

Virtual reality and haptic simulation in preclinical dental education: a bibliometric analysis

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ABSTRACT

Aims: This study aimed to provide a bibliometric overview of research on virtual reality (VR) and haptic simulation in preclinical dental education, focusing on publication trends, research themes, international collaboration, and applications across dental disciplines.

Methods: Scopus was searched on July 13, 2026, for English-language original research articles involving dental students, VR or haptic simulation, and educational outcomes. Of 555 identified records, 176 met the eligibility criteria. Bibliometric indicators were analyzed using Microsoft Excel, and keyword co-occurrence, country-level co-authorship, and bibliographic coupling analyses were performed using VOSviewer.

Results: The 176 publications, published between 2003 and 2026, received 3.818 citations. More than half (54.5%) were published between 2024 and 2026, with the highest annual output in 2025. The Journal of Dental Education was the most productive journal. China had the highest publication output, whereas the United Kingdom had the highest total link strength in the country-level collaboration network. Keyword analysis showed a shift from skill acquisition and computer-assisted instruction toward more recent themes including preclinical training, virtual simulation, and haptic simulation. Restorative and operative dentistry was the most represented discipline (36.4%), followed by endodontics (15.9%) and oral surgery/implantology (15.3%).

Conclusion: Research on VR and haptic simulation in preclinical dental education has expanded considerably in recent years. The findings reveal evolving research themes, differences in international collaboration, and a concentration of research in disciplines requiring procedural and psychomotor skills. This overview may help identify less explored areas and guide future research in technology-supported dental education.

Keywords: Bibliometrics, dental education, simulation training, virtual reality, dental students

INTRODUCTION

Dental education requires students to develop a combination of theoretical knowledge, clinical reasoning, and fine psychomotor skills before providing patient care. This is particularly important during preclinical training, where students are expected to acquire manual skills and procedural competence within a controlled learning environment. Conventional simulation methods using phantom heads and typodont teeth have long formed the basis of this training. However, advances in digital technologies have introduced new educational approaches that can complement traditional methods and provide students with more interactive and standardized learning experiences.^{1,2}

Among these technologies, virtual reality (VR) and haptic simulation have gained increasing attention in dental education. VR-based environments can simulate clinical or preclinical procedures, while haptic systems add tactile and force feedback that more closely reproduces the sensory experience associated with manipulating dental tissues and instruments.^{3,4} These systems allow students to repeat

procedures in a controlled environment and may provide objective and immediate feedback on aspects of their performance. Their applications have consequently expanded beyond individual procedures to several areas of dental education, including restorative and operative dentistry, endodontics, prosthodontics, oral and maxillofacial surgery, and pediatric dentistry.^{5,6}

The growing interest in digital educational technologies is also reflected in the dental education literature. Recent bibliometric studies have identified virtual reality and educational technology among emerging areas of interest, suggesting an increasing shift toward digitally supported learning environments.^{7,8} Bibliometric analysis provides a quantitative approach for examining such developments by evaluating publication trends, citation patterns, research themes, and collaboration networks. It can therefore provide a broader perspective on how a research field has developed, identify influential contributions, and reveal emerging areas of scientific interest.⁹⁻¹¹

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Previous bibliometric studies have examined specific aspects of immersive and simulation-based technologies in dental education. Hsu and Chang² evaluated research on haptic and force-feedback technologies published between 2001 and 2022, whereas a more recent scientometric study focused specifically on global haptic simulation research between 2020 and 2025.^{2,12} Another bibliometric analysis examined VR applications specifically within restorative dentistry.³ Although these studies provide useful insights into particular technologies, periods, or dental disciplines, a broader bibliometric evaluation focusing specifically on the use of both VR and haptic simulation for preclinical dental education and skill development across dental disciplines remains limited.

