Review Article

DOI: 10.7860/JCDR/2024/67356.19008

Augmented Reality in Dental Implants: A Systematic Review

Dentistry Section

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ABSTRACT

Introduction: Augmented Reality (AR) in dentistry has evolved from computer-generated images overlaying the real world, stemming from advancements in software-based Virtual Reality (VR) for anatomic exploration. AR applications in dentistry range from simulations aiding in training to enhancing precision in dental procedures. By overlaying digital information onto the physical environment, AR facilitates better visualisation of dental anatomy and treatment planning. Its integration has shown promise in reducing errors, improving patient outcomes, and augmenting dental education through immersive experiences.

Aim: To evaluate AR's application in dentistry, with a particular emphasis on dental implants.

Materials and Methods: A systematic review, using the Problem/patient Intervention Control or comparison Outcome (PICO) framework, selected six articles focusing on challenges in dentistry, specifically in training, practicing complex procedures accurately in implants, and maintaining patient confidentiality. The intervention compared AR with traditional methods.

Results: The AR was mostly used in precision dentistry operations. Notably, it was discovered that three-dimensional (3D) AR outperformed two-dimensional (2D) image navigation techniques, resulting in fewer implant location errors. The highest absolute effect was 24.3%, with the angle of implant errors showing a reduction of 9.5% using AR.

Conclusion: The findings support AR's role in enhancing accuracy and efficiency while maintaining patient confidentiality.

Keywords: Computer-assisted therapy, Dental health services, Dentistry, Error reduction, Patient care management, Professional education, Simulation studies, Training programmes, Technological innovations, Use of augmented reality in dental education

INTRODUCTION

The AR is a game-changing technology that seamlessly blends computer-generated graphics into physical settings to enhance perception through digital components [1]. Having its roots in VR technology, AR has found applications in various industries. However, dentistry stands out as an industry where it's potential to significantly improve oral health outcomes is increasingly recognised [1].

The widespread use of traditional fixed 2D monitors in healthcare procedures, particularly in dentistry, leads to numerous complications such as misalignment with the surgical field, restricted perspective, spatial constraints, poor depth perception, communication difficulties, reliance on the operator's point of view, and challenges with training and instruction. These difficulties stem from the different orientations of the surgical field and the monitors, necessitating creative solutions [2]. AR addresses this issue in dentistry, providing medical professionals, especially dentists, with the ability to visualise digital information related to their patients. This capability is crucial for overcoming conventional limitations and enhancing healthcare outcomes [2]. Given global concerns about the economic and social costs of poor oral health, there is a growing focus on leveraging cutting-edge technologies to improve dental care [3,4]. This study aims to explore the potential of AR systems in addressing issues specific to dental implants.

The diverse applications of AR technology in dentistry illustrate its versatility. AR proves valuable in dental restoration and training for maxillofacial procedures, spanning accurate treatment planning to support surgical interventions [5,6]. AR's multifaceted features, including recognition, projection, superimposition, and outlining, facilitate precise procedure planning. Moreover, these features represent a significant advancement in patient-centered care by providing patients with visual insights into various treatment options [6,7].

Educators justify the application of AR in dentistry by emphasising its potential to enhance surgical precision, subsequently leading to improved patient outcomes and experiences [8,9]. The unique characteristics of AR, such as identification and superimposition, are crucial for enhancing surgical precision. AR is vital for refining operative dentistry skills in dental education. By offering students realistic simulations for essential training in dental procedures, AR enhances learning and ensures that future dental healthcare professionals acquire the necessary practical skills [8,10].

The use of AR in maxillofacial surgery allows physicians to predict surgical outcomes by leveraging its capabilities. AR helps improve precision in maxillofacial treatments by providing a visual representation of soft tissues or bone features [11-13]. AR-enabled precision training becomes crucial for dental implant treatments. Apart from benefiting practitioners, ensuring precise placement and minimal invasion during these procedures also significantly enhances patient outcomes [14,15].

While AR holds the potential to revolutionise dentistry, issues such as data security and privacy must be acknowledged and resolved. As the use of AR in dental practices advances, these factors become increasingly important.

