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Review Article

Current applications and future perspective of virtual reality in dental education and practice in Saudi Arabia: A scoping review

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ABSTRACT

Objective: This scoping review aimed to evaluate the current state of virtual reality (VR) implementation in dental education and practice in Saudi Arabia, highlighting its advantages and challenges.
Methods: A scoping review examined VR's role in regrading dental education and practice in Saudi Arabia by searching electronic databases, including PubMed, Web of Science, and Scopus, from inception to July 2024. Studies including VR applications for education, skills development, or anxiety/pain management involving Saudi dental students and practitioners were included.
Results: Eleven relevant studies were identified: 5 focused on education and 6 on clinical practice. Educational studies showed mixed effectiveness of VR versus traditional methods but positive student perceptions. Clinical application studies also had mixed results on VR's impact on anxiety and pain, though some benefits were noted. VR systems included distraction-based, simulator-based, and hybrid VR/augmented reality with artificial intelligence.
Conclusion: While the current implementation of VR in dental practice in Saudi Arabia shows promise, particularly in enhancing students' engagement and reducing patients' anxiety, more comprehensive and robust research is needed to validate its effectiveness fully. Strategic efforts should focus on expanding research, tailoring applications, and integrating VR with traditional methods to align with the healthcare objectives of Vision 2030.

1. Introduction

Dental education aims to equip students to work independently and safely as dentists by integrating theoretical knowledge, clinical skills, and professional behaviors. These areas require exceptional manual dexterity, primarily developed during undergraduate training in simulation laboratories (McGleenon and Morison 2021). Despite global advancements, many institutions struggle to meet these standards within academic syllabi, facing challenges such as ethical concerns, financial constraints, and the need for substantial investment and innovation (Hendricson and Cohen 2001, Iacopino 2007).

The use of human-derived natural samples, such as extracted teeth, provides a precise depiction of anatomical structures, although it presents ethical and logistical challenges (Haji et al., 2021, McGleenon and Morison 2021). In order to overcome these obstacles, Virtual reality (VR) offers a transformative solution by delivering immersive simulations, enabling students to refine their skills in a secure setting before engaging with actual patients (Liebermann et al., 2022). Moreover, VR assists dental practitioners in planning intricate surgeries, thereby enhancing precision and ultimately improving patient outcomes (Monaghesh et al., 2023). Furthermore, VR has the potential to enhance patient satisfaction by creating serene environments during dental procedures (Bahrololoomi et al., 2024).

Different VR systems are used in dental education to enhance learning and skills. Positive feedback has been received for systems such as SIMtoCARE Dente (Philip et al., 2023) and 360° VR videos, which

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enhance student satisfaction compared to traditional 2D videos (Buchanan 2004, Im et al., 2023). Virtual surgery platforms like 3D Max and Unity 3D have proven effective for dental implant training, providing high predictability and operability (Zhou et al., 2021). Haptic devices like FreeForm are also employed in dental implant training (Kusumoto et al., 2006). The Voxel-Man simulator was tested with dental students and found to be a valuable additional tool in dental education (Pohlenz et al., 2010). Additionally, Denex image-guided implantology demonstrated faster and more significant completion of assignments during student training (Casap et al., 2011). However, traditional methods still have support, as evidenced by the Simodont haptic 3D VRS, where trainers and most respondents agreed with the feedback provided by the VRS, but trainers did not fully support replacing conventional pre-clinical training methods (Bakr et al., 2013).

The healthcare sector in Saudi Arabia is currently undergoing a rapid transformation, with a strong emphasis on improving healthcare outcomes through collaborative practices. The Vision 2030 initiative recognizes the importance of enhancing healthcare services and establishing a sustainable healthcare system (Mani and Goniewicz 2024). In line with Saudi Arabia's Vision 2030, which prioritizes innovative healthcare solutions, this study investigates the potential of VR in advancing dental training and practice, thereby ensuring higher levels of competence and improved patient outcomes. By examining existing VR applications and their efficacy, this review offers insights and strategic recommendations to facilitate the integration of VR technology in Saudi dentistry, thus contributing to the broader objectives of delivering superior healthcare services and promoting sustainability.

Despite the growing global application of VR, the current extent of VR application in dentistry within Saudi Arabia remains unclear due to limited information on its usage and specific implementation areas. This uncertainty underscores the need for a comprehensive study to assess the scope and effectiveness of VR in Saudi dental practices. This study aimed to evaluate the current applications of VR, assess their impact on dental education and patient care, and identify potential areas for future development. The findings of this study highlight the advantages and obstacles of VR implementation and propose strategic courses of action to ensure its effective utilization in line with the healthcare objectives outlined in Saudi Arabia's Vision 2030. Furthermore, recommendations are provided to enhance the integration of VR technology in the field of dentistry in Saudi Arabia.