Therefore, the present study aimed to provide a comprehensive bibliometric analysis of research on virtual reality and haptic simulation in preclinical dental education. Specifically, the study evaluated publication trends, leading journals and countries, citation patterns, international collaboration, keyword networks, bibliographic relationships, and the distribution of applications across dental disciplines. By mapping the development and current structure of this research field, the findings are intended to provide an overview of existing research patterns and identify areas that may guide future studies in technology-supported preclinical dental education.

METHODS

Ethics

This study was based exclusively on publicly available bibliographic data retrieved from the Scopus database and did not involve human participants, animals, identifiable personal data, or biological materials. Therefore, ethics committee approval and informed consent were not required. Scopus was selected as the data source because of its broad coverage of peer-reviewed literature and the availability of bibliographic and citation information suitable for bibliometric analysis. All procedures were carried out in accordance with the ethical rules and the principles.

Database and Search Strategy

The literature search was conducted on July 13, 2026 using the title, abstract, and keyword fields (TITLE-ABS-KEY) with the following search strategy:

TITLE-ABS-KEY [(“virtual reality” OR “virtual simulation” OR “haptic” OR “haptic simulation” OR “haptic feedback”) AND (“dental education” OR “preclinical dental education” OR “preclinical training” OR “dental student”)]

The initial search identified 555 records. After restricting the results to articles published in English, 392 records remained for screening. No subject-area restriction was applied because relevant studies on dental education may be published in multidisciplinary or medical education journals and could therefore be missed by limiting the search to the Dentistry subject area.

Eligibility Criteria and Study Selection

Original research articles were eligible if they investigated virtual reality or haptic simulation as an educational or training intervention involving dental students, addressed preclinical education or skills training, and evaluated at least one educational outcome. Studies focusing on student

performance, skill acquisition, procedural accuracy, learning effectiveness, or other training-related outcomes were considered within the scope of the analysis.

Reviews, bibliometric studies, editorials, opinion papers, and other non-original publications were excluded. Studies focusing on VR applications for patient treatment, patient management, or anxiety reduction were also excluded, as were technical development studies without educational evaluation involving dental students and publications unrelated to dental education.

The titles and abstracts of the 392 records were manually screened according to these predefined criteria. When eligibility could not be determined from the available information, the record was examined in greater detail. Following screening, 176 publications met the eligibility criteria and were included in the final bibliometric analysis.

Data Extraction and Bibliometric Analysis

Bibliographic data for the included publications were exported from Scopus in CSV format. The extracted information included authors, titles, publication years, source titles, affiliations, citation counts, keywords, and cited references. Microsoft Excel was used to organize the data and analyze annual publication output, citation patterns, leading journals, contributing countries, and highly cited publications.

Network analyses and scientific mapping were performed using VOSviewer (version 1.6.21). The analyses included keyword co-occurrence analysis, country-level co-authorship analysis, and document-level bibliographic coupling. Default counting methods were used for the respective analyses, with full counting applied where available.

For keyword co-occurrence analysis, author keywords occurring at least five times were included, and a thesaurus file was used to merge synonymous or closely related terms. For example, “VR” was merged with “virtual reality”, “haptic simulator” and “haptic technology” were merged under “haptic simulation”, and singular and plural forms (e.g., “dental student” and “dental students”) were unified before analysis. Country-level co-authorship analysis included countries with at least five publications. Bibliographic coupling was performed for documents with at least 10 citations, and the largest connected component was used to visualize the main intellectual structure of the field.

In the network visualizations, node size represented the weight of an item, while links and total link strength reflected the relationships and overall connectivity among items. Colors represented clusters of closely related items identified by the VOSviewer clustering algorithm.

Finally, the included publications were classified according to the primary dental discipline in which the virtual reality or haptic simulation application was used. Classification was based on the title, abstract, and keywords of each publication. Each study was assigned to a single primary category according to its main educational application. The categories included restorative/operative dentistry, endodontics, oral surgery/implantology, prosthodontics, pediatric dentistry, oral and maxillofacial radiology, periodontology, orthodontics, and general/multidisciplinary preclinical dental education.



