Enhancing Clinical Training in Dental Education Through Immersive Reality: A Systematic Review

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Abstract

Background: Becoming a skillful dentist requires extensive knowledge and skills typically gained through years of practical experience. Currently, immersive reality (IR), a combination of virtual reality and augmented reality technology, represents an innovative approach that combines the physical and virtual worlds, providing an optimal learning experience for students.

Objective: The current study aimed to provide a thorough review of the research on the benefits of immersive reality technology in dental education training.

Methods: A modified Population, Intervention, Comparison, and Outcome strategy conducted using a combination of electronic searches (PubMed, Cochrane and Embase) and manual searches between 2014 to 2024.

Results: The initial search found 135 studies, from which 13 were selected for analysis. The main findings indicated that IR technology in dental education reduced procedural time and shortened training durations, decreasing errors while contributing to knowledge and skills development. Overall, these findings collectively provide strong evidence of the benefits of IR technology in dental education.

Conclusions: IR technology greatly improves the efficiency of dental education by providing valuable information and serving as a simulation tool, thereby reducing surgical time without compromising outcomes. Clinical Trial: The protocol for the systematic review was registered to PROSPERO (CRD42024617799).

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ABSTRACT

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Keywords: Dentistry education, immersive reality, knowledge, skill training, simulator, virtual training.

Introduction

Dental education has a unique approach to learning that combines theory, laboratory work and clinical practice [1–3]. Preclinical and clinical training are important phases for students, helping them develop motor skills and knowledge necessary for managing real patients[4–9]. Digitalization in dental practice and virtual simulation enhances the learning experience by bridging information with the real environment, thereby introducing innovation in the clinical operational field within education [10–13].

The use of IR (combination of virtual reality and augmented reality) in dental education is believed to enhance learning compared with traditional methods, especially for complex procedures such as oral surgery, such as open and closed tooth extraction, and other skill-based tasks [14–16]. IR enables independent learning, allowing students to repeat the training session as needed [17–20]. These technologies have been shown to improve fine motor skills and hand-eye coordination in pre-clinical settings, addressing both the financial and intellectual challenges commonly faced in traditional training environments [15,21–23]. The flexibility offered by this technology encourages active student participation and enhances understanding of surgery procedures and related anatomy, creating a safer and more engaging learning environment [15,21,24].

However, the effects of IR technology in dental practice and education are not yet widely explored. This systematic review aimed to evaluate the effect and outcomes of IR in dental education. The evaluation focused on factors such as knowledge, clinical skills, duration of practice and user satisfaction.

Methods

Review strategy and study registration

The current systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [25]. The protocol for the systematic review was registered to PROSPERO (CRD42024617799).

Information sources and search approach

The present authors conducted a comprehensive search of electronic databases, including PubMed, Cochrane and Embase, focusing on research articles published in the last ten years (2014 - 2024). This systematic approach ensures that the most current and relevant information available is utilized in the current analysis. The initial search was conducted in June 2024 and was updated in August 2024.

The article focuses on randomized clinical trials and related literature, using specific search terms such as ‘mixed reality’, ‘immersive reality’, ‘dental training’, ‘virtual simulator’, ‘dentistry’, ‘training effectiveness’ and ‘skill improvement’. Manual searches of significant journals related to the use of IR technology in dental training were also conducted. The search strategy was customized for each specific database. A summary of the search strategies and the total number of studies retrieved is provided in Table 1.

Focus question

The Population, Intervention, Comparison and Outcome (PICO) framework for this investigation includes the following components: The study population consisted of students and residents receiving dental education/dental training combined with IR technology; the intervention examined the impact of IR-based training on dental students and residents; the comparison was made between conventional methods and alternative approaches for dental training (i.e. phantom and physical 3D model) and IR technology (i.e. virtual simulator); outcomes assessed included training time, procedural time and errors, knowledge and skill improvement, and learning duration as the primary outcome tabulated in Table 2.