2. Method

2.1. Study design and review question

This scoping review utilized a systematic approach to examine the current application of VR in dental education and practice in Saudi Arabia. The study adhered to the guidelines set forth by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-ScR) (Tricco et al., 2018). The search was not restricted by time or language; the most up-to-date search was performed in July 2024. To remove any duplicated findings, the search results were imported into EndNote (Clarivate).

The question addressed in this review was "What is the current role of VR technology in dental education and practice in Saudi Arabia?". The population included dental students and practitioners in Saudi Arabia. The key concept is using VR technology in dental education and practice, compared to traditional methods or without a comparator. The outcomes include the impact, effectiveness, benefits, challenges, or perceptions of using VR in dental education and practice in Saudi Arabia.

2.2. Eligibility criteria

Eligibility criteria included primary research studies focusing on dental students, educators, and practitioners in Saudi Arabia. Studies are needed to explore VR technology in dental education or practice, assessing learning outcomes, clinical skills development, patient outcomes, attitudes and perceptions towards VR, efficiency, and cost-effectiveness. Studies were excluded if they were conducted outside of Saudi Arabia, did not focus on dental education or practice, did not involve VR technology, lacked sufficient data or methodology, or were opinion pieces, editorials, or conference abstracts.

2.3. Database search, screening process, and data extraction

The databases searched included PubMed, Web of Science, and Scopus. The search strategy focused on MeSH keywords associated with dental education and practice, including terms such as (Virtual Reality OR virtual simulator OR VR OR Simulator OR Simulation) AND (Dental Education OR Dental OR dental training OR Dental Care OR dental practice OR Dentistry) AND (Saudi Arabia OR SA OR KSA). Additional manual searches included bibliographies of relevant articles and reputable scholarly journals. A **supplementary Table 1 (available online)** summarizes the search terms used in each database searched.

Two reviewers (A.Y.A. and H.H.H.) independently screened the titles and abstracts of the identified papers based on predefined eligibility criteria—the second phase of screening involved full-text articles that were thoroughly reviewed. The reviewers reached a consensus on the selection of studies by resolving disagreements through detailed discussions. In cases where initial discussions did not lead to agreement, a third reviewer (S.B) was consulted to mediate and ensure a final decision was reached.

Data from the included studies were extracted using a standardized form, documenting details such as study ID, city, university (school), subjects (n), and VR systems and applications. Assessment content, method, outcomes, findings, and limitations were meticulously documented.

3. Results

3.1. Search results

An online database search identified 1460 studies; an additional 16 related studies were uncovered through other sources. The screening process narrowed these down to 21 relevant articles. Upon reviewing the full text of these articles, 11 studies (Ajaj et al., 2014, Farag and Hashem 2021, Felemban et al., 2021, Al Kheraif et al., 2023, Alabduljabbar et al., 2023, Almajed et al., 2023, Alsufyani et al., 2023, Bagher et al., 2023, Faden et al., 2023, Al-Gotaumel and Al-Madi 2024, Bakhaider et al., 2024) were determined to meet the criteria for inclusion in the review (Fig. 1).

3.2. Characteristics of included studies

Most studies published recently, 6 studies in 2023 (Al Kheraif et al., 2023, Alabduljabbar et al., 2023, Almajed et al., 2023, Alsufyani et al., 2023, Bagher et al., 2023, Faden et al., 2023), with one study published in 2014 (Ajaj et al., 2014), two in 2021(Farag and Hashem 2021, Felemban et al., 2021) and two in 2024 (Al-Gotaumel and Al-Madi 2024, Bakhaider et al., 2024). Five studies were conducted in Riyadh (Al Kheraif et al., 2023, Alabduljabbar et al., 2023, Alsufyani et al., 2023, Faden et al., 2023, Al-Gotaumel and Al-Madi 2024), 4 studies in Jeddah (Ajaj et al., 2014, Felemban et al., 2021, Bagher et al., 2023, Bakhaider et al., 2024), and one study each in Al Ahsa (Almajed et al., 2023) and Madinah (Farag and Hashem 2021). Among 11 included, 5 studies (Ajaj et al., 2014, Farag and Hashem 2021, Alsufyani et al., 2023, Faden et al., 2023, Al-Gotaumel and Al-Madi 2024) focused on the impact of VR on dental education, while six of the studies (Felemban et al., 2021, Al Kheraif et al., 2023, Alabduljabbar et al., 2023, Almajed et al., 2023, Bagher et al., 2023, Bakhaider et al., 2024) examined its impact on dental practice as illustrated in Figs. 2 and 3. The detailed characteristics