RESULTS

Study Selection and Publication Trends

The initial Scopus search identified 555 records. After restricting the results to English-language articles, 392 publications remained and were screened according to the predefined eligibility criteria. Following the exclusion of 216 records that did not meet the inclusion criteria, 176 original research articles were included in the final bibliometric analysis.

The included publications covered the period from 2003 to 2026 and received a total of 3,818 citations, corresponding to an average of 21.69 citations per publication. The annual number of publications remained relatively low during the earlier years but increased markedly in recent years. The largest annual number of publications was recorded in 2025, with 45 publications (25.6%), while a further 32 articles (18.2%) had been published by July 13, 2026. Overall, 96 of the 176 publications (54.5%) were published between 2024 and 2026 (**Figure 1**).

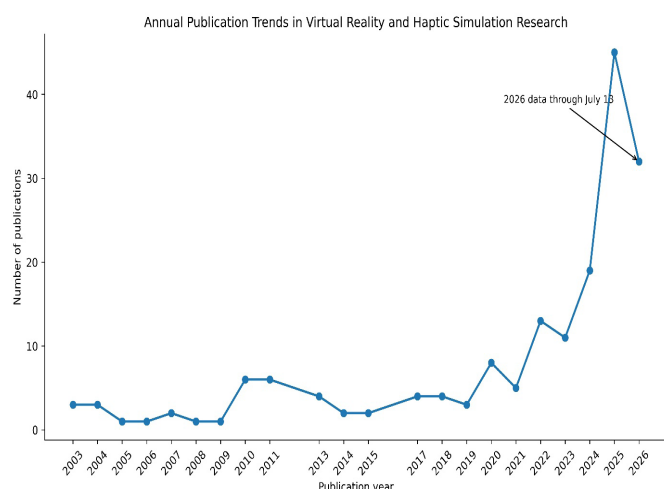


Figure 1. Annual publication trends in virtual reality and haptic simulation research in preclinical dental education from 2003 to 2026. Data for 2026 include publications indexed up to July 13, 2026

Leading Journals

The 176 publications were distributed across 59 journals. The Journal of Dental Education was the leading source, with 40 publications (22.7%) and 1,133 citations, followed by the European Journal of Dental Education with 26 publications (14.8%) and 778 citations, and BMC Medical Education with 23 publications (13.1%) and 272 citations. Together, these three journals accounted for 89 publications, representing 50.6% of the entire dataset. The International Endodontic Journal ranked fourth with eight publications, followed by Dentistry Journal with seven and BMC Oral Health with five publications. The number of publications and citation performance of the leading journals are presented in **Table 1**.

Leading Countries and International Collaboration

The included publications involved contributions from 55 countries. China was the most productive country, with 41 publications, followed by the United States with 24 and the United Kingdom with 18. Türkiye ranked fourth with 11 publications, while Germany, Saudi Arabia, Spain, and Thailand each contributed 10 publications.

Table 1. Publication output and citation performance of the leading journals in virtual reality and haptic simulation research in preclinical dental education

Rank	Journal	TP	TC	C/P
1	Journal of Dental Education	40	1,133	28.32
2	European Journal of Dental Education	26	778	29.92
3	BMC Medical Education	23	272	11.83
4	International Endodontic Journal	8	221	27.62
5	Dentistry Journal	7	64	9.14
6	BMC Oral Health	5	48	9.60
7	Journal of Dental Sciences	3	61	20.33
8	Virtual Reality	3	40	13.33
9	Frontiers in Oral Health	3	7	2.33
10	Artificial Intelligence in Medicine	2	105	52.50

TP: Total publications, TC: Total citations, C/P: Citations per publication

For the country-level co-authorship analysis, a minimum threshold of five publications per country was applied. Seventeen countries met this criterion, of which 16 formed the largest connected network. The network comprised three clusters, 60 links, and a total link strength of 83. The United Kingdom had the highest total link strength (TLS=24), followed by Australia and the United States (TLS=16 each). China had a TLS of 11, while Türkiye had a TLS of 5. The country-level co-authorship network is presented in **Figure 2**.