Eligibility criteria and study selection

The eligibility criteria for inclusion in this review were as follows: i) research focused on the outcomes of students and residents undergoing dental education or training that incorporates IR technology, pilot studies, randomized controlled trials (RCTs) study designs; ii) the study population consist of either humans or study models.

The exclusion criteria were as follows: i) review or systematic review articles; ii) research that does not involve IR technology in dental education or training; and iii) studies that do not describe the advantages or outcomes of using IR technology in the dental education or training process.

Two review authors (M. R. and C. S.) independently reviewed the titles and abstracts of the search results to identify relevant studies, while taking into account the PICO question and the established inclusion and exclusion criteria. Irrelevant studies were excluded from the review and the rationale for their exclusion was documented. In cases of disagreement among the authors, a third author (O. A.) was consulted for resolution. The full texts of potentially relevant articles were evaluated further. Those not adhering to the PICO framework or the inclusion and exclusion criteria were eliminated, and reasons for their exclusion were recorded.

Data items and collection process

One researcher (M. R.) extracted data from the selected articles, while another researcher (C. S.), confirmed the accuracy of that data extraction. Information of interest included the authors' names, publication year, country of origin, the number of samples in both treatments and control groups, platforms and devices used, interventions and outcomes such as training duration, procedural time, errors and improvements in knowledge and skills. The summary of IR technology utilization in dental practice and education outcomes is presented in Table 3.

Assessing the risk of bias

All the studies included in the current systematic review were RCTs. The risk of bias associated with the studies included was evaluated using the Joanna Briggs Institute (JBI) assessment tool for RCTs [26], as shown in Table 4.

Synthesis of the summary measures

The data extracted from the selected articles were considered appropriate as the primary outcome if they demonstrated the effective application of the IR technology training system in dental procedures. This assessment was based on criteria such as training duration, procedural time, occurrence of errors and enhancements in knowledge and skills. Comparisons among selected publications were not feasible due to the heterogeneity in the fields of dental training and IR technology, so meta-analyses could not be performed.

The data were compiled using the following parameters and subsequently organized according to predefined schemes as mentioned below: i) 'Author, year, country', which identifies the first author, the year of publication, and location where the study conducted; ii) 'Number of subjects', it describes the type and size of the samples that were utilized; iii) 'Training case', it details the type of procedure trained; iv); and v) ‘Platform, devices’, it describes the platforms and devices that are utilized in the literature.

The outcomes of all included studies were analyzed and categorized into four categories as outlined below: i) ‘Training duration’, which describes the time required to complete the training for the procedure; ii) ‘Procedural time’, which describes the time needed to complete the procedure; iii) ‘Error’, which describes the error faced by the participant during the training session and the deviation they feel in comparison with real objects; and iv) ‘Knowledge/skill improvement’, which describes the improvement of knowledge and skills among participants after virtual training.

Results

Study selection

After removing duplicate entries, a total of 135 articles were identified through the search method. A comprehensive review of titles and abstracts led to the exclusion of several articles, leaving 30 potentially relevant articles.

The 30 full-text articles from various databases were screened according to predetermined inclusion and exclusion criteria. Ultimately, 13 studies met the criteria and were included in the review, while 16 were excluded after a comprehensive evaluation. A flowchart illustrating the process of including, excluding, and identifying studies, along with the reasons for exclusion, is shown in Fig. 1.

Study characteristics

The systematic review encompassed thirteen studies, all of which were RCTs conducted between 2014 and 2024. The usage of IR technology training system in oral surgery was evaluated in three studies [19,27,28], while five studies focused on operative dentistry [4,29–32], two studies on pediatric dentistry [33,34], one study on orthodontics [35], one study on prosthodontia [36], and one study on periodontia [5] as shown in Fig. 2.

Among the included studies, the most common IR headset utilized was Oculus Rift [19,27,35], followed by Microsoft Hololens [28]. The most frequently utilized supporting IR platforms included are SIMtoCARE dente [4,33], Courseware [32,33], Unity Game Engine [36], Leap motion [19], UniDental VS System[5], iLab X [34], Simodont [32], Jugular software [35], Beijing Rainier [34], and Virteasy [30]. Additionally, utilization of haptic devices was reported in three studies, including Geomagic X [28,30] and Omni haptic [31]. A summary of outcomes analysis is presented in Table 3.