OBJECTIVE OF THE STUDY

The purpose of this systematic study was to present an overview and to evaluate AR's application in dentistry, with a specific emphasis on dental implants. This work aims to provide crucial insights into the changing landscape of dental healthcare by recognising the revolutionary applications of AR in oral care, understanding the associated challenges, and evaluating how it impacts treatment protocols and patient outcomes.

(a) Evaluate the Effectiveness of AR in Dentistry:

- Conduct a thorough evaluation of AR technology's efficacy in the dental industry.
- Examine different uses, features, and applications of AR systems, with a focus on dental implants.
- Provide a comprehensive assessment of how AR improves dental procedure execution, treatment planning, and diagnostics.
- Highlight how AR has the potential to significantly enhance dental care procedures.

(b) Examine the Broader Impact of AR in Dentistry:

- Gain a comprehensive understanding of the broader effects of AR in the field of dentistry.
- Examine the various ways that AR impacts dentistry practices, teaching strategies, patient outcomes, and healthcare provision.
- Investigate how AR affects a variety of factors, including accuracy, effectiveness, and overall patient satisfaction.

With a focus on dental implants, the study aims to conduct a thorough investigation and analysis of AR integration in dentistry by addressing these goals. The simultaneous focus on efficacy and broader impact ensures a comprehensive understanding of how AR technology can improve dental care procedures while upholding ethical norms and confidentiality protocols.

MATERIALS AND METHODS

The integration of AR systems in dentistry was thoroughly investigated using a systematic review methodology. This method provides a comprehensive and objective summary by synthesising findings from multiple research papers. To combine and assess data from disparate studies, the review employed a quantitative approach, allowing for more reliable and definitive results. This review included articles published between January 2016 and February 2022.

Research questions: The study aimed to address the following research questions:

- How well does AR technology perform in terms of enhancing the planning, execution, and diagnostics of dental procedures?
- What are AR's wider implications for dentistry in terms of how it affects dental practices, education, patient outcomes, and the provision of care as a whole?

PICOS Questions:

- Problem/patient: Training and practice in dentistry to perform complex procedures with accuracy and efficiency while maintaining patient confidentiality in line with World Health Organisation (WHO) confidentiality principles.
- Intervention: The use of AR technology in dental practice or education, including but not limited to virtual simulations, haptic feedback, and 3D modeling.
- Control or comparison: The use of traditional dental practice or education methods without AR technology.
- Outcome: The effectiveness and efficiency of AR technology in improving dental practice or education, as measured by factors such as accuracy of procedures, the time required for operations, and patient satisfaction.

Search strategy: An extensive literature search was conducted using a set of essential search phrases such as "Dentistry," "Augmented Reality," "use of AR in education," "Use of AR in dentistry practice," "Oral care," "Dental surgery," "Professional education," and "Simulation studies." Boolean operators (AND, OR, and NOT) were included in the search method to improve and refine search specificity. The Cochrane Library, SCOPUS, EMBASE, PubMed, and other major healthcare databases were thoroughly searched to ensure a comprehensive retrieval of relevant literature. Articles published between January 2016 and February 2022 was included in the search, in line with the study's timeframe. Inclusion and exclusion criteria based on the PICO framework were used to identify papers relevant to the specified research problem. Grey literature and the reference lists of the identified papers were additional resources incorporated into the search approach. In total, 589 papers were found through databases and 22 from other sources using this systematic approach, forming the basis for the systematic review.

Inclusion criteria:

- Articles discussing AR in dentistry.
- Papers released between January 2016 and February 2022.
- Publications written in English.
- Case studies, comparative studies, and randomised controlled trials.
- Study participants include dental healthcare professionals as well as undergraduate and graduate medical and dental students.

