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Current status, evidence maturity, and translational readiness of artificial intelligence in dentistry: a bibliometric and thematic analysis

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BACKGROUND: Artificial intelligence (AI) has rapidly expanded across dental research, particularly in imaging-based diagnostics and digital workflows. Despite the accelerating publication growth, the structural evolution, thematic maturity, and translational readiness of AI in dentistry remain insufficiently synthesised.

METHODS: Publications related to AI in dentistry between 2015 and 2025 were retrieved from the Scopus database. Bibliometric analyses were conducted to examine annual outputs, countries, institutions, authors, journals, and keyword co-occurrence patterns. Network visualisation and clustering were performed using VOSviewer to identify research hotspots and thematic evolution. Selected evidence syntheses were evaluated using the Risk of Bias in Systematic Reviews (ROBIS) tool to assess methodological robustness and evidence maturity.

RESULTS: A total of 3665 publications were included. Research output demonstrated marked post-2019 acceleration, with deep learning and convolutional neural networks dominating the methodological landscape. The United States, China, and India were the most productive countries, while a core group of highly connected authors shaped collaborative structures. Keyword clustering revealed a clear thematic progression from algorithmic development and image segmentation toward diagnostic imaging applications, digital dentistry integration, and workflow optimisation. Among the 75 systematic reviews evaluated using ROBIS, 50 (66.7%) demonstrated an unclear overall risk of bias, 24 (32.0%) showed a low risk of bias, and only one (1.3%) was classified as high risk, indicating that methodological transparency and evidence synthesis have not progressed at the same pace as technological innovation.

CONCLUSION: AI research in dentistry is experiencing rapid expansion and increasing international collaboration, and continuous thematic evolution towards clinically relevant applications. However, the ROBIS assessment indicates that improvements in methodological quality and reporting transparency of evidence syntheses are still required to strengthen confidence in the current evidence base. Future studies should prioritise multicentre validation, standardised evaluation frameworks, rigorous systematic reviews, and clinically meaningful outcome measures to facilitate the safe and effective translation of AI into routine dental practice.

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INTRODUCTION

Artificial intelligence (AI) refers to the development of computer systems and algorithms capable of performing tasks that traditionally require human intelligence, including reasoning, learning, and problem-solving [1–3]. In healthcare, AI has increasingly been adopted to enhance diagnostic accuracy, improve clinical decision-making, and support personalised patient management [4–7]. Core subfields such as machine learning (ML) and deep learning (DL) enable data-driven models to identify complex patterns from large datasets that may not be readily discernible by human experts [8, 9].

Recent advancements in computational power and data availability have accelerated the application of AI in healthcare,

particularly within diagnostics, medical imaging, and predictive analytics [10–12]. Deep learning architectures, including convolutional neural networks (CNNs), have demonstrated strong performance in image interpretation, disease prediction, and personalised treatment planning [13–15]. These developments have contributed to improved efficiency, reduced diagnostic variability, and enhanced clinical workflows across multiple medical disciplines.

Dentistry has emerged as a rapidly expanding domain for AI applications, with growing adoption in dental imaging, disease diagnosis, treatment planning, and digital dentistry ecosystems [16–19]. AI-assisted systems have demonstrated high diagnostic accuracy in identifying caries, periodontal bone loss, periapical

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lesions, and other oral pathologies using panoramic, periapical, and cone-beam computed tomography images [20–22]. Beyond imaging, AI-driven tools are increasingly being explored for clinical decision support, orthodontic planning, implant treatment optimisation, and workflow automation in digital dentistry [23–25].

Despite rapid publication growth, the dental AI literature remains fragmented due to its interdisciplinary nature, spanning computer science, biomedical imaging, and diverse dental specialties. While numerous studies report promising technical performance and emerging clinical applications [26–29], there remains limited consolidated understanding of how the field is evolving structurally and conceptually. In particular, existing bibliometric studies largely focus on publication volume, citation trends, and algorithm frequency [30–32], offering descriptive insights but limited evaluation of research maturity, thematic evolution, and translational readiness.

Furthermore, although an increasing number of systematic reviews have been published to synthesise evidence on AI applications across various dental disciplines, the methodological quality and reliability of these reviews have not been comprehensively evaluated. Consequently, the overall strength of the evidence supporting AI implementation in dentistry remains uncertain.

Importantly, recent evidence syntheses suggest that strong technical performance does not necessarily translate into clinical implementation [33, 34]. This highlights the need to contextualise bibliometric growth within broader thematic and evidence-based frameworks. Evaluating how research themes evolve from methodological development toward clinical validation, together with assessing the methodological quality of systematic reviews using the Risk of Bias in Systematic Reviews (ROBIS) tool, may provide deeper insight into the maturity and translational orientation of the field. Such perspectives move beyond traditional bibliometric description by integrating structural mapping with conceptual and methodological evaluation.

Therefore, this study presents a comprehensive bibliometric and thematic analysis of AI research in dentistry between 2015 and 2025. Specifically, co-authorship network analysis was used to characterise the collaborative landscape of dental AI research, bibliographic coupling to identify its intellectual structure, and keyword co-occurrence analysis to examine thematic evolution and emerging research trends. In addition, all eligible systematic reviews were critically appraised using the ROBIS tool to evaluate the methodological quality and trustworthiness of the current evidence base. By integrating bibliometric mapping, thematic synthesis, and methodological quality appraisal, this study provides a structured perspective on the evolution, evidence maturity, and translational readiness of AI in dentistry, while identifying key challenges and opportunities for its future clinical implementation.

MATERIALS AND METHODS

Bibliometric analysis

Bibliometric analysis refers to the application of mathematical and statistical methods to books and other media of scholarly communication, as originally defined by Pritchard, and is commonly used to quantitatively assess patterns within a body of academic literature [35, 36]. This approach enables the evaluation of research trends, collaboration structures, and scholarly impact based on bibliographic data such as publication output, authorship, affiliations, and citation performance [37, 38]. Owing to the rapid growth of scientific publications, bibliometric analysis has gained increasing importance as a systematic method for mapping the evolution of research themes, identifying influential studies, and revealing emerging research areas [39, 40]. Research performance is typically assessed using

indicators such as citation counts, citations per year, h-index, and g-index, while the intellectual structure of a field can be visualised through network-based techniques including keyword co-occurrence, co-authorship, co-citation, and bibliographic coupling analyses [41, 42]. The widespread adoption of bibliometric analysis is further supported by the accessibility of large bibliographic databases, such as Scopus and Web of Science, and the availability of specialised analytical tools, including VOSviewer, which facilitate data processing, visualisation, and thematic mapping of research landscapes.

Data collection

A comprehensive literature search was conducted using the Scopus database on 16 December 2025. Scopus was selected as the primary data source due to its extensive journal coverage and broad multidisciplinary scope, which is particularly important for capturing research at the intersection of dentistry, AI, and medical imaging. Scopus is recognised as one of the largest abstract and citation databases, providing comprehensive coverage of international research in science, technology, medicine, and health-related disciplines, and is widely used in bibliometric analyses across diverse research fields [43, 44].

Relevant publications were identified using a structured search strategy that combined AI-related terms with dentistry-related terms. The search was applied to the title, abstract, and keywords fields to maximise retrieval sensitivity.

The following search query was used in Scopus:

TITLE-ABS-KEY (dental OR dentistry OR dentist) AND TITLE-ABS-KEY ("artificial intelligence" OR "machine learning" OR "deep learning")*

The search was limited to publications published between January 2015 and December 2025. This temporal range was selected to capture the most relevant and contemporary phase of AI research in dentistry, reflecting the rapid growth and widespread adoption of data-driven and imaging-based AI approaches during this period, while avoiding fragmentation associated with early exploratory studies.

The analysis was restricted to English-language peer-reviewed original research articles and review papers to ensure academic quality, consistency of interpretation, and comparability with existing bibliometric studies. The overall search and screening process for bibliometric analysis is illustrated in Fig. 1.

Selection of systematic reviews for ROBIS assessment

To evaluate the methodological quality of the available evidence syntheses, only systematic reviews and systematic reviews with meta-analysis identified from the bibliometric dataset were considered for ROBIS assessment. Narrative reviews, scoping reviews, conference papers, editorials, letters, and other review types were excluded.

Of the 3665 publications retrieved from the Scopus database, 620 were identified as review articles after excluding non-review publications. Among these, 153 were classified as systematic reviews or systematic reviews with meta-analyses and were sought for full-text retrieval. Five full-text reports could not be retrieved, leaving 148 reviews for eligibility assessment. Following full-text assessment, 73 reviews were excluded because they were either outside the scope of clinical dentistry ($n = 61$) or did not meet the predefined study objectives ($n = 12$). Consequently, 75 systematic reviews were included in the ROBIS assessment. The study selection process for the ROBIS assessment is illustrated in Fig. 2.