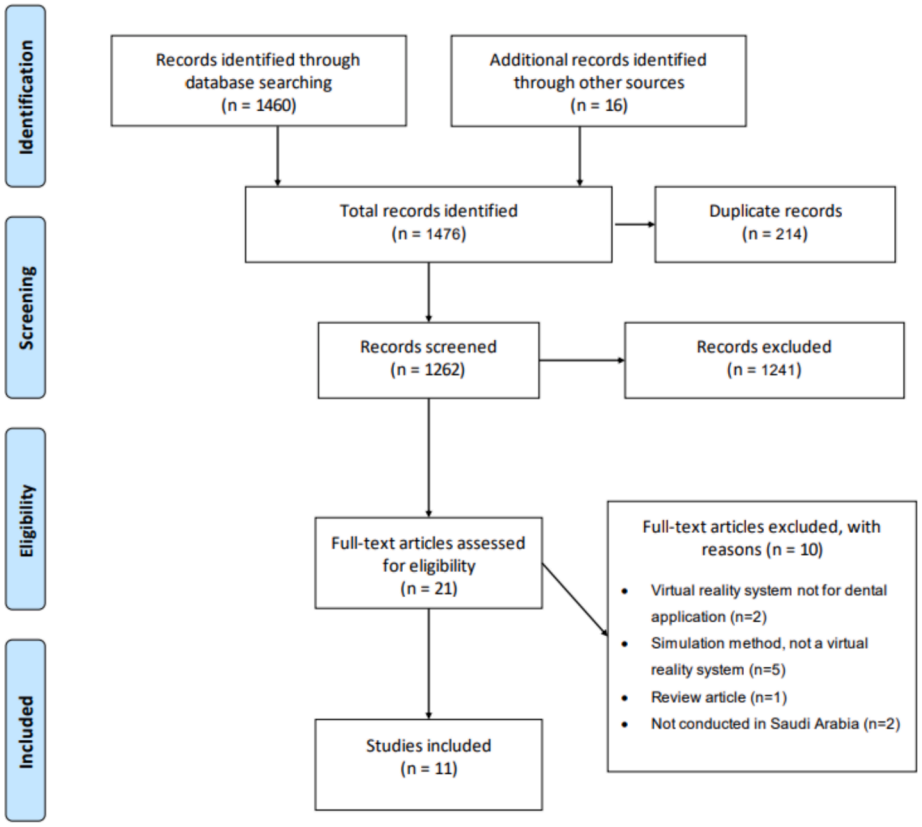

Fig. 1. PRISMA Flow Diagram for the scoping review process.

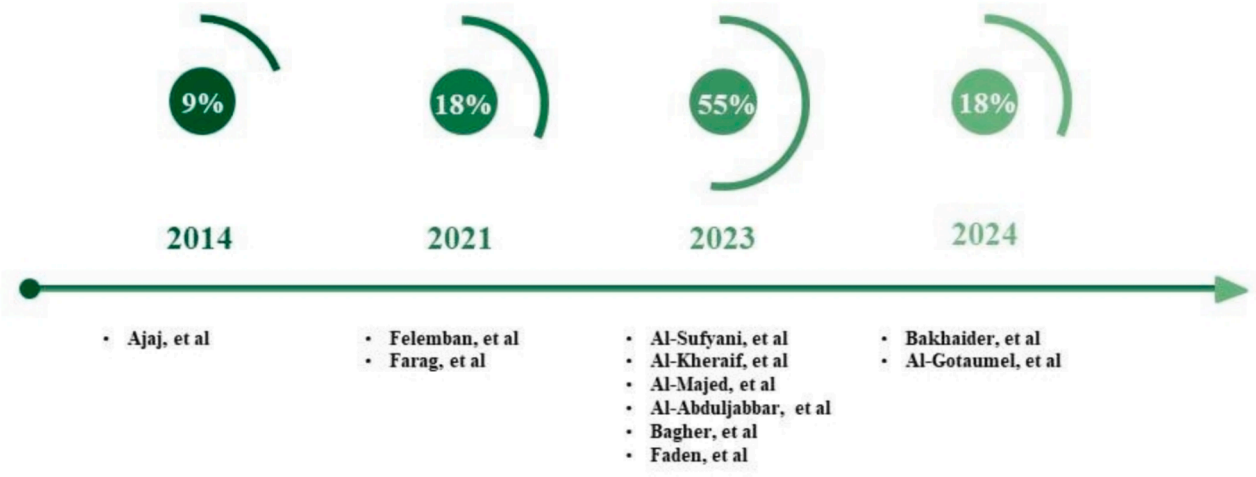

Fig. 2. Timeline of published research regarding dental VR application in Saudi Arabia.

of the included studies are presented in Table 1.

3.3. VR in dental education

Five studies evaluated the effectiveness of VR in enhancing dental education. Overall, the results were mixed regarding virtual reality's ability to improve learning outcomes compared to traditional teaching methods. Two studies assessed VR simulation training for cavity preparation skills. Ajaj et al., (2014) found no significant differences in skills after VR training, while Farag and Hashem (2021) observed improvements in psychomotor skills following VR use.