Risk of bias

Upon evaluating the seventeen studies using the JBI assessment tool, the risk of bias was found to be low risk (94.08%). Among the 13 studies, 11 included a control group [4,5,19,27,29–34,36], which highlighted differences between conventional and IR-based training. However, the remaining two studies without control groups had limited generalizability and introduced bias to their results [28,35]. The detailed risk of bias assessment of all the studies can be found in Table 4.

Summary of results

In the reviewed studies, various assessments were conducted to evaluate the benefits of the interventions of IR technology in dental training procedures. This assessment focused on training duration, procedural time, system error, and knowledge and skills improvements. Out of the thirteen studies that met the inclusion criteria, the training duration was measured in eight studies [4,5,19,27,30,32,33,35], procedural time was evaluated in six studies [28,30–33,35], system errors were assessed in two studies [28,32], and all studies examined knowledge/skill improvement.

These studies demonstrated improvements in technical skills and performance among dental students, residents and surgeons. Additionally, there were reductions in training duration and procedural time, with minimal errors reported.

Training duration

Training duration measures how long students/participants engage in simulations and complete all the virtual tasks. Peters et al. compared different learning methods for performing simple sutures, including e-learning, HMD-based and tutor-led training [27]. The training duration was 40 min of recorded lectures with a 180° instruction video on HMD and 60 min of self-directed training [27]. They found that course suitability was highest in tutor-led ($\bar{x}$=4.8), followed by HMD-based ($\bar{x}$= 3.6) and e-learning ($\bar{x}$=2.5) courses. Based on the global rating score, there were no significant differences between the three instructional methods evaluated [27]. Similarly, Fu et al. reported an experiment of 90 min of dental scaling training with the virtual simulator (VS) compared with conventional training in typodont (TT) and quail egg (QE) [5]. The results revealed that students in the VS group had higher scores than those in the QE and TT groups, which were 87.89±6.81, 83.53±8.14 and 85.05±6.81, respectively [5].

Philip et al. reported the advantages of 60 min of training using a haptic virtual reality simulator (HVRS) called SIMtoCARE dente® for practicing pulpotomy, in comparison with conventional pulpotomy training [33]. According to the perception questionnaire, there were no significant differences between the two methods. Additionally, all participants agreed that HVRS was a useful adjunct for pre-clinical training[33]. Similarly, Daud et al. utilized the same SIMtoCare dente® system for Class I tooth preparation, conducting 40 min training in major operative dentistry [4]. After a comparative analysis with the conventional method, it was found that out of 23 participating students, there was strong agreement that virtual reality with haptic simulation (VRHS) training could serve as a valuable supplement to pre-clinical training and enhance participant's manual dexterity[4].

Sytek et al. report an experiment involving 2D, 3D and VR treatment planning and simulation tasks were conducted by orthodontic residents [35]. The mean training time of 2D, 3D and VR was 2.13, 3.95 and 6.59 minutes, respectively. According to Board Case Oral Examination (BCOE) worksheet scores, participants in 3D simulation have the highest total score (56.69), followed by VR simulation (56.38) and 2D simulation (55.21) [35]. Participants provided positive comments on the VR training method which was focused on its perceived accuracy, and described it as a cool, interactive and immersive environment.[35] Vincent et al. also found that the virtual drilling exercise time in the first phase was 216±107 seconds. and significantly reduced in the third phase to 150±60 seconds, while in the conventional method group the exercise time in the first phase was 547±73 seconds and decreased in the third phase to 424±105 seconds [30]. The exercise time in the virtual training was faster than that in the conventional training group while achieving similar learning outcomes [30]. This demonstrates that the IR simulator introduces innovation in training, with an improved understanding among the students.