Exclusion criteria:

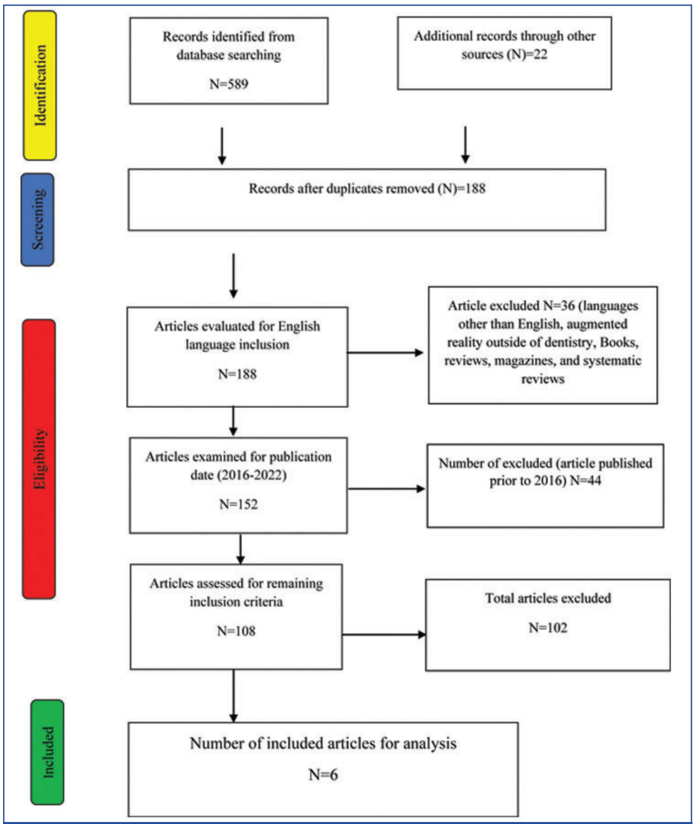
- Research works released prior to January 2016.
- Research that has been published in languages other than English.
- Studies on AR outside of dentistry.
- Books, reviews, magazines, and systematic reviews.

Data collection, extraction, and synthesis: The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was followed during the data extraction process. Study characteristics such as the nation, design, patient population, interventions, results, and adverse events were extracted. For a thorough examination, quantitative information such as means, confidence intervals, and standard deviations was compared. A total of 589 articles were found from the original database search, and an additional 22 articles were found from sources like reference lists and grey literature through the systematic literature search. The PRISMA checklist, a commonly used instrument for conducting systematic reviews, was then used to carefully evaluate and screen the papers that were found. The papers underwent a methodical reduction process culminating in a final selection of six studies, following a thorough examination of the checklist and strict adherence to the pre-established inclusion and exclusion criteria. [Table/Fig-1], which follows the PRISMA flowchart, provides a visual representation of this meticulous procedure by showing the methodical movement from the first search to the carefully chosen studies for the latter phases of analysis and synthesis.

Quality assessment: The selected papers were critically assessed to determine their validity, suitability for clinical practice, and risk of bias. To enhance the reliability of the review, the GRADE method was used to evaluate publication bias, inconsistency, imprecision, and indirectness.

Risk of bias assessment: A modified Newcastle-Ottawa Scale [16] was used to evaluate representativeness, sample size, non response rate, tool ascertainment, confounder investigation, blinding, and statistical testing in order to determine the risk of bias. The study quality was summarised by the ratings, which facilitated a methodical assessment of bias in several study parameters.

Data synthesis and analysis: The process of data analysis involved locating, evaluating, and comparing the key findings from selected publications. To illustrate the various effects of AR in dentistry, particularly in implant procedures, the results were categorised thematically. In comparison to conventional treatment methods, the Standardised Mean Difference (SMD) was computed for the selected trials to observe the significance of AR in absolute risk reduction during surgery.



[Table/Fig-1]: The PRISMA flowchart for the review.

RESULTS

Participants and setting: The six studies that were chosen featured a variety of participant groups, including patients, dentists using AR, dogs, specialists, and maxillofacial models [Table/Fig-2,3] [17-22]. The study locations included China, the Netherlands, Germany, Asia, and an undisclosed location. Jiang W et al., study [17] focused on the function of AR in dental implants, while other research [18,19] discussed enhanced dental and oral surgical techniques. Juan MC et al., investigation examined the usefulness of AR technology in dental student education [20].