Regarding dental anatomy education, Alsufyani et al., (2023) found that lecture-based teaching yielded better quiz scores, but students had positive perceptions of VR. Similarly, Faden et al., (2023) found traditional lessons led to higher quiz performance, though students felt VR enhanced learning. The study by Al-Gotaumel and Al-Madi (2024) used VR to deliver educational resources to 1285 students, finding it significantly improved oral health literacy and status versus conventional methods as measured by objective indices and evaluations.

3.4. VR in dental practice

Six studies evaluated the effectiveness of VR distraction in reducing anxiety and pain and improving cooperative behavior during dental

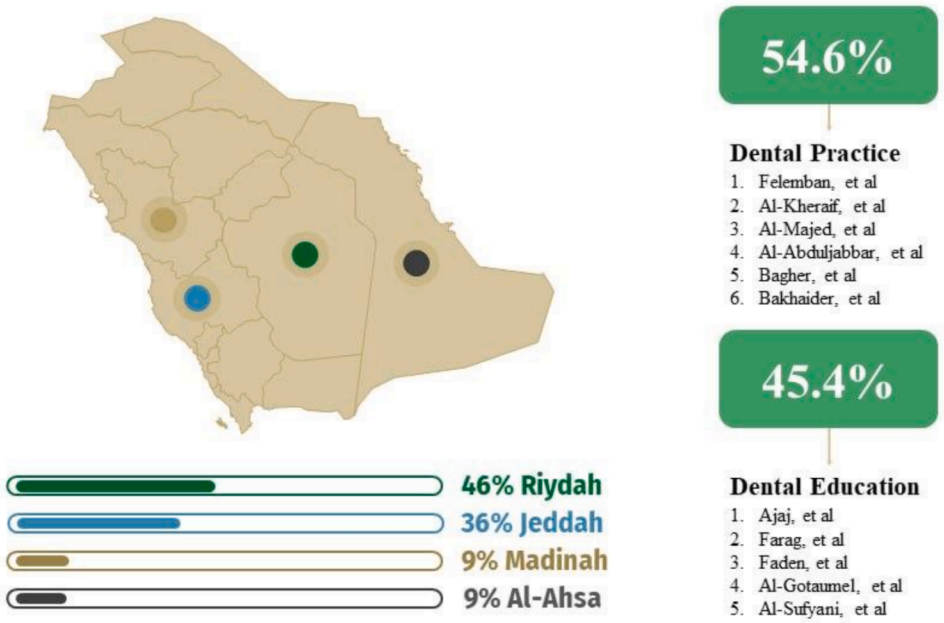

Fig. 3. Distribution of studies according to Saudi Arabia cities and virtual reality in dental education and practices.

procedures. The studies tested VR in populations ranging from healthy children to adults with disabilities. Two studies by Felemban et al., (2021) and Bagher et al., (2023) found that using VR headsets during local anesthesia administration had a similar impact on anxiety scales and heart rate as traditional screen distraction methods. However, Bagher et al., (2023) observed significantly lower cortisol levels post-procedure in the VR group, indicating less stress. Both studies incorporated physiological monitoring and standardized anxiety measurements but had limitations such as small sample sizes of only 25–36 subjects each.

Al Kheraif et al., (2023) utilized VR simulation via Oculus Quest headsets combined with AI to familiarize adults with intellectual disabilities undergoing basic dental treatments in a rehabilitation facility. The study demonstrated that VR and AI significantly reduced anxiety levels and improved cooperation through objective galvanic skin response testing and subjective behavior rating scales administered before and after treatments. However, the single-site study involved a relatively small sample of 90 individuals. In contrast, Almajed et al., (2023) found no significant differences in standard measures of anxiety, pain, heart rate, or oxygen levels when comparing 4–6-year-old children who did or did not use VR glasses during dental treatments. The lack of observed benefit may be attributed to limitations such as only including a small set of 20 children from one clinic or the young age range studied.

Two studies investigated VR applications specifically designed for dental anxiety reduction. Alabduljabbar et al., (2023) created an integrated VR/AR system that virtually recreated a clinic and educated children about dental tools and hygiene via interactive stories. User testing supported its usability and engagement, and pre-/post-consultation anxiety surveys showed significantly lower scores afterward in the 16-child sample. Finally, Bakhaider et al., (2024) study of 40 children found VR significantly diminished pulse rate and self-reported pain levels during local anesthesia administration versus no VR. However, it measured only short-term impacts and excluded some child behaviors from the analysis.

4. Discussion

This scoping review aimed to evaluate the existing state of VR implementation in dental practices and education in Saudi Arabia while emphasizing both the advantages and challenges linked with VR applications. Moreover, strategic courses of action were proposed to guarantee effective utilization in alignment with the healthcare objectives delineated in Saudi Arabia's Vision 2030. The findings of this scoping review revealed the potential of VR to improve learning outcomes compared to traditional teaching methods. Additionally, the effects of VR on pain, anxiety, and cooperation during dental treatments were examined in six research papers, and the results were deemed promising.