Procedural time and errors

Prolonged procedural time, especially in surgical practices among students, may lead to complications that are twice as likely to occur [21]. This issue often arises from operators who are either inexperienced or lack the necessary skills, resulting in extended decision-making periods during surgery [37]. Studies suggest that the longer operation time may increase the prevalence of surgical complications, including wound dehiscence and infection, undesired sutures, paraesthesia, and unhealed wounds due to longer operation time [37,38].

There is a clear correlation between procedural time (the time taken to complete a task) and the skills and knowledge of the operator. Enhanced skills and knowledge are typically developed through years of training and expert guidance [10,39]. An IR simulator supports learning by enabling realistic and interactive training in real-time, making procedural learning easier to understand [17,40,41]. Additionally, students can practice repeatedly, which reinforces their skills and understanding. Philip et al. reported that students who used HVRS with SIMtoCARE dente® for pulpotomy on molar tooth had lower procedural time (23.7±1 min) compared with those using a conventional mannequin simulator (25.9±8.9 min) [33]. Similarly, Liu et al. reported the usage of AR navigation during craniofacial fibrous dysplasia shortened the procedural time to 60-80 min, with a mean error of 1,442±0.234 mm [28]. They conclude that this system provided surgeons with a comprehensive view of recontouring borders and depth in real time, promoting a more efficient surgical procedure [28].

Another study conducted by Sytek et al. compared the use of VR, 3D and 2D orthodontics planning among orthodontic residents [35]. The findings indicated that students who engaged in VR and 3D planning had more questions regarding manipulations and features of the software. They also exhibited more movements during surgical practice, although there were no significant differences in their written treatment plan analysis score compared with those using 2D analysis [35]. Additionally, students required more time to complete tasks in VR and 3D. Qualitative feedback highlighted that student showed positive attitudes toward the fidelity of visualization, the ease of manipulation and the enjoyment of the simulation. Similarly, Vincent et al. demonstrated the positive impact of the haptic simulator Virteasy on restorative dentistry training among students. The study found no significant differences between the haptic simulator and conventional practice on plastic analogue teeth (Kavo) [30].

Knowledge and skill improvement

The learning process for students can be delivered in different ways, including textbooks, tutorials, video learning, live demos or hands-on practice with real patients under expert supervision [1,42]. However, traditional methods often do not provide students with sufficient understanding and knowledge, as it typically takes years of experience to perform procedures independently [43]. IR simulators provide a safe environment that allows a real-time interaction that is repeatable and fully controlled for the training of students [7,22,23]. These simulators enable students to easily explore and self-practice dental procedures according to curriculum and theoretical knowledge acquired in routine lectures [7,44,45]. Lu et al. reported that students who underwent immersive reality (IR) training for pulpotomy in pediatric dentistry achieved higher scores compared to those in the control group who received conventional training [34]. Student progress can be monitored and assessed through the IR system. Students may attain improved knowledge and skills necessary for dental treatment, achieved higher score both in theoritical and clinical practice, result in improved healthcare outcomes with fewer complications [46–48].

The utilization of an IR simulator in the oral surgery department was reported in three studies [19,27,28]. Peters et al. investigated the application of an IR simulator for single-button suture training [27]. They conclude that the use of this learning method provides stereoscopic and immersive learning for students, as well as enhances concentration on the learning objects. Similarly, Liu et al. utilized IR technology as surgical navigation in a case of craniofacial fibrous dysplasia [28]. They found it to be effective, reducing the operating time to 60-80 min with minimal errors and no complications in the healing process. Additionally, also by Pulijala et al. reported that IR-based training for Le Fort I Osteotomy increased self-confidence among novice surgeons, positively impacting their performance [19].

In line with that, IR technology is utilized in operative dentistry for several procedures. Daud et al. utilized IR technology for Black's Class I cavity preparation training involving 23 dental students [4]. The qualitative result indicated that students 'strongly agreed' that virtual reality with VRHS could be adopted as a complement to their learning method [4]. San Diego et al. investigated the positive impact of haptic-based simulator training among first-year students involved in the removal of carious lesions. After the training session, these students were able to hold the dental instruments appropriately without significant differences compared with those receiving conventional training [29]. Similarly, Vincent et al. investigated the benefits of using IR as a simulator for Black's Class II cavity preparation training which effectively improved student's dexterity when performing real procedures for the first time [30].