Integration of AR in dentistry and confidentiality compliance: Based on observations from a subset of studies, it appears that AR is incorporated into conventional dental care systems using Clinical Management and Record-keeping Tools (CMRT) to improve precision in dental treatments such as implant insertion and reconstructions [17,18,21,22]. Notably, it was discovered that 3D AR outperformed 2D image navigation techniques, resulting in fewer implant location errors [17]. AR also made dental operation planning easier and helped with learning dental morphology, demonstrating its critical function in enhancing patient outcomes and minimising injury [19,20]. Using AR for dental treatment has been shown to significantly reduce treatment times in several studies. Glas HH et al., found that AR was 1.71 times faster than traditional approaches [18].

Stage of intervention: Instead of being used to diagnose the advancement of tooth disease, AR has primarily been utilised in precision dentistry operations. Although technology is a relatively new addition to dentistry, it is essential for improving accuracy. Research has shown how crucial it is to combine surgical instruments with 3D AR software, such as Microsoft HoloLens, to track the position of the patient and surgical instruments during operations and avoid the unintentional retention of foreign items [19,21].

Clinical context and ethical considerations: The six research studies underscored the adherence of AR technology integration to the data confidentiality rules set forth by the World Health Organisation (WHO). Consistently pursuing informed permission and ethical approval allowed for patient data collection to align with research goals [18,20,21]. In order to improve accuracy in dental implant procedures, AR integration was implemented with patient safety in mind for both dental training simulations and practice [17,19,22]. Obstacles were identified, including the operational complexity resulting from the inability to incorporate all surgical equipment into the AR system for tracking [19].

Study	Cohort name	Country	Study year	Type of study	Sample size	Study details	Conclusion
Jiang W et al., [17]	Rapid prototyping mandibular models	China	2018	A comparative-pre-post quantitative study	12 participants	Dental implant placement guided by the proposed 3D AR navigation approach depicted better applicability, accuracy, and higher efficiency than the traditional 2D image navigation approach	Improved applicability, accuracy, and efficiency seen in 3D AR navigation compared to 2D image navigation.
Glas HH et al., [18]	3D printed phantom	Netherlands	2021	A comparative-pre-post quantitative study	12 participants	Navigation tasks were 1.71 times faster using AR (p-value 0.034)., with improved accuracy (p-value <0.01)	AR navigation was significantly faster and more accurate than traditional methods.
Ochandiano S et al., [22]	Head and neck reconstructed oncologic patients	Spain	2021	A comparative-pre-post quantitative study	11 patients	Computer-aided implant surgery based on 3D printed surgical modified guides (AR), and dynamic navigation is a precise and valuable technique for implant placement that is prosthetically driven	AR-based dynamic navigation is a precise and valuable technique for prosthetically driven implant placement.
Kikovics M et al., [21]	3D-printed study models	Germany	2022	A comparative-pre-post quantitative study	48 implants	Implant positioning accuracy using AR-based dynamic navigation is comparable to static Computer Assisted Implant Surgery (CAIS) and better than the outcome of using a free-hand approach	AR-based dynamic navigation comparable to static CAIS, superior to free-hand approach for implant accuracy.
Hou Y et al., [19]	Beagle dogs	Asia	2022	A comparative-pre-post quantitative study	10 Beagle dogs	The accuracy of the AR-guided system can meet clinical requirements, and hence it's a possibly helpful tool to enhance the precision of craniomaxillofacial surgery	AR-guided system meets clinical requirements and can enhance precision in craniomaxillofacial surgery.
Juan MC et al., [20]	Undergraduate and master employees	Spain	2016	A comparative-pre-post quantitative study	38 undergraduates 6 masters 11 employees	No statistically significant difference exists between learning with mobile AR and video sessions	No significant difference between mobile AR and video sessions in the learning context.

[Table/Fig-2]: List of studies included in the review [17-22].