4.1. VR applications in dental education

VR has been examined in Saudi Arabia to assess its potential in evaluating the effectiveness of VR in only 3 educational domains that include the enhancement of cavity preparation skills, dental anatomy education, and overall oral health literacy as presented in result section. This reveal a relatively low research activity in comparison to the global research conducted in this field. Globally, there is an increasing trend of integrating VR into dental education (Dzyuba et al., 2022, Koolivand et al., 2024). In contrast to limited VR applications in dental education in Saudi Arabia, VR applications in dentistry vary widely from one field to another (Mai et al., 2024). A systematic review in prosthodontics reported that using VR in prosthodontic education might improve students' learning outcomes (Mai et al., 2024). Two studies found that VR successfully increased the realism of drilling sensations in the context of full-crown preparation, resulting in a notable improvement in shoulder preparation (Zuo, 2021, Wang, 2022). In periodontology, Zhang et al. reported that a combination of VR and jaw models during periodontal pre-clinical training can help students develop professional skills and may improve their grades (Zhang et al., 2021). Also, some studies evaluated the impact of VR on endodontic access cavity preparations (Yuan et al., 2021, Ba-Hattab et al., 2023). Moreover, VR systems appear to be beneficial for postgraduate dentistry education, usually because of their immersive qualities (Pulijala et al., 2018). For example, the VR surgery training system greatly increased the self-confidence of inexperienced surgical residents compared to the control group (Moro et al., 2017, Kim et al., 2019). Monaghesh et al. reported that VR is an effective method for teaching and planning the implant process (Monaghesh et al., 2023). Also, several studies have supported the use of VR in teaching about anesthesia injection (Correa et al., 2017, Mladenovic et al., 2019).

Table 1
Characteristics of included studies.

Study ID	City	University	Subjects (n)	Virtual reality Systems	Virtual reality applications	Assessment content	Assessment methods	Outcomes
Ajaj et al., (2014)	Jeddah	King Abdulaziz University, Faculty of Dentistry	Dental students and interns in King Abdulaziz University (41)	Simodont® Dental Trainer	Class I cavity preparation on a lower second molar plastic tooth	- Computerized dental simulators was employed to train students and interns in cavity preparation skills. - Participants were divided into test and control groups, received baseline assessments, underwent training on simulators, and were assessed again based on a detailed rubric.	- All groups received baseline and final assessments of a class I cavity preparation on a manikin. - Testing groups trained on a computerized dental simulator until achieving target scores, which were recorded. - Participants were evaluated using a detailed rubric by two examiners. Statistical analysis compared mean scores between groups. - A survey collected feedback from testing groups on their experience with the simulator.	- The study found no statistically significant improvement in cavity preparation skills among students.
Farag and Hashem (2021)	Madinah	Taibah University, College of Dentistry,	Novice dental students (21)	HVRS Simodont	Class I amalgam cavity preparations	- Before and after four weeks of haptic virtual reality simulator training on Simodont dental trainer, 21 dental students' Class I cavity preparations on plastic teeth were assessed twice based on 16 criteria by two calibrated evaluators and total marks, while timing the procedures.	- Two external calibrated evaluators independently assessed the cavity preparations performed by students on plastic teeth before and after training based on predefined criteria. - The assessment took into account factors like cavity design, features, duration and total scores.	- Evaluate the effect of haptic virtual reality simulation (HVRS) training on dental students' psychomotor skills for preclinical cavity preparations. - The primary outcomes assessed were changes in students' performance scores, timing, and technical quality when conducting Class I amalgam cavity preparations after exposure to HVRS training versus before.
Felemban et al., (2021)	Jeddah	King Abdulaziz University, Faculty of Dentistry	Healthy and cooperative 6- to 12-year-old children, with no known allergy and/or sensitivity to local anesthesia who needed non-urgent dental treatment 50 subjects (25 in the test group and 25 in the control group)	LG 360 virtual reality headset, LG Electronics) connected to a mobile phone.	virtual reality distraction technique to divert the patient's attention from the local anesthesia administration process.	Two assessment scales: FLACC behavioral pain assessment scale. Wong–Baker FACES pain rating scale.	- Pulse oximeter was used to record subjects' heart rates at five time points. The two assessment scales were used to evaluate pain and anxiety levels.	- Evaluate the effect of virtual reality distraction on anxiety and pain during buccal infiltration anesthesia in pediatric patients.