Additionally, Dwisaptarini et al. investigated minimal invasive caries removal training among sixth-year dental students. They conclude that VR simulator training has equivalent effects on improving the visuo-tactile performance of students [31]. This result in line with Al-Saud et al. that discovered that the utilization of IR-based training for tooth cavity preparation improves student's motor skills [32]. Similarly, a periodontology department implemented IR-based training on dental scaling in the challenging anatomical area for dental students [5]. As a result, the students were found to have their skills upgraded and received improved training that could be effectively applied when treating real patients [5].

Virtual simulator helped students to improve their knowledge and achieve higher score. Lu et al. that discovered higher score achieved by dental students who had IR training for pulpotomy in pediatric dentistry compared with control group who had conventional training[34].

Discussion

The studies reviewed demonstrated the various uses of IR technology in dental education, encompassing restorative dentistry, endodontics, prosthodontics and maxillofacial surgery. The application of IR technology providing a safer environment for training, real-time interaction and effective learning process.

The effectiveness of IR technology is evidenced in several studies. Moussa et al. discovered that VR technology, used as a teaching simulation and assessment method, is considered an advanced approach that improves the quality of dental education outcomes [49]. During the learning process they found that the use of 3D simulation helps students gain an improved understanding, although the presence of teachers and verbal instructions are still needed to reinforce their performance [49]. IR-based learning effectiveness is comparable with conventional learning methods [44]. They discovered that this learning method effectively enhances students' theoretical knowledge and practical skills. Furthermore, this learning approach may affect the self-confidence of students and create attractive learning environments [44].

The integration of IR technologies in dental education has demonstrated significant potential for enhancing both theoretical and practical learning outcomes [50]. This discussion synthesizes findings from various reviewed studies, focusing on the efficacy of IR applications in developing cognitive skills, technical proficiencies and learner confidence while addressing the limitations and implications of these findings [18,51]. For example, haptic feedback devices consistently enhanced students' fine motor skills and precision during cavity preparation tasks, outperforming traditional mannequin-based simulations [52,53].

In terms of cognitive outcomes, IR immersive environments foster a deeper understanding of complex anatomical and procedural concepts [17,18]. This is particularly evident in endodontic training, where IR simulations improved spatial navigation and root canal anatomy comprehension [14,53]. The ability to repeat procedures without time constraints further supports the development of procedural expertise, contributing to improved confidence and reduced error rates among learners.

Learners and educators alike expressed positive attitudes toward the role of IR in dental education. The immersive and interactive nature of IR motivated students, making the learning process more engaging and enjoyable. This aligns with findings that IR enhances satisfaction and self-assessment capabilities, promoting autonomous learning [14,53]. However, it is essential to address variability in acceptance levels, which may depend on prior exposure to technology and individual learning preferences.

While IR technologies exhibit numerous advantages, several limitations persist. Cost remains a significant barrier, with high initial investments for hardware and software development [53]. Additionally, the technical sophistication required for IR maintenance and updates may not be accessible to all educational institutions. Variations in IR fidelity across studies also underscore the need for standardization in design and implementation to ensure consistent learning experiences [54,55]. Another limitation is the predominance of subjective assessment methods, such as self-reported surveys and qualitative feedback, which may lack objectivity [56]. Incorporating quantitative measures like procedural time and error rates could provide more robust evaluations of the effectiveness of the IR integration [14,53]. The findings advocate for broader implementation of IR in dental education, particularly as a complementary tool alongside traditional method. The limitations of this systematic review lie on the high heterogeneity of publications included, making comparisons, validation and meta-analysis impossible.

In conclusion, this study established that IR as a transformative tool in dental education, offering a unique blend of immersive learning, skill refinement and learner engagement. By addressing current challenges and investing in further research, IR has the potential to revolutionize dental training and prepare students more effectively for clinical practice.