Author (publication year)	Selection				Comparability	Outcome		Quality score	Comment
	Representativeness of the cases	Sample size	Non response rate	Ascertainment of the screening/ surveillance tool	The potential confounders were investigated	Assessment of the outcome	Statistical test		
Kikovics M et al., (2022) [21]	Truly representative (random)*	Justified but not satisfactory*	The response rate is satisfactory (all sample analysed)*	Not validated but described*	The study not investigated potential confounders	Blinded and independent**	Described and appropriate*	Good quality	The study quality was good as the selection domain obtained four stars although the sample size was not satisfactory, they explained the reason in the limitation section. The overall points were 7 which referes to good quality.
Jiang W et al., (2018) [17]	No description	Not justified	All sample analysed*	Described but no information about validation*	The study not investigated potential confounders	Blinded and independent**	Described, appropriate*	Satisfactory quality	The overall quality was satisfactory (5 points) as no descriptions were found for sampling and representative of sample as well as potential confounders.
Juan MC et al., (2016) [20]	Selected group, non random	Not justified	All sample analysed*	Described but no information about validation*	The study not investigated potential confounders	Not validated questionnaire	Described, appropriate*	Unsatisfactory study	The overall quality was unsatisfactory (3 points) as no descriptions were found for sampling and representative of sample as well as potential confounders, and validation of the questionnaire used for assessment of participants knowledge.
Ochandiano S et al., (2022) [22]	No description of the derivation of included subjects	Not justified	One patient was excluded with justification for the reason*	Validated tool**	Data results not adjusted for confounders	Unblind, but with validated instrument**	Descriped, appropriate*	Satisfactory quality	The overall quality was satisfactory (6 points) as no descriptions were found for sampling and representative of sample as well as potential confounders.
Hou Y et al., (2022) [19]	Random sample*	Not justified	All sample analysed*	Described but no information about validation*	The results not investigated potential confounders	Unblind, but with validated instrument**	Described, appropriate*	Satisfactory quality	The overall quality was satisfactory (5 points) as no descriptions were found for representative of sample as well as potential confounders.
Glas HH et al., (2022) [18]	Selected group, non random	Not justified	No description	Described but no information about validation*	Data results not adjusted for confounders	Unblind, but with validated instrument**	Described, appropriate*	Unsatisfactory study	The overall quality was unsatisfactory (4 points) as no descriptions were found for sampling and representative of sample as well as potential confounders, and validation of the questionnaire used for assessment of participants knowledge.

[Table/Fig-3]: Assessment of risk of bias for the included studies [17-22]. *, ** [16]

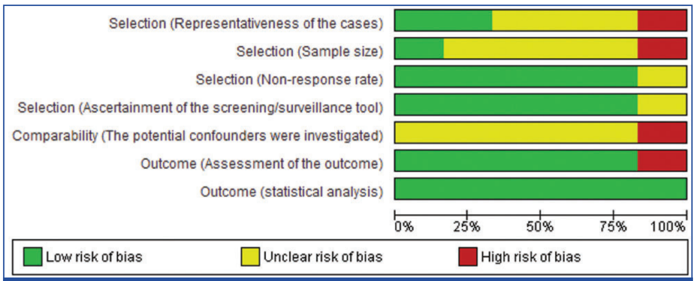
Impact of AR in dental implants: The selected publications have demonstrated how integrating AR significantly enhances dental teaching and oral care interventions. Using the SMD, errors between AR-guided and conventional dental care regimens were compared. The findings, presented in [Table/Fig-4] [17-22], indicate that AR notably contributed to a decrease in surgical and implant-related errors, particularly in terms of angle and implant errors. For instance, Jiang W et al., found that the implant error had an absolute effect size of 14% and a SMD of 0.416 [17]. Glas HH et al., reported a 9% absolute effect size with an SMD of 1.384 [18]. Research consistently demonstrates that the use of AR improves accuracy and precision in dental implant treatments. One potential development that has emerged is the integration of AR into dentistry, which has been shown to enhance efficiency and outcomes in various clinical settings.

Therefore, the results from the chosen papers highlight how AR is revolutionising dentistry, particularly in the context of dental implants. The system maintains confidentiality protocols and ethical considerations while enhancing process precision and reducing treatment times. The noted improvements in accuracy and error reduction demonstrate how AR can transform dental care procedures and enhance patient outcomes.