ROBIS assessment

The methodological quality of the included systematic reviews was evaluated using the ROBIS tool. ROBIS is specifically designed to assess the risk of bias in systematic reviews and comprises three phases,

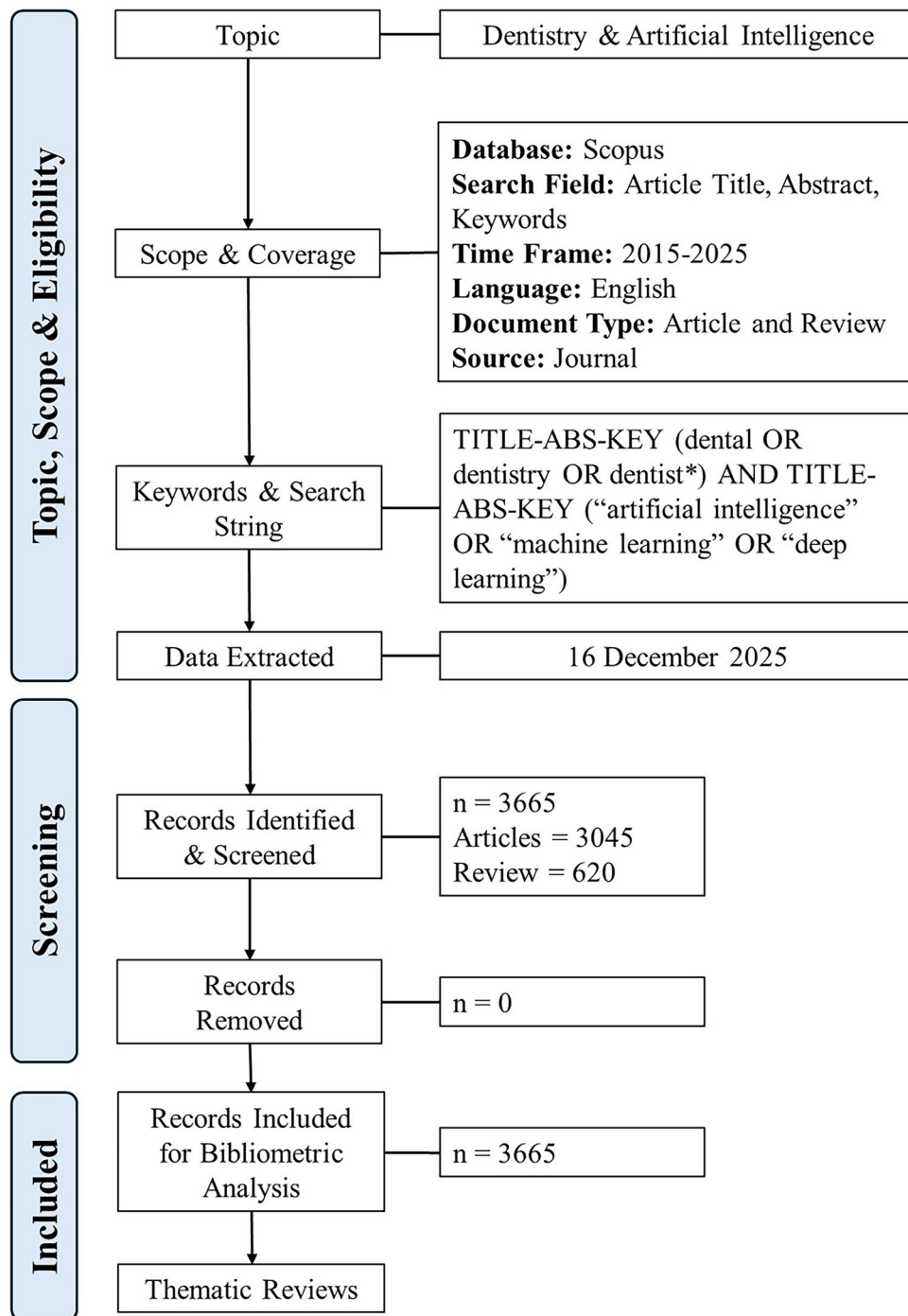


Fig. 1 Flow diagram of the search strategy.

including assessment of relevance (Phase 1), evaluation across four methodological domains (Phase 2), and overall judgement of risk of bias (Phase 3). The four domains in Phase 2 include study eligibility criteria, identification and selection of studies, data collection and study appraisal, and synthesis and findings.

The ROBIS assessment was performed independently by two reviewers using the published ROBIS guidance. Each eligible systematic review was evaluated across Phase 1, Phase 2 (Domains 1–4), and Phase 3 according to the ROBIS signalling questions. Any discrepancies between the two reviewers were resolved through discussion, and when consensus could not be reached, a third reviewer adjudicated the final judgement.

Bibliometric network analysis

All records identified through the Scopus search were exported in comma-separated values (CSV) format, including complete bibliographic information such as authors, titles, abstracts, keywords, affiliations, countries, source titles, citation counts, and reference lists.

Prior to analysis, the exported Scopus dataset was cleaned and harmonised to improve metadata consistency and the accuracy of network mapping. Author name disambiguation was performed to consolidate variant forms of the same author and keyword harmonisation was conducted to merge synonymous or equivalent terms. These standardisation steps were implemented using

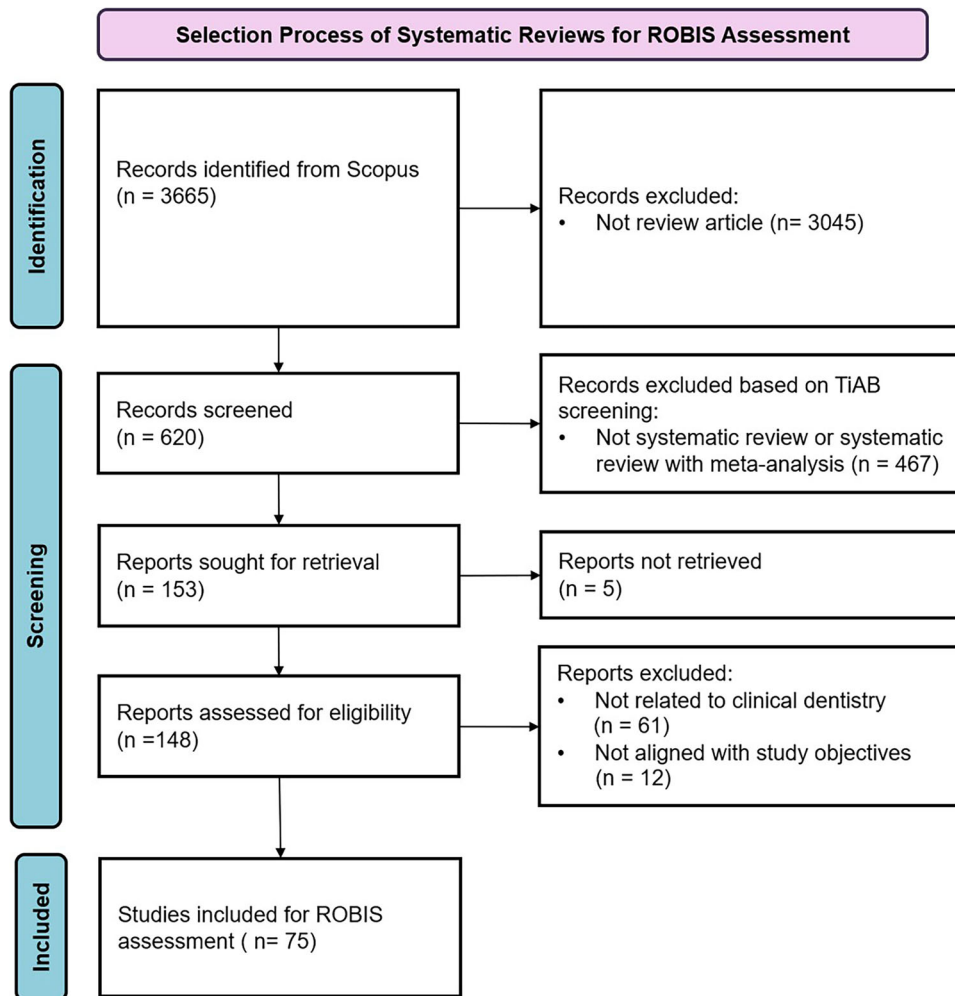


Fig. 2 Flow diagram illustrating the selection process of systematic reviews included in the ROBIS assessment.

thesaurus files in VOSviewer, ensuring consistent representation of entities across co-authorship and keyword co-occurrence analyses.

VOSviewer (version 1.6.20) was employed to construct and visualise bibliometric networks due to its flexibility in network visualisation and user-friendly interface. The bibliometric networks were presented as network visualisation maps, in which node colour represents cluster membership, node size reflects the level of productivity or citation impact, and the thickness of connecting lines indicates the strength of relationships or collaboration between units [45].

In this study, co-authorship and co-occurrence analyses were performed to generate maps illustrating: (1) co-authorship networks among authors and countries, (2) bibliographic coupling of sources, and (3) co-occurrence networks of author keywords. Network relationships were quantified using total link strength, and clustering was conducted using the default VOSviewer algorithm to identify major thematic groupings within the literature. These analyses collectively address the research questions related to publication trends, research productivity, collaboration patterns, influential sources, and emerging research themes in dental AI.

RESULTS

Publication growth

Overall, the search conducted in the Scopus database retrieved a total of 3665 scientific publications related to dentistry and AI

published between 2015 and 2025. As illustrated in Fig. 3, the annual number of publications demonstrates a clear and sustained upward trend over the study period, indicating a rapidly growing research interest in the application of AI within dentistry.

From 2015 to 2018, publication output remained relatively low, reflecting the early adoption phase of AI technologies in dental research. A noticeable increase emerged from 2019 onwards, followed by a sharp acceleration after 2020, coinciding with the widespread adoption of deep learning and data-driven approaches in medical and dental imaging. The highest publication output was observed in 2025, with 1370 publications, representing the peak of research productivity during the analysed period.

In parallel with publication growth, total citation counts also increased substantially over time, suggesting not only an expansion in research volume but also a rising scholarly impact of studies in dental AI. These findings highlight the rapid maturation and increasing influence of AI research in dentistry over the past decade.