List of Abbreviations

PICO:	Population, Intervention, Comparison, Outcome
IR:	Immersive reality
AR:	Augmented reality
VR:	Virtual reality
$\bar{X}$:	Mean of dataset

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Figure legends

Fig 1. Flowchart of the article selection process
Fig 2. Studies distribution based on dental specialty category

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Table 1. Custom search strategy of each database
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Table 1 Custom search strategy of each database

Databases	Search strategy used	Hits
PubMed	(dental management OR dental training OR tooth extraction AND mixed reality OR immersive reality OR virtual reality OR augmented reality)	159
Cochrane	#1 'Dental training OR dentist competency OR dental management OR tooth extraction' 10562 #2 'Immersive reality OR mixed reality OR virtual reality OR virtual simulator' 2614 #1 AND #2	59
Embase	Dentist AND immersive reality OR mixed OR virtual AND tooth extraction AND dental training OR dental management AND dentistry competency	18

Table 2 PICO framework

Population:	Dental students, surgeons, patients receiving dental treatment/training combined with IR (VR/AR) technology.
Intervention:	Dental training procedure (oral surgery, operative dentistry, pediatric dentistry, orthodontia, prosthodontia, periodontia, etc.) on human or study model utilizing IR technology.
Comparison:	Dental training procedure between immersive reality based and conventional.
Outcome:	Training duration, procedural time, error, and knowledge/skill improvement.

Table 3 Analysis results based on outcomes for IR technology utilization in dental training

Author. Year. Country	Number of subjects	Training case	Platform, devices	Training duration (min)	Outcomes		
					Procedural time	Error	Knowledge/ skills improvement
Fu et al.[5] 2024. China	108 fourth-year students	Periodontia: Periodontal scalling	• UniDental VS system (Beijing UniDraw Virtual Reality Technology Research Institute Co., Ltd., 2014).	90 minutes	NS	NS	Students had better understand about scalling procedure in challenging location.
Peters et al. [27] 2023. Germany	150 participants	Oral surgery: Single button suture technique.	• Oculus quest 2 VR-HMD (Meta platforms Inc., United States).	• 40 minutes recorded lecture and 180° instruction video with HMD • 60 minutes self-directed training	NS	NS	Stereoscopic and immersive learning through HMD help students concentrate to the learning substances.
Philip et al. [33] 2023. Switzerland	14 students	Pediatric dentistry: Pulpotomy on primary teeth.	• SIMtoCARE Dente® (SIMtoCARE B.V., Vreeland, The Netherlands). • Courseware (Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands).	60 minutes	23.7 ± 1 minutes (lower than conventional method 25.9 ± 8.9 minutes).	NS	Higher scores achieved compared with conventional method.
Daud et al.[4] 2023. Qatar	23 dental students	Operative dentistry: Class I Cavity preparation	• SIMtoCARE Dente® (SIMtoCARE B.V., Vreeland, The Netherlands).	40 minutes	NS	NS	Students strongly agreed that VRHS can be used as supplement on pre-clinical training.
Lu et al.[34] 2022. China	199 students of fourth-year stomatology course	Pediatric dentistry: Pulpotomy.	• Beijing Rainier Network Technology (Bijing, China; www.rainier.et.cn). • iLab x (www.ilab-x.com).	NS	NS	NS	Grades Band C of experimental group had higher score than control group. Students thought experimental virtual simulation very helpful master the difficult aspects of pulpotomy.
Mansoory et al.[36]	50 dental students	Prosthodontia: Practical	• Unity game engine	NS	NS	NS	Students in