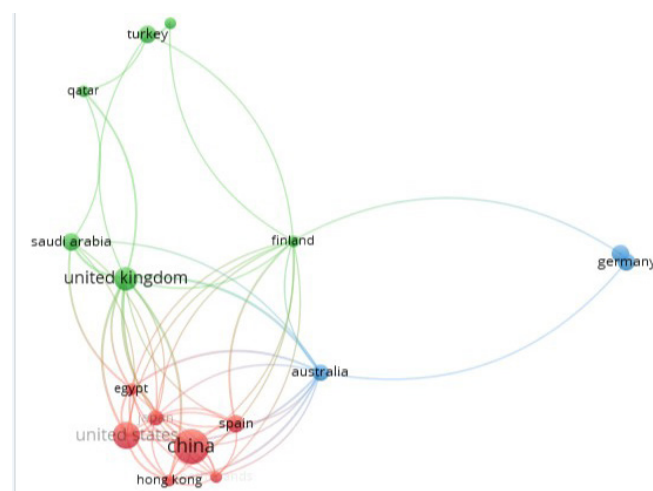


Figure 2. Network visualization of country-level co-authorship in virtual reality and haptic simulation research in preclinical dental education. Node size represents the number of publications, while links indicate co-authorship relationships between countries. Different colors represent clusters of closely connected countries

Most Cited Publications

The 10 most highly cited publications are presented in **Table 2**. The most cited study was “feedback and motor skill acquisition using a haptic dental simulator” by Al-Saud et al.,¹³ with 127 citations. This was followed by “an evaluation of two dental simulation systems: virtual reality versus contemporary non-computer-assisted” by Jasinevicius et al.,¹⁴ with 121 citations, and “evaluation of the introduction of a dental virtual simulator on the performance of undergraduate dental students in the pre-clinical operative dentistry course” by Murbay et al.,¹⁵ with 117 citations.



Table 2. Most cited publications in virtual reality and haptic simulation research in preclinical dental education

Rank	First author	Year	Article title	Journal	TC
1	Al-Saud ¹³	2017	Feedback and motor skill acquisition using a haptic dental simulator	European Journal of Dental Education	127
2	Jasinevicius ¹⁴	2004	An evaluation of two dental simulation systems: virtual reality versus contemporary non-computer-assisted	Journal of Dental Education	121
3	Murbay ¹⁵	2020	Evaluation of the introduction of a dental virtual simulator on the performance of undergraduate dental students in the pre-clinical operative dentistry course	European Journal of Dental Education	117
4	Buchanan ¹⁶	2004	Experience with virtual reality-based technology in teaching restorative dental procedures	Journal of Dental Education	112
5	LeBlanc ¹⁷	2004	A preliminary study in using virtual reality to train dental students	Journal of Dental Education	106

TC: Total citations

Keyword Co-occurrence Analysis

The keyword co-occurrence analysis identified 24 author keywords meeting the minimum threshold of five occurrences. The resulting network was organized into five clusters. Virtual reality was the most frequently occurring keyword (96 occurrences; TLS=181), followed by dental education (88 occurrences; TLS=167), haptics (21 occurrences; TLS=62), and simulation (18 occurrences; TLS=47). Other prominent terms included preclinical training (12 occurrences), virtual simulation (12 occurrences), and endodontics (11 occurrences). The relationships and clustering patterns among the author keywords are presented in **Figure 3A**.

The overlay visualization demonstrated differences in the average publication years of the identified keywords (**Figure 3B**). Earlier terms included skill acquisition (average publication year: 2008), computer-assisted instruction (2015), and computer simulation (2017), whereas more recent terms included preclinical training (2024), pediatric dentistry (2025), virtual simulation (2025), simulation training (2025), and haptic simulation (2025).