Bibliometric network analysis

A bibliometric analysis was conducted to construct network maps based on scientific publication data, illustrating collaborative relationships among authors and countries in the field of AI in dentistry. Bibliographic coupling analysis of sources was performed to identify influential journals based on shared reference patterns, reflecting similarities in research focus across

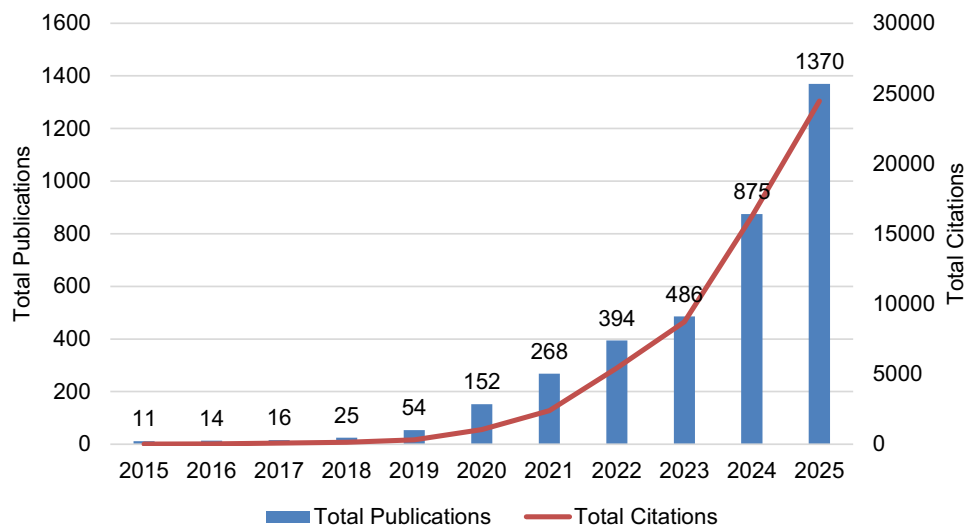


Fig. 3 Publication growth and total citations of scientific articles published related to dental and AI from 2015 to 2025.

publications. Author keywords were analysed using co-occurrence analysis to identify major research themes and emerging topics within dental AI research.

Co-authorship authors network

The co-authorship authors' network of publications on AI in dentistry from 2015 to 2025 comprised a total of 14,637 contributing authors. To enhance the interpretability of the collaboration network and minimise the influence of marginal contributions, documents with more than 25 co-authors were excluded from the analysis. This exclusion was applied to reduce the impact of large consortium-based publications that may obscure meaningful collaborative relationships within the network.

A minimum threshold of five publications per author with five citations per author, 371 authors were identified but only 229 authors were visually mapped in Fig. 3 because some of the authors were not connected to each other.

Figure 4 presents the co-authorship network of authors, where nodes represent individual authors, node size reflects publication output, and links indicate collaborative relationships between authors. The thickness of the links corresponds to the total link strength, representing the intensity of collaboration. A total of 19 different colours denote distinct collaboration clusters identified using the VOSviewer clustering algorithm.

Among the most productive and influential authors identified in this network, Schwendicke, Falk ranked first with 89 publications, 4614 citations, and the highest total link strength (243), indicating both high productivity and strong collaborative engagement (Table 1). Other prominent contributors included Krois, Joachim, Orhan, Kaan, and Bayrakdar, Ibrahim Şevki, each demonstrating substantial publication output and collaborative connectivity within the field.

Although the top 10 authors belonged to different collaboration clusters, strong interconnections were observed among them, suggesting a highly interconnected research community in dental AI. These findings indicate that research in this field is driven by a core group of prolific authors who maintain extensive collaborative networks, facilitating knowledge exchange and interdisciplinary development.

Co-authorship countries network

Figure 5 shows the worldwide distribution of scientific production on AI in dentistry based on Scopus-indexed publications. Research output was globally distributed, with higher concentrations

observed in North America, Europe, and Asia. The United States recorded the highest number of publications (628 documents), followed by China (574 documents) and India (418 documents). Other countries with notable publication output included the United Kingdom (182), Germany (257), Saudi Arabia (257), Brazil (175), and South Korea (242).

The international co-authorship network of countries publishing on AI in dentistry is visualised in Fig. 6 using VOSviewer. In this network, nodes represent countries, node size corresponds to the number of publications, and links indicate co-authorship relationships between countries. The thickness of the links reflects the total link strength, representing the intensity of international collaboration. After applying a minimum threshold of five documents and five citations per country, 78 countries were included in the analysis and grouped into eight collaboration clusters. Cluster formation was based on co-authorship link strength rather than geographical proximity.

The top 20 contributing countries ranked by total link strength are summarised in Table 2. The United States ranked first, with the highest total link strength (756), 64 collaborative links, 628 documents, and 11,749 citations. Germany ranked second (434), followed by Saudi Arabia (373) and India (369). The United Kingdom ranked fifth with a total link strength of 335 and 182 publications.

Among Asian countries, China demonstrated a high publication output (574 documents) with a total link strength of 299, while South Korea recorded a total link strength of 135 alongside a high citation count (7214). Brazil emerged as the leading contributor from Latin America, with a total link strength of 278 and 175 publications. Several European countries, including Switzerland, Belgium, Sweden, Italy, Spain, and France, also appeared among the top 20 countries, reflecting consistent international collaboration activity within Europe.

Bibliographic coupling of sources

Bibliographic coupling analysis was conducted to identify influential journals and examine the structural relationships among sources publishing research on AI in dentistry between 2015 and 2025. By applying a threshold of at least 10 publications per journal and a minimum of 10 citations, 66 journals were retained from an initial pool of 971 sources. These journals were subsequently grouped into four distinct clusters based on their bibliographic coupling relationships, as visualised in Fig. 7.

Figure 6 illustrates the bibliographic coupling network of journals based on shared references. In this network, nodes

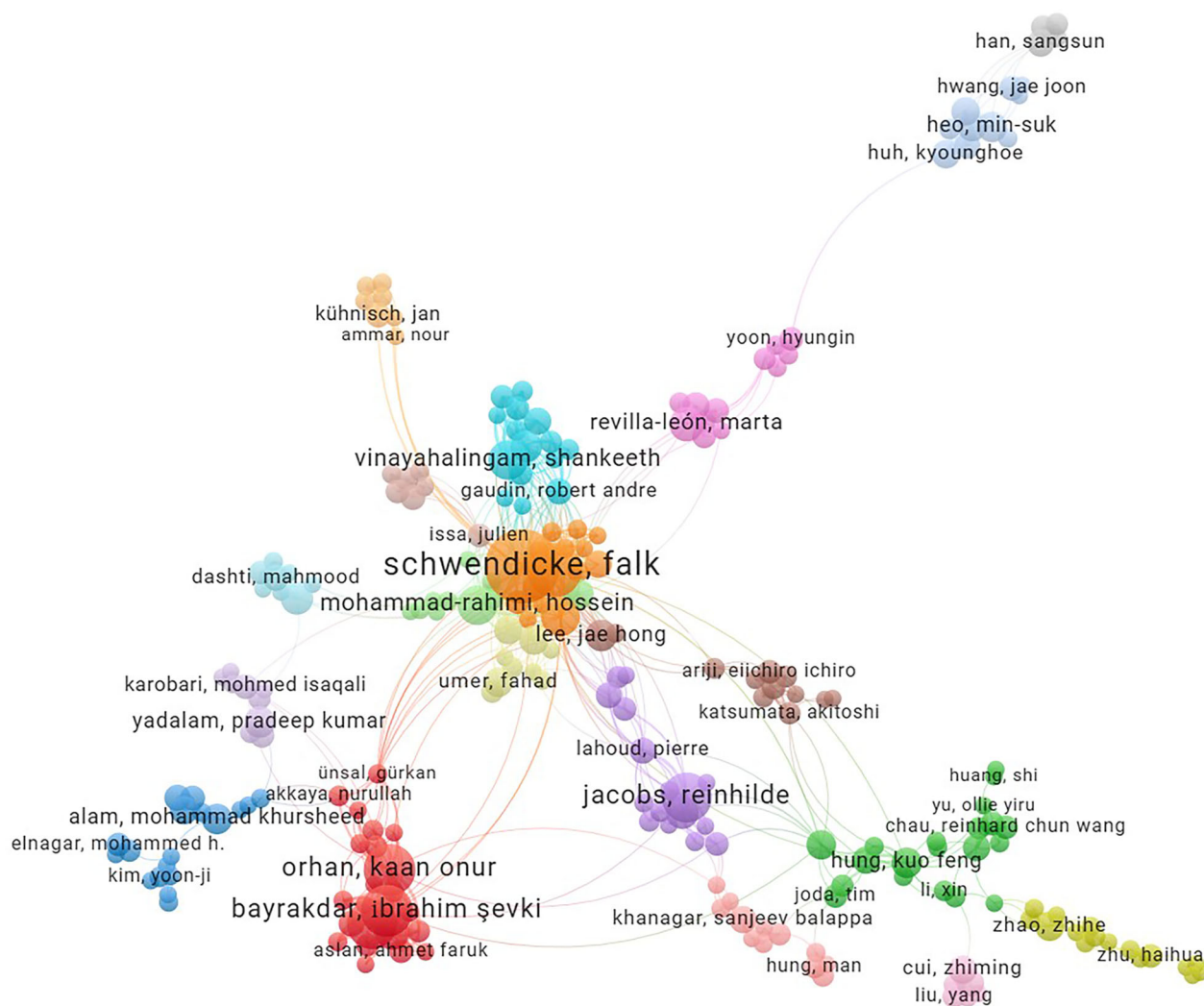


Fig. 4 Co-authorship network map of authors publishing on dentistry and AI from 2015 to 2025.

represent journals, node size corresponds to publication output, and links indicate the extent to which journals share common references. The thickness of the links reflects total link strength, representing the intensity of bibliographic coupling between sources.