2022. Iran		skill test on the neutral zone design and teeth arrangement.	• Gear VR (Samsung Company Inc. Oculus Company).				experimental group had higher score in practical skills of neutral zone design. No significant differences on teeh arrangement practical skill test.
San Diego et al.[29] 2022. United Kingdom	264 first-year students	Operative dentistry: Removal of artificial carious lesions.	• Haptic-based simulators	NS	NS	NS	• Students holding instruments appropriately. • No difference in the quality of cavity cut.
Liu et al.[28] 2021. China	5 patients	Oral surgery: Craniofacial fibrous dysplasia.	• HMD Hololens (Microsoft Corporation, USA). • Geomagic control X, 3D Systems Inc., South Carolina, USA).	NS	Operating time: 60-80 minutes	(2.4081 – 3.0903 mm) Max error on zygomatic maxillary complex	• AR navigation help reduce the operative time compared with conventional method; all patient underwent uneventful healing without any complications.
Sytek et al. [35] 2021. USA	20 graduated students of orthodontia department	Orthodontia: Orthodontic treatment planning.	• Oculus Rift HMD (Oculus VR Inc., Menlo Park, CA). • Jugular software (University of Michigan's VR platform).	NS	5.823 minutes	NS	• VR brings positive attitudes toward higher fidelity tools with regard to visualization, manipulation, and student's enjoyment.
Vincent et al. [30] 2020. France	88 first-year dental students	Operative dentistry: Black's Class II cavity on a first right mandibular molar (#46).	• Virteasy haptic simulator • Geomagic touch x haptic device (Geomagic Inc., Morrisville, NC, USA).	10 minutes	10 minutes	NS	• Simulator usage effectively improved student's dexterity when experiencing a

								physical model for the first time.
Dwisaptarini et al.[31] 2018. Indonesia	32 sixth-year dental students	Operative dentistry: Minimally invasive caries-removal training.	Omni haptic device (SensAble, Inc, Woburn, MA, USA).		10.82 ± 4.17 minutes (faster than control group 10.87 ± 4.47)			VR simulator training had equivallent effects in improving visuo-tactile performance of students.
Pulijala et al. [19] 2018. United Kingdom	95 novice surgical residents	Oral surgery: Le Fort I Osteotomy.	• Oculus Rift HMD (Oculus VR Inc., Menlo Park, CA) • Leap Motion controllers	45 minutes	NS		NS	Significant higher self confidence level of first-year novices.
Al-Saud et al. [32] 2016. United Kingdom	63 participants	Operative dentistry: (tooth drilling with five geometric shapes, with depths of 0.4 mm and 0.8 mm).	• Simodont VR haptic dental simulator (MOOG, Nieuw-Vennep, Netherlands). • Courseware (Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands).	Not significantly different in all groups.	DFB higher percentage than other groups.	IDFB group lower (13.68) than DFB group (21.4).		Integration of VR into a dental curriculum needs consideration in order to maximise VR's potential utility in motor skill learning and to complement existing simulation techniques.

Abbreviations: *NS: Not specified; mm: milimeters; IDFB: instructor device feedback; DFB: device feedback.*

Table 4 The risk of bias of included studies based on the Joanna Briggs Institute (JBI) assessment for Randomized Controlled Study [26].