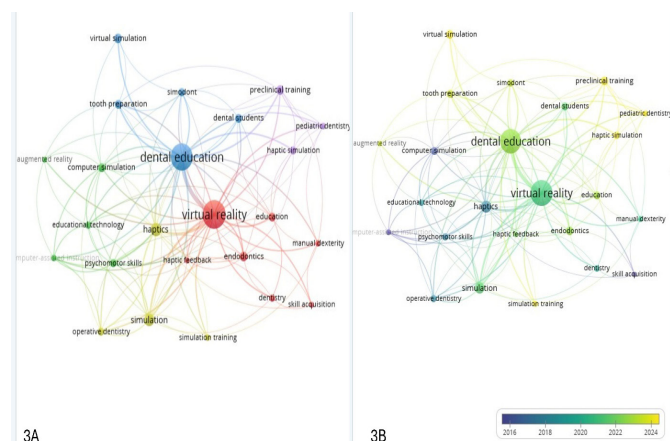


Figure 3. Author keyword co-occurrence analysis of virtual reality and haptic simulation research in preclinical dental education. (A) Network visualization showing relationships among frequently occurring author keywords, with node size reflecting keyword occurrence and colors indicating clusters. (B) Overlay visualization showing the temporal distribution of keywords according to their average publication year, with colors ranging from earlier to more recent publication years

Bibliographic Coupling Analysis

Bibliographic coupling analysis was performed to examine relationships among publications based on shared references. Of the publications with at least 10 citations, 83 formed the largest connected network and were grouped into eight clusters. The network comprised 1,392 links and a total link strength of 2,664 (**Figure 4**).

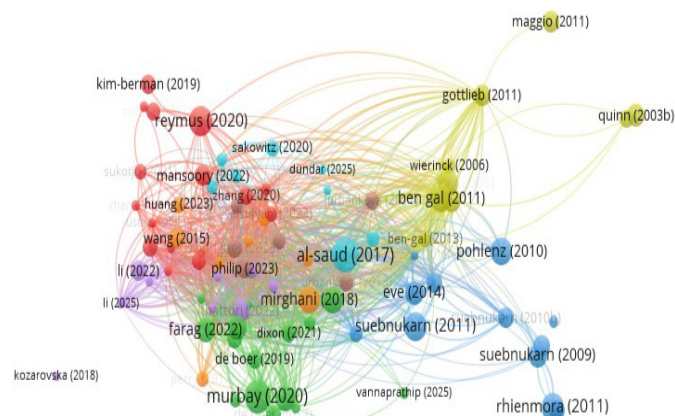


Figure 4. Network visualization of bibliographic coupling among publications on virtual reality and haptic simulation in preclinical dental education. Node size represents the relative weight of individual publications, links indicate bibliographic coupling relationships based on shared references, and colors represent clusters of bibliographically related publications

Among the publications in the network, Liu et al.¹⁸ (2020) had the highest total link strength (TLS=185), followed by Rodrigues et al.¹⁹ (2023) (TLS=134), Sheng et al.²⁰ (2022) (TLS=128), and Philip et al.²¹ (2023) and Farag et al.²² (2022) (TLS=127 each).

Distribution Across Dental Disciplines

The distribution of virtual reality and haptic simulation applications varied across dental disciplines. Restorative and operative dentistry represented the largest area of application, accounting for 64 publications (36.4%), followed by endodontics with 28 (15.9%) and oral surgery/implantology with 27 (15.3%). General or multidisciplinary preclinical dental education accounted for 17 publications (9.7%), while 16 studies (9.1%) focused on prosthodontics. Pediatric dentistry and oral and maxillofacial radiology each accounted for seven publications (4.0%), followed by periodontology with six (3.4%) and orthodontics with four (2.3%). The distribution across dental disciplines is presented in **Figure 5**.