The top 10 journals identified through bibliographic coupling analysis are summarised in Table 3. The *Journal of Dentistry* ranked first, exhibiting the highest total link strength (6153), with 65 links, 145 documents, and 4021 citations. *BMC Oral Health* ranked second (total link strength = 4824), followed by *Diagnostics* (4444) and *Scientific Reports* (2622). Other highly connected journals included *Journal of Clinical Medicine*, *Applied Sciences (Switzerland)*, *Dentomaxillofacial Radiology*, *Clinical Oral Investigations*, *International Dental Journal*, and *Journal of Prosthetic Dentistry*, reflecting substantial shared reference patterns within the field.

Keyword co-occurrence analysis and thematic clustering

A co-occurrence analysis of author keywords was conducted to identify the major research themes in AI applications within dentistry from 2015 to 2025. A minimum threshold of 10 occurrences per keyword was applied to focus on frequently studied concepts and to reduce noise from infrequently used terms. Based on this criterion, 112 keywords were retained from an initial pool of 6584 author keywords. The analysis resulted in seven distinct thematic clusters, as visualised in Fig. 8,

representing major research domains in dental AI. In the network visualisation, node size reflects keyword frequency, link thickness indicates the strength of co-occurrence relationships, and colours denote different clusters generated using the VOSviewer clustering algorithm. Table 4 summarises the dominant themes and representative keywords associated with each cluster.

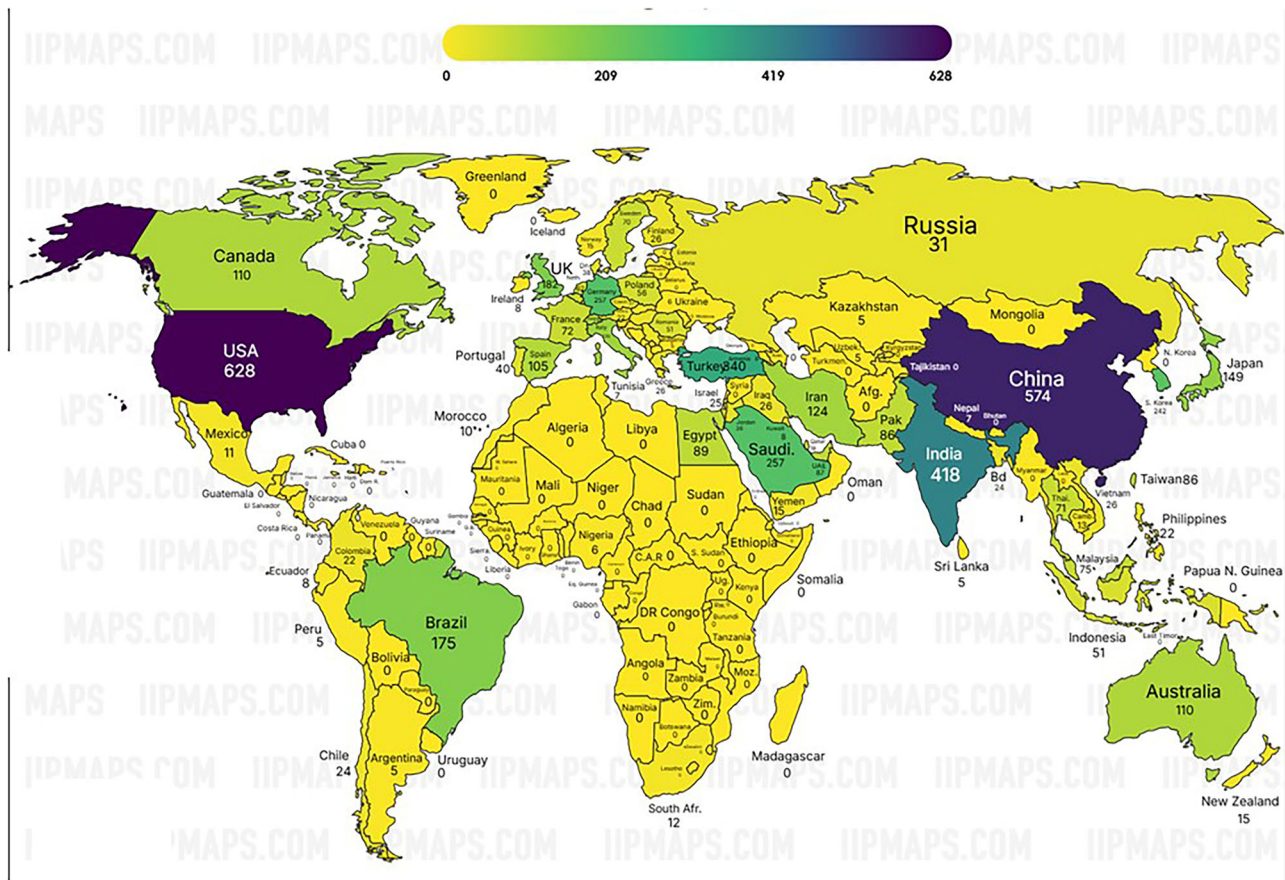
This study further expanded the network visualisation presented in Fig. 8 by applying an overlay visualisation to illustrate the temporal evolution of AI research in dentistry over time (Fig. 9). In the overlay map, colours represent the average publication year of keywords, where blue to purple nodes indicate earlier research topics, while yellow to orange nodes reflect more recent research activity.

Earlier research themes were predominantly centred on conventional machine learning techniques and dental imaging applications, including *machine learning*, *deep learning*, *convolutional neural network*, *dental radiography*, *cone-beam computed tomography*, *segmentation*, and *tooth detection*. These keywords formed the foundational core of AI research in dentistry and were strongly interconnected with diagnostic and imaging-related terms.

More recent research trends were characterised by the emergence of clinically oriented and digitally integrated themes. Keywords such as *digital dentistry*, *implant planning*, *digital workflow*, *additive manufacturing*, *augmented reality*, and

Table 1. Top 10 authors publishing on dentistry and AI (rank based on total link strength).

Author	Total link strength	Links	Documents	Citations	Cluster
Schwendicke, Falk	243	50	89	4614	7
Krois, Joachim	165	32	48	4029	7
Orhan, Kaan	164	26	43	1175	1
Bayrakdar, Ibrahim Şevki	156	23	43	904	1
Celik, Ozer	141	18	40	742	1
Vinayahalingam, Shankeeth	109	24	25	462	6
Chaurasia, Akhilanand	99	33	24	1165	7
Bilgir, Elif	87	14	19	722	1
Jacobs, Reinhilde	87	18	40	1049	5
Mohammad-Rahimi, Hossein	84	28	25	851	11

**Fig. 5** Worldwide scientific production on AI in dentistry indexed by Scopus, distributed by country.

prosthodontics appeared with warmer colours, indicating increased research activity in later years. In parallel, the growing presence of *chatbot*, *large language model*, *education*, and *bibliometric analysis* suggests an expansion of AI applications beyond diagnostics toward education, decision support, and research analytics.

Disease-focused themes, including *periodontal diseases*, *dental caries*, and *oral diseases*, remained consistently connected to AI and machine learning techniques throughout the study period, reflecting sustained interest in clinical problem-solving.

Table 5 presents the top 30 keywords in AI and dentistry research ranked by total link strength. Overall, the keyword network was dominated by methodological and technology-

related terms, reflecting the central role of AI techniques in dental research.

Artificial intelligence emerged as the most prominent keyword, recording the highest total link strength (3473) and occurrence frequency (1570), followed by *deep learning* (total link strength = 2198; occurrences = 928) and *machine learning* (1433; 669 occurrences). These keywords formed the core of the network and exhibited extensive connections with both clinical and imaging-related terms.

Imaging- and diagnostics-related keywords were also highly represented, including *convolutional neural network*, *cone-beam computed tomography*, *panoramic radiography*, *computer vision*, *dental radiography*, and *digital imaging*, indicating the strong