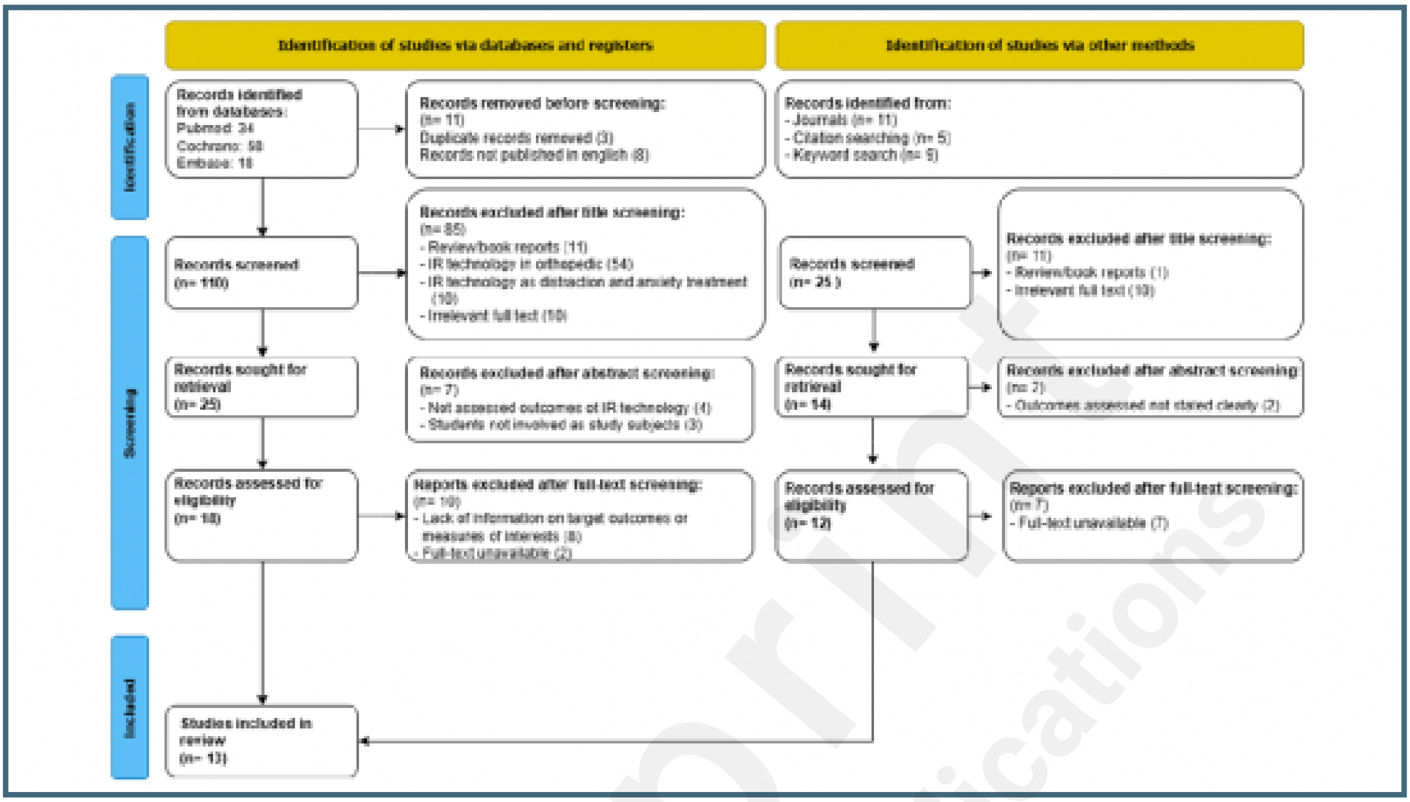
JBI Assessment Tools	Questions													Score % (category of bias)
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	
Fu et al, [5] 2024	□	□	□	□	□	□	□	□	□	□	□	□	□	**92.30**
Peters et al, [27] 2023	□	□	□	□	□	□	□	□	□	□	□	□	□	84.61
Philip et al, [33] 2023	□	□	□	□	□	□	□	□	□	□	□	□	□	100
Daud et al, [4] 2023	□	□	□	□	□	□	□	□	□	□	□	□	□	84.61
Lu et al, [34] 2022	□	□	□	□	□	□	□	□	□	□	□	□	□	92.30
Mansoory et al, [36] 2022	□	□	□	□	□	□	□	□	□	□	□	□	□	92.30
San Diego et al, [29] 2022	□	□	□	□	□	□	□	□	□	□	□	□	□	100
Liu et al, [28] 2021	□	□	□	□	□	□	□	□	□	□	□	□	□	76.92
Sytek et al, [35] 2021	□	□	□	□	□	□	□	□	□	□	□	□	□	100
Vincent et al, [30] 2020	□	□	□	□	□	□	□	□	□	□	□	□	□	100
Dwisaptarini et al, [31] 2018	□	□	□	□	□	□	□	□	□	□	□	□	□	100
Pulijala et al, [19] 2018	□	□	□	□	□	□	□	□	□	□	□	□	□	100
Al-Saud et al, [32] 2016	□	□	□	□	□	□	□	□	□	□	□	□	□	100
Average score														**94.08 (Low risk)**

Abbreviations: □(Yes), □ (No),□ (Unclear), □ (Not applicable).

Supplementary Files

Figures

Flowchart of the article selection process.



Studies distribution based on dental specialty category.