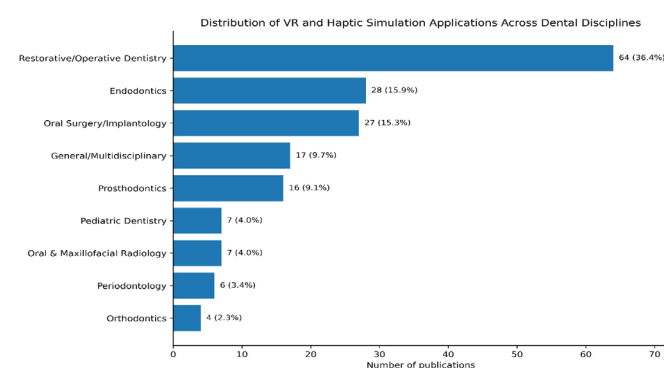


Figure 5. Distribution of virtual reality and haptic simulation applications across dental disciplines. Values indicate the number and percentage of publications assigned to each discipline



DISCUSSION

The present bibliometric analysis provides an overview of the development of research on virtual reality and haptic simulation in preclinical dental education. More than half of the included publications appeared between 2024 and 2026, indicating a marked increase in publication activity in recent years. The literature was concentrated in a relatively small number of dental and medical education journals, while publication patterns and international collaboration varied across countries. Keyword and bibliographic coupling analyses revealed the evolving structure of the field, and the discipline-based classification showed that restorative and operative dentistry represented the largest area of application, followed by endodontics and oral surgery/implantology.

This recent increase is consistent with broader developments in dental education research. Kandaswamy⁷ identified virtual reality and educational technology among emerging topics in the dental education literature, while Chen et al.⁸ similarly reported VR as an emerging research focus. More specifically, Hsu and Chang² observed an increase in publications on haptic and force-feedback technologies toward the end of their 2001-2022 study period, and Barriga-Yauri et al.¹² subsequently reported rapid growth in haptic simulation research between 2020 and 2025. Our findings extend these observations, with 54.5% of the included studies published between 2024 and 2026. This expansion may reflect the increasing availability of simulation technologies and growing interest in educational environments that support repeated practice and objective performance assessment before students progress to patient care.^{1,23,24}

The concentration of publications in a relatively small number of journals reflects the close relationship between this research field and the broader dental education literature. The Journal of Dental Education, European Journal of Dental Education, and BMC Medical Education together accounted for more than half of all included publications. A similar pattern was reported by Matoug-Elwerfelli et al.,³ who identified these journals among the most productive sources in their bibliometric analysis of VR research in restorative dentistry. The prominence of dedicated dental education journals is also consistent with previous bibliometric evaluations of the field.^{7-9,25} The presence of publications in specialty-specific journals, particularly the International Endodontic Journal, further indicates that VR and haptic simulation research extends beyond general educational research into discipline-specific training.

The geographical distribution of publications demonstrated broad international interest, with contributions from 55 countries. China produced the highest number of publications, whereas the United Kingdom showed the highest total link strength in the country-level collaboration network, suggesting that scientific productivity and international connectivity do not necessarily develop in parallel. Previous studies have similarly identified China and the United States as major contributors to research on haptic and force-feedback technologies, while broader analyses of dental education have highlighted the substantial contribution of the United States and other established research environments.^{2,7,8} Recent scientometric evidence has also indicated increasing collaboration within haptic simulation research.¹² Nevertheless, the variation in total link strength observed in the present study suggests that

opportunities remain for broader international collaboration, particularly given potential differences in access to simulation technologies and approaches to preclinical training across educational settings.^{2,7,8,12}

The temporal evolution of keywords illustrates changes in both the terminology and focus of the field. Earlier terms such as skill acquisition, computer-assisted instruction, and computer simulation reflect the educational and technical foundations of simulation-based training. In contrast, more recent terms including preclinical training, virtual simulation, simulation training, and haptic simulation indicate a move toward more specific descriptions of technology-supported educational applications. The emergence of pediatric dentistry among recent keywords may also reflect the expansion of these technologies into a broader range of dental disciplines. This pattern is consistent with previous bibliometric studies identifying VR and educational technologies as emerging areas in dental education.^{2,7,9}