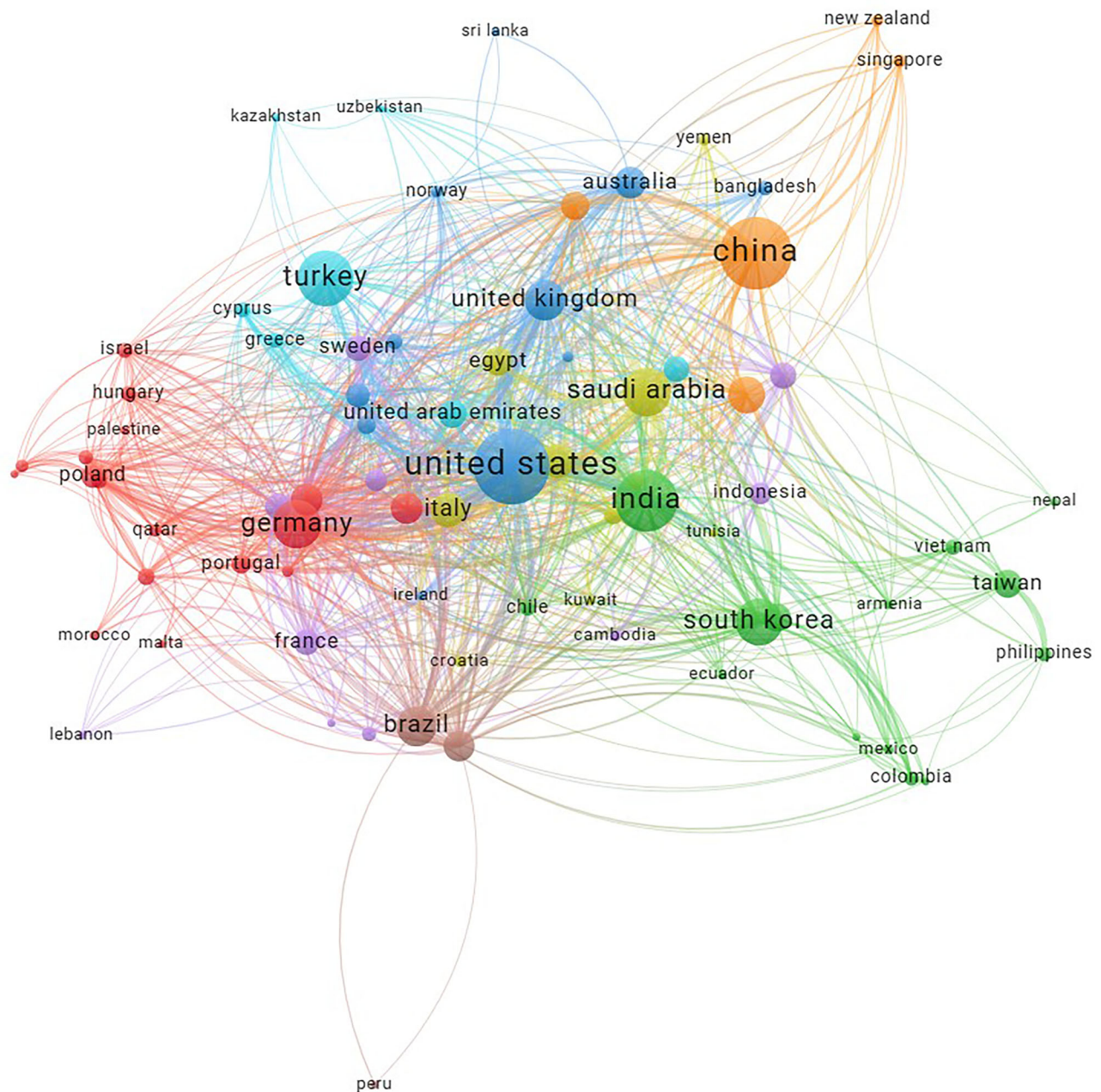


Fig. 6 Co authorship network map of countries publishing on dentistry and AI from 2015 to 2025.

integration of AI with dental imaging modalities. In parallel, segmentation-based terms such as *tooth segmentation*, *segmentation*, and *classification* appeared frequently, reflecting the importance of image-based analytical tasks.

Clinically oriented keywords, including *periodontal diseases*, *dental caries*, *dental implant*, *orthodontics*, *endodontics*, and *diagnosis*, were consistently connected to AI techniques, demonstrating the application of computational approaches across multiple dental specialties. Emerging technology-related keywords such as *chatbot* and *large language model* were also observed among the top-ranked terms, suggesting the expansion of AI research toward decision support, education, and human-computer interaction.

Methodological quality assessment of systematic reviews (ROBIS)

The methodological quality and risk of bias of the included systematic reviews was evaluated using the ROBIS tool. The

detailed ROBIS assessment for each of the 75 included systematic reviews is presented in Supplementary Table 1.

Among the 75 systematic reviews assessed, 50 (66.7%) were judged as having an unclear overall risk of bias, followed by 24 (32.0%) with a low risk of bias, whereas only one review (1.3%) was classified as having a high risk of bias (Table 6).

Overall, most systematic reviews demonstrated a low risk of bias in Phase 1 (assessing relevance), Domain 1 (study eligibility criteria), and Domain 2 (identification and selection of studies), indicating that review questions, eligibility criteria, and literature searches were generally well defined. However, uncertainty was predominantly observed in Domain 3 (data collection and study appraisal) and Domain 4 (synthesis and findings), largely because several reviews did not sufficiently report duplicate data extraction procedures, critical appraisal methods, or the incorporation of study quality into evidence synthesis. Consequently, the majority of reviews were classified as having an overall unclear risk of bias.

Table 2. Top 20 countries publishing on dentistry and AI research (rank based on total link strength).

Country	Total link strength	Links	Documents	Citations	Cluster
United States	756	64	628	11,749	3
Germany	434	60	257	7728	1
Saudi Arabia	373	48	257	4148	4
India	369	61	418	5874	2
United Kingdom	335	56	182	4261	3
China	299	49	574	9437	7
Brazil	278	52	175	2947	8
Switzerland	236	45	110	3662	1
Belgium	200	44	74	1744	5
Sweden	190	40	70	2304	5
Italy	187	51	130	1863	4
Iran	186	40	124	1853	4
Spain	167	47	105	2149	8
United Arab Emirates	164	39	87	1567	6
Australia	162	39	110	1978	3
Egypt	162	40	89	1046	4
Canada	161	41	110	1778	1
Hong Kong	156	36	87	2984	7
France	153	40	72	1503	5
South Korea	135	37	242	7214	2

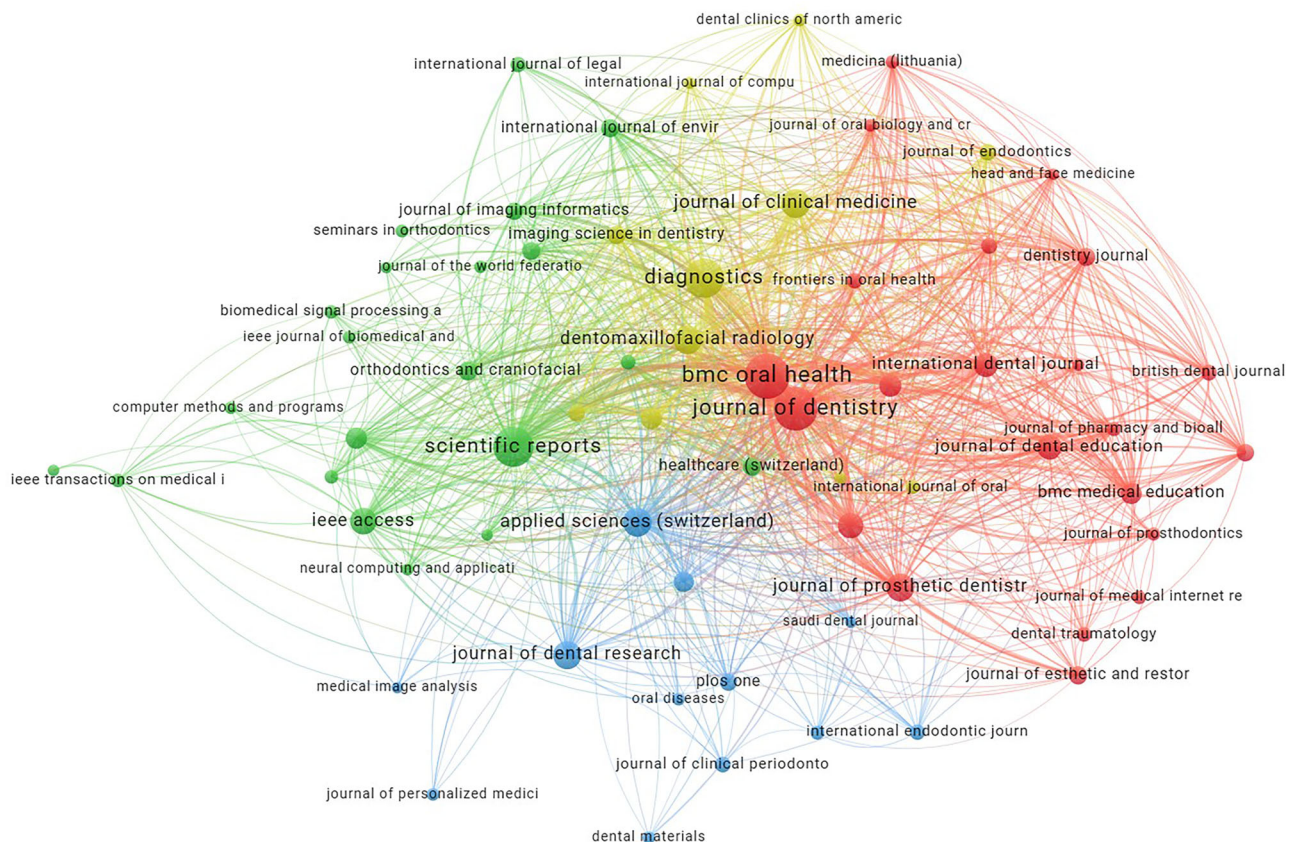
**Fig. 7** Bibliographic coupling of journals based on shared references in dental and AI research (2015–2025).

Table 3. Top 10 journals identified through bibliographic coupling analysis in dental AI research (2015–2025).