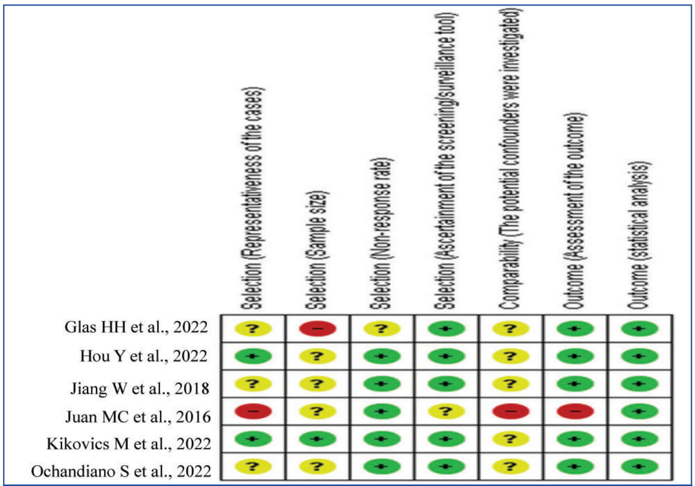
Risk of bias assessment: The risk of bias evaluation indicates that the included research varies in terms of study quality [Table/Fig-5,6] [17-22]. Jiang W et al., study in 2018 had a moderate risk of bias despite its good quality, as it lacks descriptions of potential confounders and sample [17]. In the study by Hou Y et al., a moderate risk of bias and satisfactory quality were depicted [19]. Due to missing descriptions for sampling, representativeness, and the validation of the assessment questionnaire, the research

Studies	Augmented Reality (AR) enabled	No Augmented Reality (AR) to guide surgery	Standard deviation	Mean effect difference	Sample size	Absolute effect size	SMD
Jiang W et al., (2018) [17]	0.99 (Implant error)	1.27 (Implant error)	0.673 (Implant error)	0.28	12	14%	0.416
	3.95 (Angle error)	4.92 (Angle error)	0.537 (Angle error)	0.97		48.5%	1.806
Glas HH et al., (2022) [18]	1.46 (Implant error)	2.54 (Implant error)	0.78 (Implant error)	1.08	12	9%	1.384
	Not measured (Angle error)	Not measured (Angle error)	Not measured (Angle error)				
Kikovics M et al., (2022) [21]	1.27 (Implant error)	1.31 (Implant error)	0.42 (Implant error)	0.04	48	0.08%	0.0952
	3.21 (Angle error)	4.09 (Angle error)	2.79 (Angle error)	0.88		1.8%	0.315
Hou Y et al., (2022) [19]	0.20 (Implant error)	0.26 (Implant error)	0.567 (Implant error)	0.06	10	0.6%	0.106
	0.66 (Angle error)	0.94 (Angle error)	0.97 (Angle error)	0.28		2.8%	0.289
Ochandiano S et al., (2022) [22]	1.27 (Implant error)	3.94 (Implant error)	0.238 (Implant error)	2.67	11	24.3%	11.218
	0.59 (Angle error)	1.64 (Angle error)	0.298 (Angle error)	1.05		9.5%	3.523
Juan MC et al., (2016) [20]	9.00 (Implant error)	9.60 (Implant error)	0.56 (Implant error)	0.6	38	1.6%	1.071
	7.54 (Angle error)	8.23 (Angle error)	0.72 (Angle error)	0.69		1.8%	0.958

[Table/Fig-4]: Implantation region error comparison based on the method of implantation [17-22].



[Table/Fig-5]: Graphical representation of risk of bias.



[Table/Fig-6]: Risk of bias of included studies.

by Glas HH et al., is seen as inadequate and shows a high-risk of bias [18].

DISCUSSION

In dentistry, AR has become a game-changing technology that offers creative ways to improve clinical processes, teaching, and general practice. This in-depth conversation explores the effects of AR in dentistry, based on a systematic review that includes studies covering efficiency improvements, educational applications, simulation training, and the decrease of errors in dental implant procedures. Through the synthesis of evidence from various sources, this discourse considers methodological issues, offers a comprehensive perspective of how AR is changing the dental care scene, and paves the path for future research in this rapidly evolving subject.

A consistent pattern across research is highlighted by the systematic review, which shows that AR considerably lowers mistakes in dental implant procedures [17,20,22]. Using AR-guided intraoperative positioning, Jiang W et al., claimed enhanced accuracy and efficiency in implant placements [17]. Additionally, Juan MC et al., and Ochandiano S et al., demonstrated how the accurate views provided by AR result in a significant reduction in surgical errors, highlighting the technology's potential to improve the efficacy and safety of dental implant surgeries [20,22].