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Table 1 (*continued*)

Study ID	City	University	Subjects (n)	Virtual reality Systems	Virtual reality applications	Assessment content	Assessment methods	Outcomes
Al Kheraif et al., (2023)	Riyadh	female rehabilitation center in Diriyah	Saudi female residents in a female rehabilitation center (90)	Oculus Quest 2	Anxiety and Behavior	Anxiety levels measurements: Galvanic skin response (GSR) sensor behavioral responses Venham Anxiety and Behavior Scale Frankl Behavior Rating Scale	- Galvanic skin response sensor objectively measured changes in electrodermal activity pre, during and post-treatment as an indication of anxiety levels. Trained practitioners subjectively rated participants' behaviors and anxiety before and after using the Venham and Frankl scales to evaluate the impact of VR and AI distraction on anxiety and cooperation.	- Virtual Reality and Artificial Intelligence significantly reduced anxiety and improved behavior in individuals with mental disabilities undergoing dental treatments.
Almajed et al., (2023)	Al Ahsa	King Faisal University, Al Ahsa, Kingdom of Saudi Arabia	4–6 Year old Children (20)	VR Box VR Headset	Anxiety and Behavior	Anxiety and Behavior: Sound-Eye-Motor (SEM) Scaleulse rate and oxygen saturation levels (SpO2) Venham's Picture Test (VPT) Frankl's Behavior Rating Scale (FBRS)	- Sound-eye-motor (SEM) scores, pulse rate, oxygen saturation levels, Venham's Picture Test (VPT) scores, and Frankl's Behavior Rating Scale (FBRS) were assessed before and after the dental procedures. Statistical tests like ANOVA, Tukey's post hoc, and paired *t*-test were used to compare the scores and levels within and between the control and experimental groups, with and without the use of virtual reality glasses during treatment.	- The primary outcome measured was the effectiveness of VR in reducing anxiety and pain in children aged 4–6 years during dental procedures. Secondary outcomes included comparing children's anxiety levels with and without VR and assessing vital parameters (SEM scores, pulse rate, oxygen saturation).
Alabduljabbar et al., (2023)	Riyadh	King Saud University, College of Computer and Information Sciences	Children (16)	The system comprises three primary components: a 360-degree VR video that replicates a dental clinic environment, educational descriptions of dental tools using AR technology, and interactive stories aimed at educating children about dental hygiene.	Anxiety and Behavior	- Validated Child Fear Survey Schedule. Dental Subscale questionnaire to measure anxiety levels.	- The effectiveness of the proposed system was evaluated: unit and integration testing to check functionality, performance testing to measure response time, user acceptance testing with children, and the validated Child Fear Survey Schedule-Dental Subscale questionnaire to measure anxiety levels before and after use.	- The proposed VR and AR-based dental anxiety application was found to be easy to use, engaging, and effective in decreasing negative emotions in children visiting the clinic, according to user testing. A feasibility study also demonstrated the system helped significantly reduce anxiety levels in children after dental consultation compared to conventional methods.
Bagher et al., (2023)	Jeddah	King Abdulaziz University,	Healthy and anxious	(LG) 360 virtual reality headset	Anxiety and Behavior	- Modified Abeer Children Dental	- Participants were evaluated before	- Changes in children's anxiety

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Table 1 (*continued*)

Study ID	City	University	Subjects (n)	Virtual reality Systems	Virtual reality applications	Assessment content	Assessment methods	Outcomes
		Faculty of Dentistry	children aged 6 to 14 years (36)			Anxiety Scale. Venham Anxiety Behavioral Rating Scale. Heart rate recording. Salivary cortisol level measurement before and after prophylactic dental treatment.	and after treatment using subjective and objective measures. Subjectively, anxiety was assessed using a behavior rating scale and previously validated dental anxiety questionnaire. Objectively, heart rate and salivary cortisol levels were measured as physiological indicators of anxiety. Statistical analysis compared these measures between the virtual reality and control groups.	levels were measured by subjective (Venham Anxiety and Behavioral Rating Scale scores) and objective (heart rate and salivary cortisol level) measures before and after prophylactic dental treatment with or without virtual reality distraction.
Alsufyani et al., (2023)	Riyadh	King Saud University, College of Dentistry	First-year students in the College of Dentistry at King Saud University (69)	Oculus Quest 2	learning and interpretation of panoramic radiographic anatomy among dental students	- Control (lecture-based) and experimental (VR) groups. A 20-question quiz and online survey were used to assess knowledge and feedback from the students.	- Valuated students with an identical 20-question multiple choice quiz after VR or lecture instruction to compare knowledge retention. A survey also assessed VR students' perceptions. Responses were statistically analyzed, and the identification proportions between the structures between groups were compared. An oral radiologist developed the assessment tools, and two evaluators independently scored participants' performance in identifying anatomical landmarks.	- Changes in students' knowledge and perception were assessed when identifying anatomical structures on panoramic radiographs after exposure to a virtual reality simulation versus a lecture.
Faden et al., (2023)	Riyadh	Dental College, King Saud University, Riyadh	first-year dental 69 students were divided into a control group and an experimental group	VR interactive software viewed using VR headsets	dental radiographic anatomical interpretation in dental education	- Online quiz: this was used as the main assessment tool to compare learning outcomes between the control and experimental groups. It consisted of identifying various anatomical landmarks on dental panoramic radiographs.	- Online quiz: This was used as the main assessment tool to compare learning outcomes between the control and experimental groups. It consisted of identifying various anatomical landmarks on dental panoramic radiographs. Subjective student perceptions survey: In addition to the	- Key outcomes showed VR was perceived positively by students but did not lead to superior quiz performance over traditional teaching based on this initial assessment. Student feedback suggested VR enhanced the learning process.