Journal	Total link strength	Links	Documents	Citations	Cluster
Journal of Dentistry	6153	65	145	4021	2
BMC Oral Health	4824	64	154	1790	2
Diagnostics	4444	65	118	2315	1
Scientific Reports	2622	65	122	3471	1
Journal of Clinical Medicine	2442	65	63	1246	4
Applied Sciences (Switzerland)	2248	65	63	987	1
Dentomaxillofacial Radiology	2127	65	62	1688	1
Clinical Oral Investigations	1664	65	49	653	2
International Dental Journal	1617	64	44	444	2
Journal of Prosthetic Dentistry	1565	63	59	835	2

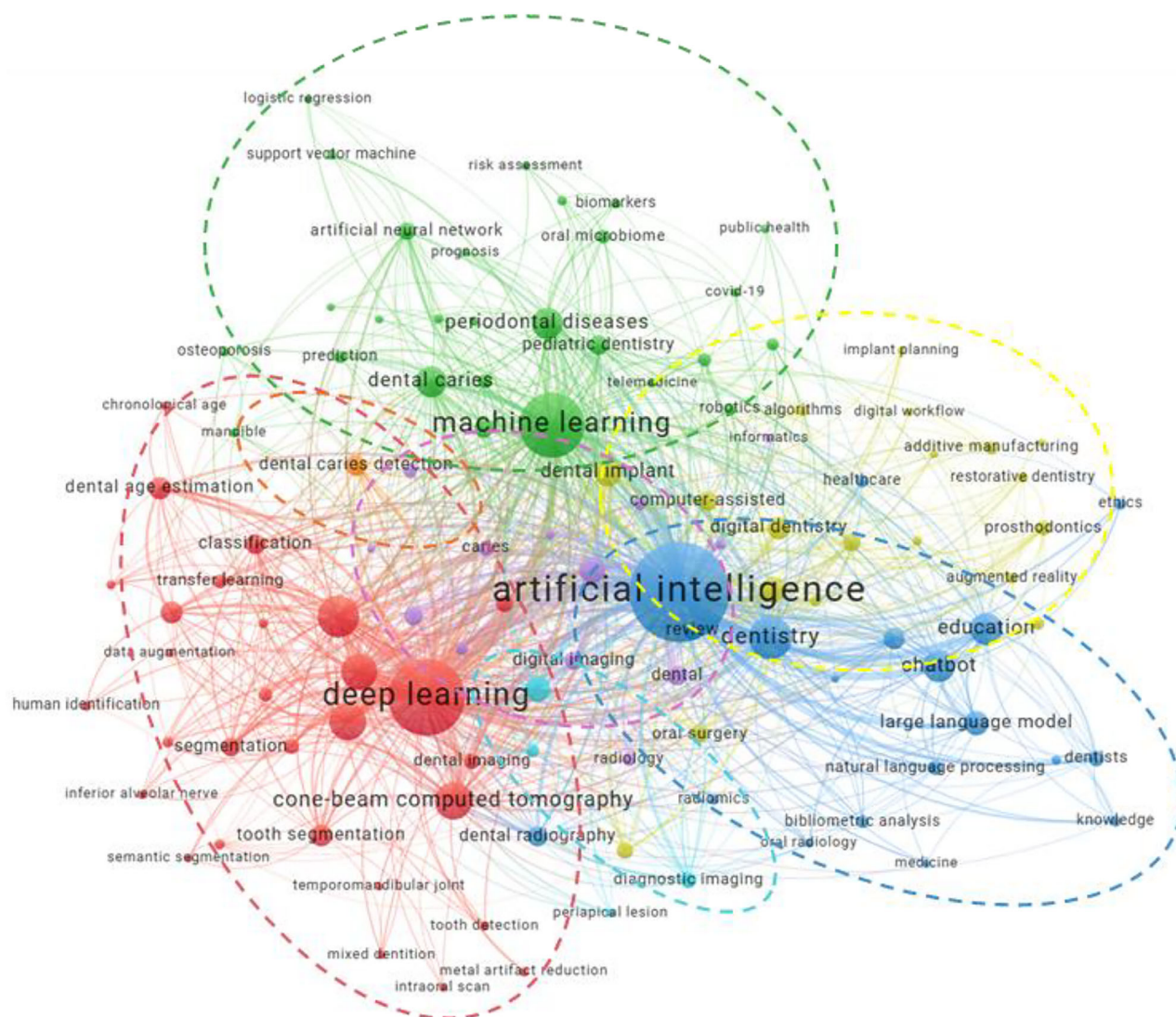


Fig. 8 Co-occurrence network map of keywords from articles published on dentistry and AI from 2015 to 2025.

DISCUSSION

This study provides a comprehensive overview of the global research landscape of AI in dentistry by integrating bibliometric analysis with methodological quality assessment of systematic reviews using the ROBIS tool. Beyond documenting publication growth, collaborative structures, and thematic evolution, the

present study also evaluated the robustness of the current evidence base, providing additional insight into the translational readiness of AI applications in dentistry.

The temporal analysis revealed a modest level of publication activity prior to 2018, followed by a pronounced acceleration from 2019 onwards. This inflection point coincides with the widespread

Table 4. Major research themes identified through author keyword co-occurrence analysis in dental AI research (2015–2025).

Cluster (Colour)	Dominant theme	Key supporting keywords
Cluster 1 (Red)	Deep learning-based computer vision for dental imaging	deep learning, convolutional neural network, transfer learning, image segmentation, object detection, tooth segmentation, cone-beam computed tomography, dental imaging
Cluster 2 (Green)	Machine learning applications in oral diseases and risk assessment	machine learning, periodontal diseases, dental caries, biomarkers, oral microbiome, risk assessment, public health, logistic regression, support vector machine
Cluster 3 (Blue)	Artificial intelligence in dentistry, diagnostics, and education	artificial intelligence, dentistry, dental radiography, diagnostic imaging, radiomics, bibliometric analysis, education, chatbot, large language model
Cluster 4 (Yellow)	Digital dentistry technologies and clinical workflow	digital dentistry, implant planning, additive manufacturing, augmented reality, virtual reality, prosthodontics, restorative dentistry
Cluster 5 (Purple)	Clinical decision support systems and dental informatics	diagnosis, diagnostics, clinical decision support, informatics, dental informatics, decision-making, oral diagnosis
Cluster 6 (Cyan)	Dental radiology and diagnostic imaging applications	diagnostic imaging, oral radiology, radiology, periapical lesion, periapical radiograph
Cluster 7 (Orange)	AI-assisted dental caries detection	dental caries detection

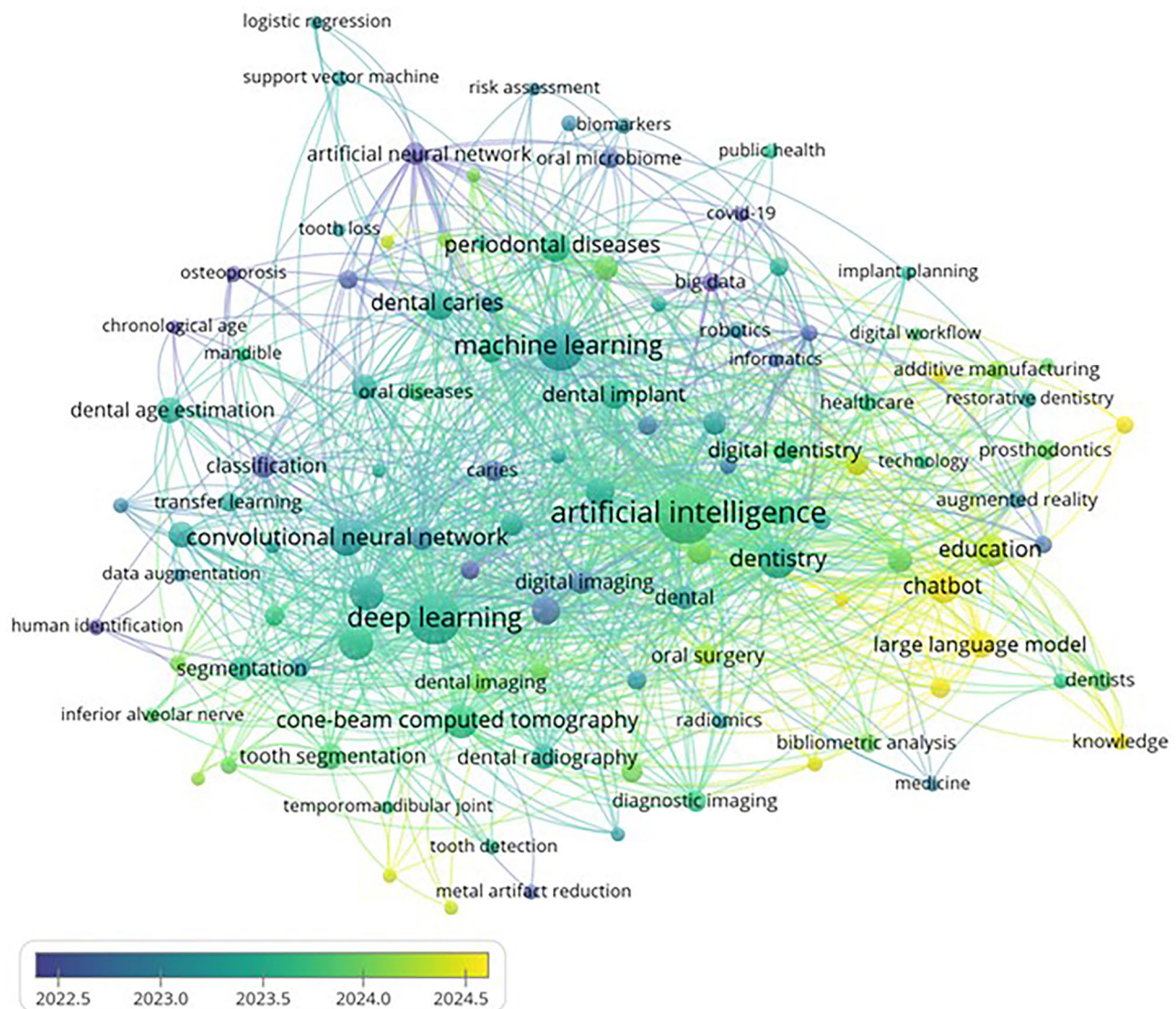
**Fig. 9** Evolution of dentistry and AI research from 2015 to 2025 based on the author keywords.

Table 5. The top 30 keywords of dentistry and AI research publication (rank based on total link strength).