The use of AR in dentistry has been linked to improved efficiency, increased skill learning, and a decrease in errors [18,19,21]. Faster task navigation during dental treatments using AR was demonstrated by Glas HH et al., and Kikovics M et al., highlighting a significant increase in efficiency [18,21]. Hou Y et al., shed light on how AR can provide real-time guidance while lowering operating time [19]. These results are consistent with observations made by Wagner A et al., indicating that AR helps to enhance navigation and results in an essential component of dental practice [11].

The systematic study highlights the importance of AR's involvement in simulation training and precision guidance [13-15,20]. Pinheiro TJ and Torres JP suggest a VR -based computer-guided approach for dental implant surgery, indicating the possibility of thorough simulation training [15]. Ohtani T et al., work emphasises the precision training opportunities provided by AR technology, with a particular focus on haptic devices in implant dentistry [14]. Another example of the many uses of AR in dentistry education is the mobile AR system developed by Juan MC et al., providing interactive and immersive learning environments [20].

Beyond clinical practice, AR has a significant impact on dental education [13-15,20,23]. The high-fidelity VR orthognathic surgery simulator developed by Arikatla VS et al., and the overview of AR research in education both demonstrate how AR might change the nature of education [13]. This is supported by Juan et al.'s mobile AR system for dental morphology, which offers a useful illustration of AR's impact on dental education [20]. These innovations have the potential to transform dental education and enhance teaching approaches.

The growing application of AR in dental operations is also discussed, along with the advancements in computer-mediated reality technology [23-25]. Smith JA approach for qualitative psychology provides insights into how AR is accepted and experienced by users in dentistry settings [26]. Ibrahim and Money's conceptual framework and Haji Z et al., investigation of AR in clinical dentistry education and training further contextualise the integration process, highlighting the necessity of practical and efficient AR applications [23,24].

The systematic review provides a thorough summary of the effects of AR in dentistry by synthesising data from several studies. AR appears to be a flexible technology with broad implications for dental practices, ranging from the elimination of errors in dental implant operations to the revolutionary possibilities in education. The discourse is further enhanced by methodological considerations and the investigation of computer-mediated reality frameworks, which open the door for future research initiatives in this quickly developing field.

Limitation(s)

The current study reveals significant benefits and provides insightful information about the use of AR in dentistry. However, there are some issues with the studies included in the review, most notably the small sample sizes, which could restrict how broadly the results can be applied. Further limiting external validity is the lack of regional variety, with an emphasis on Europe and Asia. Additionally, differences in study designs, sample sizes, and outcome measures complicate generalisability and comparability. Notwithstanding these drawbacks, the work makes a substantial contribution to our understanding of AR's function in dental treatment, highlighting the necessity of ongoing research to address these issues and obtain a more complete picture.

CONCLUSION(S)

The study concludes by highlighting the significant advantages of AR technology in dentistry, focusing on increased surgical precision and improved learning outcomes. To enhance the generalisability of results, future research should investigate broadening geographical representation, addressing differences in study designs, sample sizes, and outcome measures. Maximising the beneficial effects of AR on dental practice and education will also require ongoing research into the technology's potential uses, improvements in dental education, and efforts to overcome obstacles such as small sample sizes.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: Oct 26, 2023
- Manual Googling: Dec 06, 2023
- iThenticate Software: Dec 25, 2023 (8%)

ETYMOLOGY: Author Origin

EMENDATIONS: 6

AUTHOR DECLARATION:
- Financial or Other Competing Interests: Funded by Ministry of Higher Education through the Dental Simulation and Virtual Learning Research Excellence Consortium KKP Programme JPT(BPKI)1000/016/018/25 Jld. 2(2)
- Was informed consent obtained from the subjects involved in the study? NA
- For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: Oct 20, 2023
Date of Peer Review: Nov 14, 2023
Date of Acceptance: Dec 28, 2023
Date of Publishing: Jan 01, 2024