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Table 1 (*continued*)

Study ID	City	University	Subjects (n)	Virtual reality Systems	Virtual reality applications	Assessment content	Assessment methods	Outcomes
							quiz, students in the experimental VR group were asked to provide feedback on 15 statements to assess their perceptions of the VR learning experience.	
Al-Gotaumel and Al-Madi (2024)	Riyadh	Schools in Riyadh city, Ministry of Education. It involved 10 schools total (5 boys schools and 5 girls schools)	1285 students across 10 schools aged 10–18 years	A custom-built virtual reality platform/ infrastructure designed specifically for the study (custom VR platform using VR glasses and the Unity engine delivered engaging and interactive dental education simulations and resources to the students)	Oral Health	- Plaque Index: measured plaque accumulation levels on teeth. Brushing Technique: evaluated correctness of technique, areas brushed, use of auxiliary tools, etc. Dental Health Literacy: Causes of caries Correct brushing method Best brush type Key areas to brush Use of auxiliary tools Benefits of dental floss Main factors for oral problems Reasons for visiting the dentist	- Plaque Index Scoring: Plaque accumulation was objectively measured using the validated Silness-Löe plaque index scale at baseline and follow-up. Brushing Technique Evaluation: A qualitative observation and checklist evaluation of students' daily brushing skills was conducted. Questionnaire: Self-administered questionnaires assessed dental health literacy levels both before and after the interventions.	- The study found that after 1 month, students who received virtual reality dental education demonstrated significantly greater reductions in plaque index scores and percentage compared to baseline, indicating less plaque accumulation. Their brushing technique scores also improved markedly, showing enhanced skills. Statistical analysis confirmed the improvements in these three oral health measures between pre and post-for the VR group were highly significant. Additionally, dental health literacy levels increased more for those taught with VR versus traditional methods.
Bakhaider et al., (2024)	Jeddah	Dentistry Program, Ibn Sina National College,	40 children aged 6–12 years.	(Samsung VR headset) powered by a smartphone	Dental Pain in Children during Local Anesthesia Administration	- Oxygen saturation (SpO2) levels: measured preoperatively, during LA administration, and postoperatively. Pulse rate (PR): measured at the same three time points as SpO2. Anxiety/pain rating: Participants were asked to rate their perceived pain using the Wong-Baker Pain Scale, both preoperatively and during LA administration.	- Oxygen saturation levels (SpO2) and pulse rate (PR) were monitored and measured using a pulse oximeter. Participants' perceived anxiety/ pain levels were assessed using the Wong Baker Pain Scale, which is a self-reported face scale commonly used to evaluate pain in pediatric patients. Participants' preoperative anxiety level was assessed using a self-reported	- Use of virtual reality was found to significantly reduce pulse rate and perceived pain levels during local anesthesia administration but did not considerably impact oxygen saturation levels or pre-procedure anxiety levels compared to the control group.

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Table 1 (*continued*)

Study ID	City	University	Subjects (n)	Virtual reality Systems	Virtual reality applications	Assessment content	Assessment methods	Outcomes
						Anxiety score: Participants self-reported their anxiety level pre-operatively using an unspecified anxiety scale.	anxiety scale, though the specific scale used is not mentioned. Data collected from the above measures were analyzed statistically using mean, standard deviation and *t*-test to compare the values between the study and control groups.	

4.2. VR applications in dental practice

In addition to its application in dental education, VR is being utilized in dental practice in Saudi Arabia to address three key issues: anxiety, pain management, and cooperative behavior during various dental procedures. Again, This indicates a comparatively lower level of research activity compared to the global efforts in this field. Globally, VR is also being utilized in the field of dental practice to address patient anxiety and pain effectively (Wiederhold et al., 2014). Comparable to the outcomes observed in Saudi Arabia, research conducted worldwide has presented a combination of results. Certain studies have demonstrated notable reductions in anxiety and pain levels, whereas others have indicated no significant variance when compared to traditional approaches (Wiederhold et al., 2014, Fan et al., 2023, Ghobadi et al., 2024). Generally, VR has been positively received by both children and adults, as it promotes patient engagement and cooperation during dental procedures (Sweta et al., 2019). Worldwide, VR and augmented reality advances are used in several domains of dentistry, such as oral and maxillofacial surgery, to help with surgical planning and performance (Stucki et al., 2024). In implantology, preoperative CBCT determines the dimensions, orientation, and distance of implants from important structures. Then, this information is transferred using static and dynamic guides to the surgical site. Dynamic navigation allows real-time feedback during implant placement (Hariharan 2021). Studies conducted by Ruppin and Kang revealed comparable accuracy between static and dynamic surgeries (Srinivasan and Basdogan 1997). However, dynamic surgery provides a direct view of the surgical field, overcoming some of the limitations of a static guide, such as the time needed for impressions and lab procedures (Hariharan 2021).