Keyword	Total link strength	Links	Occurrences	Cluster
Artificial intelligence	3473	105	1570	3
Deep learning	2198	101	928	1
Machine learning	1433	103	669	2
Dentistry	811	82	292	3
Convolutional neural network	701	76	273	1
Cone-beam computed tomography	492	66	222	1
Panoramic radiography	586	68	216	1
Computer vision	496	70	206	1
Education	363	51	163	3
Chatbot	387	55	161	3
Periodontal diseases	348	61	153	2
Dental caries	377	61	150	2
Dental implant	276	47	122	4
Diagnosis	316	61	108	5
Neural network	296	57	104	6
Orthodontics	273	57	102	4
Large language model	240	35	94	3
Dental age estimation	183	35	79	1
Forensic odontology	183	41	77	1
Tooth segmentation	155	37	75	1
Endodontics	208	44	71	3
Dental caries detection	184	40	66	7
Classification	168	38	64	1
Dental radiography	174	41	63	3
Dental	168	49	60	5
Review	167	53	56	3
Segmentation	154	35	56	1
Radiography	168	39	54	5
Digital imaging	162	41	54	1
Diagnostic accuracy	120	37	50	4

adoption of deep learning architectures, improved computational power, and increased accessibility of large annotated imaging datasets in healthcare research [46, 47]. In dentistry, the rapid digitisation of radiographic workflows and the routine use of cone-beam computed tomography further created favourable conditions for AI-driven research, particularly in diagnostic and image-based applications [48].

Notably, citation trends closely paralleled publication growth, with highly productive years also exhibiting elevated citation counts. This alignment suggests that the surge in output was not merely quantitative, but accompanied by increasing scholarly influence. The strong citation performance of recent studies reflects heightened global interest in AI-enabled dental diagnostics and decision support systems, as well as the tendency for AI-related publications to attract cross-disciplinary citations from computer science, biomedical engineering, and medical imaging communities [49]. Given the continued expansion of generative AI, large language models, and real-world clinical deployment, publication and citation trajectories are expected to further increase in the coming years.

The co-authorship analysis revealed a highly skewed authorship structure, in which the majority of top contributing authors were concentrated within a single dominant cluster. In contrast, authors belonging to clusters 2, 3, 4, 8, 9, and 10 were not represented among the top 10 authors ranked by total link strength. This pattern suggests that dental AI research is currently driven by a

relatively small group of highly connected researchers who act as intellectual and collaborative hubs.

Several factors may explain this asymmetry. First, authors in the dominant cluster are likely embedded within large, well-funded research groups or international consortia, enabling frequent collaboration and higher visibility. Second, methodological expertise in AI, such as clinicians, computer scientists, and data analysts, particularly in deep learning and medical image analyses tends to be concentrated within specialised interdisciplinary teams, limiting broader diffusion of authorship influence [50]. In contrast, authors in smaller clusters may contribute valuable niche or application-specific studies, but with fewer collaborative ties, resulting in lower total link strength despite meaningful scholarly contributions. This finding highlights an opportunity for broader inclusion and cross-cluster collaboration to reduce intellectual centralisation within the field [51, 52].

At the country level, dental AI research was dominated by a small number of highly connected nations, with the United States occupying a central position within the global co-authorship network. Its leading total link strength and publication volume underscore its role as a global collaboration hub. This centrality mirrors broader patterns in AI research, where the United States consistently ranks among the most internationally collaborative countries [53], frequently partnering with China, the United Kingdom, Canada, and Germany [54]. Such dominance likely reflects early AI adoption, strong federal and private research

Table 6. Summary of the overall ROBIS assessment of the included systematic reviews.

Overall ROBIS classification	n	%
Low risk	24	32.0
Unclear risk	50	66.7
High risk	1	1.3

L Low risk, U Unclear risk, H High risk.

funding, and well-established interdisciplinary linkages between dental schools, engineering departments, and data science institutes.

Germany, Saudi Arabia, India, and the United Kingdom also demonstrated strong collaborative engagement, indicating that dental AI research has expanded beyond traditional Western centres. The prominence of Saudi Arabia and India, in particular, reflects increasing national investment in digital health and AI as part of broader healthcare transformation strategies [55, 56]. China's combination of high publication output and strong citation impact, despite a slightly lower total link strength, suggests a research model characterised by high productivity with selectively targeted international collaborations rather than broad network integration [57].

Although not ranked among the top 20 countries by total link strength, Malaysia exhibited moderate international collaboration, reflecting its emerging position within the regional dental AI ecosystem. This pattern aligns with trends observed in other health-related AI domains, where developing countries increasingly contribute through focused collaborations and applied research rather than large-scale output [58].

Bibliographic coupling analysis revealed a clearly defined core of influential journals shaping the intellectual structure of dental AI research. Journals such as *Journal of Dentistry*, *BMC Oral Health*, *Diagnostics*, and *Scientific Reports* exhibited high total link strength, indicating strong shared reference patterns and central roles in knowledge dissemination. These journals collectively bridge clinical dentistry, diagnostic imaging, and computational methodology, reinforcing their importance as interdisciplinary platforms.

The clustering of journals highlighted meaningful thematic differentiation. Clusters dominated by clinical dental journals primarily focused on disease detection, diagnostic accuracy, and treatment planning, whereas clusters comprising multidisciplinary and open-access journals emphasised methodological innovation, algorithm development, and translational research. Interestingly, one cluster was absent from the top 20 journals, suggesting the presence of emerging or niche publication venues that contribute conceptually but remain peripheral in terms of citation and coupling strength. Conversely, the largest cluster contained the majority of high-impact journals, reflecting a consolidation of influence within broadly scoped, internationally visible outlets. This imbalance suggests that dental AI knowledge dissemination currently favours journals with wide interdisciplinary reach over highly specialised titles [59].

The evolution of keywords revealed a clear methodological trajectory. Early research predominantly focused on traditional machine learning and image analysis techniques applied to dental radiography and cone-beam computed tomography (CBCT) [48, 60]. These methods were essential in automating and enhancing the accuracy of dental imaging, which traditionally relied on manual analysis. This emphasis can be attributed to the structured nature of radiographic data, the availability of labelled datasets, and the immediate clinical relevance of imaging-based diagnostics. As computational capabilities advanced, the field rapidly transitioned towards deep learning, CNN, and automated segmentation, driven by their superior performance in complex visual tasks [61, 62].

More recently, the emergence of keywords such as “large language model”, “chatbot”, “education”, and “digital workflow” signals a shift beyond image-centric applications towards system-level integration. This trend reflects the maturation of dental AI research, moving from isolated algorithm development to comprehensive clinical and educational ecosystems that support decision-making, workflow optimisation, and patient engagement. The appearance of bibliometric analysis itself as a keyword further indicates growing reflexivity within the field, as researchers seek to synthesise and strategically guide an increasingly dense literature. Interestingly, keywords related to ethics, algorithmic bias, explainability, governance, and regulatory approval were not among the dominant research themes identified in the keyword co-occurrence analysis. This observation suggests that the current dental AI literature remains primarily focused on technological development and diagnostic performance rather than the broader challenges associated with responsible clinical implementation. As AI applications move closer to routine dental practice, issues related to fairness, transparency, patient privacy, regulatory compliance, and ethical governance are expected to become increasingly important. The limited prominence of these topics therefore represents an emerging research gap and highlights the need for future studies to integrate technical innovation with ethical, regulatory, and implementation considerations.

The convergence of high-impact keywords around periodontal diseases, dental caries, implants, and diagnostic accuracy underscores the growing clinical relevance of AI applications in dentistry. These conditions are characterised by high prevalence, diagnostic variability, and heavy reliance on imaging data, making them particularly suitable for AI-assisted solutions. At the same time, the increasing emphasis on decision support, precision dentistry, and digital workflows suggests a clear shift from isolated algorithmic development toward clinically integrated systems prioritising explainability, interoperability, and real-time usability [63].

Nevertheless, successful translation into routine clinical practice will require validation across diverse populations, clinician-centred system design, and sustained multidisciplinary collaboration to address challenges related to data heterogeneity, external validation, ethical deployment, and generalisability. Overall, these findings indicate that dental AI research has evolved through identifiable conceptual stages, progressing from methodological and algorithmic development to imaging-driven diagnostics, digital workflow integration, and ultimately clinical translation and real-world implementation. However, as demonstrated by the ROBIS assessment presented later in this discussion, the methodological quality of evidence synthesis has not progressed at the same pace as technological innovation, indicating that important translational challenges remain despite rapid research growth.

Collectively, these bibliometric findings demonstrate that the evolution of AI in dentistry extends beyond a simple increase in publication output. Rather, the co-authorship analyses characterise the collaborative landscape and capacity for knowledge exchange within the field, bibliographic coupling reveals its intellectual structure, and keyword co-occurrence analysis illustrates the progression of research themes from methodological innovation towards clinically oriented applications. Together, these complementary analyses provide a comprehensive understanding of how dental AI has evolved over the past decade and establish the contextual foundation for interpreting the methodological quality of the current evidence base through the subsequent ROBIS assessment.

