Journal of Dental Education, 86(S3), 1751–1752. Portico. https://doi.org/10.1002/jdd.12962

Dzhendov, D., & Georgieva, G. (2022). The application of simulators in dental medicine students' training. Scripta Scientifica Medica, 54(0), 20. https://doi.org/10.14748/ssm.v54i0.8993

Eng, C. M., Calkosz, D. M., Yang, S. Y., et al. (2020). Doctoral Colloquium—Enhancing Brain Plasticity and Cognition Utilizing Immersive Technology and Virtual Reality Contexts for Gameplay. Proceedings of the 2020 6th International Conference of the Immersive Learning Research Network (ILRN), 395–398. https://doi.org/10.23919/ilrn47897.2020.9155120

Farrukh, A., & Sajjad, A. (2023). A Critical Review of Literature Review Methodologies. Advancing Methodologies of Conducting Literature Review in Management Domain, 103–123. https://doi.org/10.1108/s2754-586520230000002006

Gileva, M. A., Manaeva, M. V., Rudin, V. V., et al. (2023). Improving the effectiveness of medical care in dental emergencies using simulation training. Virtual Technologies in Medicine, 3. https://doi.org/10.46594/2687-0037_2023_3_1768

Hamza, T., Conca, R. A., Dragan, I. F. (2023). Are simulators paving a new way for continuing education?. Compend Contin Educ Dent.

Hu, C., Wang, K., Zhang, X., et al. (2022). A Critical Review of Simulation-Based Medical Education: An Advanced Opportunity for Next Generation of Medical Education. Journal of Clinical Case Reports and Studies, 3(7), 01–06. https://doi.org/10.31579/2690-8808/118

Kaskova, L., Novikova, S., Khmil, O., et al. (2022). Modern Aspects of the Practical Training of Future Dentists. Ukrainian Dental Almanac, 4, 73–77. https://doi.org/10.31718/2409-0255.4.2022.13

Kim, K., Chun, C., & Moon, S.-Y. (2023). Conformer-Based Dental AI Patient Clinical Diagnosis Simulation Using Korean Synthetic Data Generator for Multiple Standardized Patient Scenarios. Bioengineering, 10(5), 615. https://doi.org/10.3390/bioengineering10050615

Knox, A. (2023). Game-based learning design optimized for cognitive load. In: Reimagining Education: Studies and Stories for Effective Learning in an Evolving Digital Environment. Educational Communications and Technology: Issues and Innovations. Springer. pp. 239-250.

Kober, S. E., Wood, G., Kiili, K., et al. (2020). Game-based learning environments affect frontal brain activity. PLOS ONE, 15(11), e0242573. https://doi.org/10.1371/journal.pone.0242573

Kweki, A. G., Sarwar Khan Tharin, M., Baptista, V., et al. (2023). The Impact of Simulation-Based Training in Cardiovascular Medicine: A Systematic Review. Cureus. https://doi.org/10.7759/cureus.50414

Lee, S. C., Duffy, V. G. (2021). Use of simulation technology in transportation training: A systematic literature review. In: HCI International 2021 - Late Breaking Papers: HCI Applications in Health, Transport, and Industry. Lecture Notes in Computer Science. Springer. pp. 546–561.

Maimon, N. B., Bez, M., Drobot, D., et al. (2022). Continuous Monitoring of Mental Load During Virtual Simulator Training for Laparoscopic Surgery Reflects Laparoscopic Dexterity: A Comparative Study Using a Novel Wireless Device. Frontiers in Neuroscience, 15. https://doi.org/10.3389/fnins.2021.694010

Marsden, J. E., Deboo, S. P., Cripps, M., et al. (2022). Improving dental student confidence through the use of simulated patient cases. European Journal of Dental Education, 29(1), 104–115. Portico. https://doi.org/10.1111/eje.12867

Mustilwar, R., Gupta, I., Hardiya, H., et al. (2022). Skill and Simulation Lab in Dentistry—A Futuristic Era. Journal of Pharmaceutical Negative Results, 3258–3264. https://doi.org/10.47750/pnr.2022.13.s06.440

Nahum, M., & Bavelier, D. (2020). Video games as rich environments to foster brain plasticity. Brain-Computer Interfaces, 117–136. https://doi.org/10.1016/b978-0-444-63934-9.00010-x

Nöttgen, H., Czappa, F., Wolf, F. (2022). Accelerating brain simulations with the fast multipole method. In: Euro-Par 2022: Parallel Processing. Euro-Par 2022. Lecture Notes in Computer Science. Springer. pp. 387–402.

Nurunnabi, A. M., Haroon, K., Mohammad, T., et al. (2024). Simulation based teaching and learning in clinical education. Bangladesh Journal of Neurosurgery, 13(1): 24–28. https://doi.org/10.3329/bjns.v13i1.72291

Ostafiichuk, M. O., Batig, V. M., Bambuliak, A. V., et al. (2022). Use of Pedagogical Technologies in Future Dentists' Training Course. Актуальні Проблеми Сучасної Медицини: Вісник Української Медичної Стоматологічної Академії, 22(1), 162–167. https://doi.org/10.31718/2077-1096.22.1.162

Patel, S., Akinlotan, M. A., Nimmons, K., et al. (2024). The impact of an aging simulation program for dental students in two community dental clinics. Journal of Dental Education, 88(11), 1520–1529. Portico. https://doi.org/10.1002/jdd.13624

Ranauta, A., Audsley, B., & Coulthard, P. (2023). The integration of haptic training into the QMUL dental curriculum. European Journal of Dental Education. Portico. https://doi.org/10.1111/eje.12963

Sevcenko, N., Ninaus, M., Wortha, F., et al. (2021). Measuring Cognitive Load Using In-Game Metrics of a Serious Simulation Game. Frontiers in Psychology, 12. https://doi.org/10.3389/fpsyg.2021.572437

Sevcenko, N., Schopp, B., Dresler, T., et al. (2022). Neural Correlates of Cognitive Load While Playing an Emergency Simulation Game: A Functional Near-Infrared Spectroscopy (fNIRS) Study. IEEE Transactions on Games, 14(4), 696–705. https://doi.org/10.1109/tg.2022.3142954

Slaidina, A., Ozolins, K., Berzina, S., et al. (2023). Patient-specific virtual simulation in the clinical training for prosthetic dentistry. European Journal of Dental Education. Portico. https://doi.org/10.1111/eje.12949

Strub, M. (2024). Do we feel the same emotions in simulation as with a real patient ? A pilot study among dental students. Research Square. https://doi.org/10.21203/rs.3.rs-3953844/v1

Uppgaard, R., Huang, B., Johnson, A., et al. (2023). The effect of smartphone filming on student confidence in dental anesthesia techniques: A randomized trial. Journal of Dental Education, 87(5), 676–685. Portico. https://doi.org/10.1002/jdd.13168

Veremeenko, S., Kriventsev, A., Bogatyrev, R., et al. (2022). Simulation Training as a Significant Factor in the Process of Preparing Dentists for Further Practical Activity. In: Proceedings of the 2022 2nd International Conference on Technology Enhanced Learning in Higher Education (TELE); 2022. https://doi.org/10.1109/tele55498.2022.9801071

Watz, E., Neubauer, P., Shires, R., et al. (2023). Precision learning through data intelligence. Adaptive Instructional Systems. https://doi.org/10.1007/978-3-031-34735-1_13

Wu, J. H., Lin, P. C., Lee, K. T., et al. (2024). Situational simulation teaching effectively improves dental students' non-operational clinical competency and objective structured clinical examination performance. BMC Medical Education, 24(1). https://doi.org/10.1186/s12909-024-05546-4