4.3. Limitations

The studies reviewed have limitations, including small sample sizes, short-term evaluations, single-site studies, and comparison of VR to teacher-centered rather than other active learning methods which can significantly impact their generalizability. The small sample sizes can lead to less reliable results, as they may not accurately represent the larger population. Short-term evaluations may fail to capture long-term effects or trends. Single-site studies limit the diversity of participants and environmental factors, reducing the ability to apply findings broadly. Together, these limitations can skew results and hinder the applicability of the research to different contexts or populations.

One potential limitation of this scoping review is the absence of a rigorous evaluation of the incorporated studies, which might impact the interpretation of the results. However, this study, conducted as a scoping review rather than a systematic review, will not include a critical evaluation phase for the included studies, as scoping reviews do not comprehensively examine each study against specific inclusion criteria.

4.4. Recommendations

VR has the potential to revolutionize dentistry by enhancing patient care, education, and training. To ensure the maximum utilization of VR applications in dentistry at a national level, the following recommendations are proposed:

- Firstly, it is advisable to incorporate VR integration into routine dental practice and educational curricula. This integration will provide immersive and interactive experiences that can alleviate patient anxiety and pain and enhance student learning. By integrating VR with traditional methods, engagement can be optimized and educational outcomes can be improved.
- Dental professionals and educators should receive training on effectively using VR technologies. This training will enable them to fully exploit the potential benefits of VR in their respective fields.
- Researchers should prioritize expanding research initiatives in diverse locations and populations throughout Saudi Arabia. Large-scale, long-term studies should be conducted to evaluate the effectiveness of VR in different populations and settings. To achieve this, multi-institutional collaborations should be established to diversify study participants, minimize biases, and strengthen the validity of the findings.
- Furthermore, VR should be utilized for public health education to enhance oral health literacy and awareness, especially among children and individuals with disabilities.
- Policymakers should prioritize investing in VR technology, training, and infrastructure to implement VR in dental practice and education effectively.

These recommendations align with Saudi Arabia's Vision 2030 goals to modernize healthcare and education by incorporating innovative technologies to enhance results. Integrating VR in dental practice and education aligns with this vision, as it promotes advanced solutions that improve patient care and learning experiences (Mani and Goniewicz 2024). By embracing VR, Saudi Arabia can elevate the quality of dental care and education, ensuring that patients receive contemporary and comprehensive treatment and that students engage in interactive and immersive learning environments. Moreover, VR can contribute to public health initiatives, enhancing oral health literacy and outcomes. The adoption of VR not only aligns with the goals of Vision 2030 to modernize healthcare and education and establishes Saudi Arabia as a frontrunner in implementing state-of-the-art technologies.

5. Conclusions

Based on the included studies reviewed, the following conclusions can be drawn:

1. Most studies were conducted in Riyadh and Jeddah, indicating a need for broader research across Saudi Arabia to ensure diverse representation.
2. Five studies on VR in dental education showed mixed results. While some studies found no significant skill improvement, others noted enhanced psychomotor skills and oral health literacy. Students generally perceived VR positively, suggesting it enhances engagement and learning experiences even if it doesn't always outperform traditional methods.
3. Six studies examined VR's role in reducing anxiety and pain and improving cooperation during dental procedures. Results were mixed, but VR was particularly effective in specialized applications, such as helping adults with intellectual disabilities.
4. VR technology benefits student engagement-specific psychomotor skills and reduces anxiety and stress during dental procedures. Positive feedback from students and patients highlights VR's role in improving overall experiences in dental education and practice.
5. To enhance VR applications in dentistry nationwide, research should expand across Saudi Arabia, improve design with larger sample sizes and multi-institutional collaborations, focus on promising areas like psychomotor skills and anxiety reduction, integrate VR with traditional methods, and receive policy and funding support to achieve Vision 2030′s healthcare goals.

Ethical Approval.

Since the present study is a scoping review, we did not collect primary data from human participants. Therefore, ethical approval was not required.

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CRediT authorship contribution statement

Ahmed Yaseen Alqutaibi: Conceptualization, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Hatem Hazzaa Hamadallah:** Conceptualization, Data curation, Methodology, Writing – original draft. **Harith Fahad Oqbi:** Conceptualization, Data curation, Methodology, Writing – original draft. **Sarah A. Almuzaini:** Conceptualization, Data curation, Methodology, Writing – original draft. **Sary Borzangy:** Conceptualization, Data curation, Methodology, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sdentj.2024.09.007.

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