Bibliographic coupling revealed eight interconnected clusters within the literature, indicating that research on VR and haptic simulation draws on several related bodies of knowledge rather than a single educational theme. The relatively high connectivity among publications suggests substantial overlap in the references supporting different areas of research. Notably, several publications with high total link strength were relatively recent, indicating their central position within the current literature. These findings complement previous bibliometric analyses showing an increasingly interconnected research landscape surrounding haptic simulation and technology-supported dental education.^{2,11}

One of the distinctive findings of the present study was the distribution of VR and haptic simulation applications across dental disciplines. More than one-third of the publications focused on restorative and operative dentistry, followed by endodontics and oral surgery/implantology. These disciplines rely heavily on psychomotor skills, hand-eye coordination, spatial perception, and precise instrument manipulation, which may make them particularly suitable for simulation-based training.²⁶⁻²⁸ Procedures such as cavity and access cavity preparation, implant placement, and surgical procedures can be practiced repeatedly within virtual environments while allowing structured performance feedback.^{29,30} Previous literature has similarly identified restorative dentistry and endodontics among the common applications of VR and haptic technologies.^{1,3-6} The present study extends these findings by quantitatively demonstrating how publications are distributed across dental disciplines and highlighting areas in which these technologies have been less extensively investigated.

Limitations

The findings of this study should be interpreted in light of several limitations. The analysis was based exclusively on Scopus, and publications indexed only in other databases may therefore not have been captured. Restricting the search to English-language original research articles may also have excluded relevant literature. Citation-based indicators are influenced by publication age, giving earlier studies more time to accumulate citations. Moreover, citation counts do not necessarily reflect the scientific quality or methodological rigor of individual publications and may also be affected by journal visibility, self-citation practices, and differences in



citation behavior across disciplines. Bibliometric network analyses may also be affected by the search strategy, selected thresholds, and consistency of bibliographic metadata. Although a thesaurus file was used to merge synonymous or closely related keywords, variations in terminology may still have influenced the analysis. Finally, publications were classified according to their primary dental discipline; therefore, studies involving overlapping applications were assigned to a single category. These considerations should be taken into account when interpreting the research patterns identified in this study.

CONCLUSION

This bibliometric analysis provides a broad overview of the development of research on virtual reality and haptic simulation in preclinical dental education. The marked increase in publications in recent years demonstrates the growing interest in technology-supported approaches to dental training. The literature was concentrated primarily in dental and medical education journals, with China, the United States, and the United Kingdom among the leading contributors, although patterns of research productivity and international collaboration differed across countries. Keyword and bibliographic coupling analyses demonstrated an evolving research landscape, while the discipline-based analysis showed that restorative and operative dentistry, endodontics, and oral surgery/implantology were the most extensively investigated areas. Overall, the findings provide a structured overview of the current research landscape and may help identify less explored dental disciplines and opportunities for broader international collaboration in future research.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was based exclusively on publicly available bibliographic data and did not involve human or animal participants, clinical interventions, biological materials, or identifiable personal data. Therefore, ethics committee approval was not required.

Informed Consent

As the study did not involve human participants or identifiable personal data, informed consent was not applicable.

Conflict of Interest

The author declares no conflict of interest related to this study.

Financial Disclosure

The author received no financial support for the conduct, authorship, or publication of this research.

Author Contributions

The author was solely responsible for the study conception and design, data collection, analysis and interpretation, and preparation of the manuscript.

Editor Note

Sema Yazıcı Akbıyık is a member of the Editorial Board of this journal. She was not involved in the editor assignment, reviewer selection, peer review process, or editorial decision for this manuscript. The peer review process was managed independently by another editor.

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