While the bibliometric analyses characterise the overall development and research landscape of AI in dentistry, the subsequent ROBIS assessment specifically evaluates the methodological quality of the available systematic reviews. Therefore, conclusions regarding evidence maturity and translational readiness are

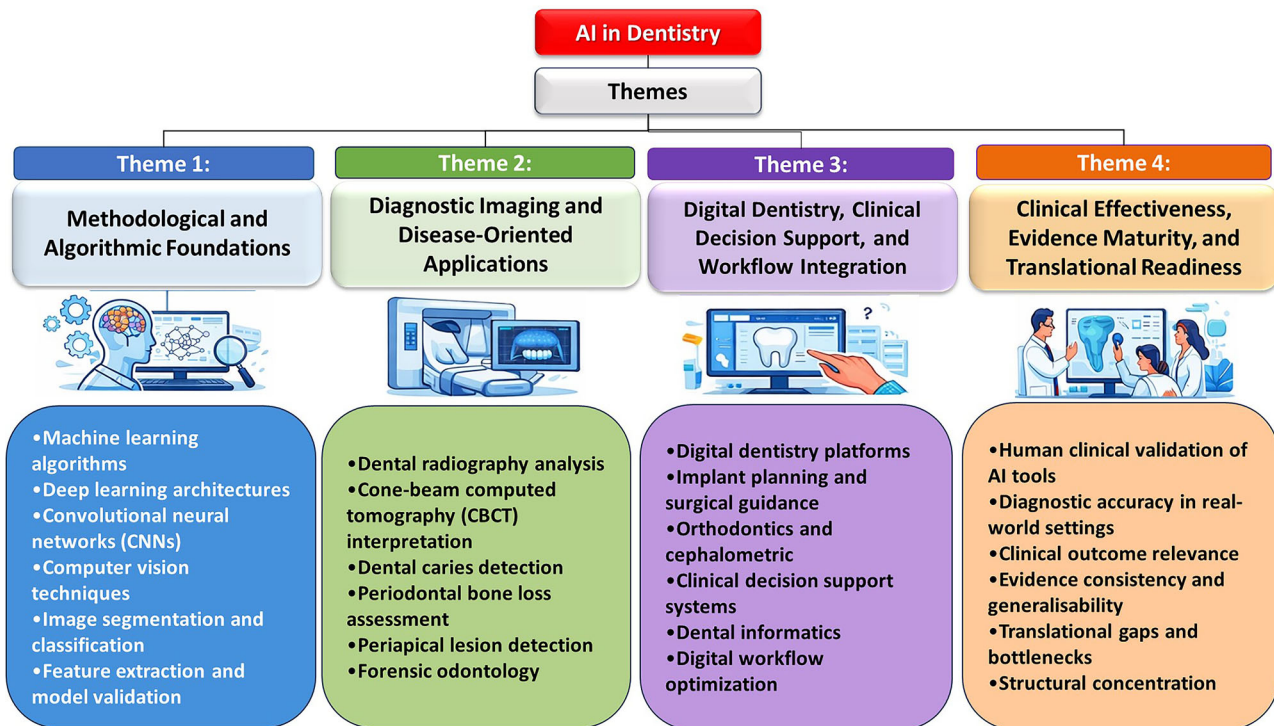


Fig. 10 Conceptual thematic roadmap summarising the principal research themes in AI applications in dentistry, highlighting the progression from methodological development and diagnostic imaging applications to digital clinical integration and translational readiness.

interpreted within the context of the available evidence syntheses rather than the entire body of primary AI research.

To synthesise these developments into a coherent conceptual framework, a thematic roadmap is presented in Fig. 10, summarising the principal research domains identified in this study.

Milestone Reviews of methodological and algorithmic foundations of AI in Dentistry

AI research in dentistry is fundamentally grounded in methodological advances in ML, DL, and computer vision, which collectively form the computational backbone of the field. Early narrative and critical reviews highlighted the potential of ML-based techniques for automated interpretation of dental data, disease prediction, and decision support, while also outlining technical and ethical challenges associated with data quality and algorithmic bias [64, 65]. These early works established the conceptual foundation for the application of AI in dental research and practice.

Subsequent reviews and mapping studies documented a rapid methodological transition toward deep learning approaches, particularly CNNs, driven by the increasing availability of digital dental imaging data. Comprehensive analyses over the past decade consistently reported the dominance of CNN-based architectures in tasks such as image classification, segmentation, and detection across panoramic radiographs, periapical images, and cone-beam computed tomography scans [49, 66, 67]. These milestone studies demonstrated that CNNs offer superior performance in automated feature extraction and pattern recognition, leading to their widespread adoption as the standard methodological framework for dental AI.

More recent systematic and critical reviews further consolidated this methodological landscape, emphasising the repeated application of similar deep learning architectures across diverse dental imaging tasks [16, 24]. While these reviews highlighted incremental improvements in model performance and robustness, they also indicated that fundamental methodological innovation has slowed, with research largely focusing on optimisation within

established algorithmic paradigms. Overall, these milestone reviews suggest that the methodological foundations of dental AI have stabilised, providing a mature computational framework that underpins the subsequent expansion of diagnostic applications and translational efforts within the field.

Milestone reviews of diagnostic imaging and disease-oriented applications of AI in Dentistry

Following the consolidation of deep learning- and CNN-based frameworks, AI research in dentistry has expanded predominantly into diagnostic imaging and disease-oriented applications. Evidence syntheses consistently identify imaging-based diagnostics as the most extensively studied and application-mature domain, encompassing radiography, CBCT, and disease detection tasks across multiple specialties. Systematic and umbrella reviews show that AI-assisted interpretation of panoramic, periapical, and bitewing radiographs improves diagnostic accuracy and inter-observer consistency [68, 69], while reviews in oral and maxillofacial radiology reinforce its role in reducing diagnostic variability and supporting clinical decision-making [70, 71].

Caries detection remains the most comprehensively synthesised disease domain, with CNN-based models demonstrating consistently high diagnostic performance [72–74]. Evidence syntheses also emphasise that AI can standardise diagnostic processes and reduce interpretation time [75, 76], although variability in study methodologies and validation approaches persists [77]. Similarly, systematic reviews report accurate AI-based detection of periodontal bone loss [78–80]. Suggesting potential support for diagnosis and treatment planning. However, methodological heterogeneity and the limited availability of high-quality annotated datasets remain important challenges.

The application of AI extends to more specialised imaging-based domains, including periapical lesion detection, tooth segmentation, dental age estimation, and forensic odontology [81, 82]. Reviews in forensic dentistry highlight the use of AI for tooth segmentation and age estimation with performance comparable to trained experts, underscoring the value of AI in

identification and medico-legal contexts [81]. These applications illustrate the breadth of disease-oriented AI research in dentistry while reinforcing the central role of imaging data across diverse use cases.

Diagnostic imaging is the most mature application domain of dental AI, characterised by repeated focus on similar imaging tasks and established algorithmic approaches. Nevertheless, limited clinical validation, external generalisability, and reliance on retrospective single-centre datasets restrict real-world translation. Accordingly, current maturity reflects technical rather than clinical readiness.

Milestone reviews of digital dentistry, clinical decision support, and workflow integration

Beyond imaging-centred diagnosis, milestone reviews increasingly describe a broader shift toward integrating AI within digital dentistry ecosystems, including treatment planning, workflow automation, and decision support. Contemporary syntheses position AI as an enabling layer across specialties, supporting diagnostic interpretation, digital treatment planning, and patient management, reflecting growing emphasis on end-to-end clinical utility rather than isolated algorithmic performance [83–85]. Nevertheless, most validated applications remain imaging-driven, with deep learning, particularly CNN, continuing to form the dominant technical backbone of workflow tools [47].

Within digital platforms, AI is discussed as enhancing treatment predictability, automating planning steps, and supporting patient communication, including digital smile design [86, 87]. Workflow-oriented applications are also reported in implant planning, prosthodontics, orthodontics, and cephalometric, where AI facilitates digital implantology pipelines, landmark identification, and standardised measurements [16, 88, 89]. Collectively, these milestone reviews indicate a clear thematic expansion from “AI for diagnosis” toward “AI for digital treatment workflows,” including dental informatics and workflow optimisation as enabling infrastructures.

However, evidence syntheses focused on deployment indicate that workflow-oriented applications remain less mature, with most studies limited to validation rather than real-world implementation. Adoption barriers include interoperability challenges, chair-side usability constraints, and the absence of consistent regulatory and evaluation frameworks [30, 90]. Moreover, the predominance of retrospective and controlled study designs underscores the need for prospective, outcome-based validation before routine clinical integration [84, 91]. Importantly, usability and human factors repeatedly emerge as practical barriers, with calls for user-centred design and clinician involvement to ensure that AI tools complement, rather than complicate, established clinical workflows.

Clinical effectiveness, evidence maturity, and translational readiness of AI in Dentistry

Despite rapid technical advancement, the clinical effectiveness and translational readiness of AI in dentistry remain under active evaluation. Recent systematic and scoping reviews emphasise that human clinical validation is a critical determinant of evidence strength, with most studies assessed using reporting standards such as PRISMA and quality frameworks including QUADAS-2 [92, 93]. Although many AI systems demonstrate strong agreement with clinician-labelled datasets, genuine human-in-the-loop validation in real clinical environments remains limited.

Across disease domains, AI has shown high diagnostic accuracy under controlled conditions. Meta-analyses and systematic reviews report favourable sensitivity, specificity, and interobserver agreement for caries detection, periodontal assessment, and radiographic interpretation [94, 95]. Bor et al. further demonstrated substantial agreement between AI outputs and clinician assessments, supporting technical validity [96]. However, most

studies rely on retrospective datasets and laboratory-based validation, raising concerns regarding generalisability to routine clinical practice.

Evidence regarding meaningful clinical outcomes is comparatively limited. While AI performance frequently aligns with established clinical guidelines [97, 98], few studies demonstrate measurable improvements in patient-centred outcomes such as disease progression, treatment success, or workflow efficiency [84, 99]. This imbalance suggests that diagnostic performance metrics often substitute for broader clinical relevance.

To complement the bibliometric findings and evaluate the methodological quality of the current evidence base, all 75 eligible systematic reviews were critically appraised using the ROBIS tool [100]. The included systematic reviews covered a broad spectrum of AI applications in dentistry, including disease detection, diagnostic imaging, image segmentation, treatment planning, implant dentistry, orthodontics, prosthodontics, and digital clinical workflows [68, 71, 72, 78, 79, 101–170]. Overall, the ROBIS assessment indicated that the methodological quality of evidence synthesis has not progressed at the same pace as technological advancement. Rather than demonstrating widespread methodological flaws, the predominance of reviews with an unclear overall risk of bias primarily reflected insufficient reporting transparency, particularly in review conduct and evidence synthesis, limiting confidence in the reliability of the available evidence.

Systematic reviews further highlight substantial heterogeneity in imaging protocols, dataset composition, and validation strategies [171]. Limited external validation across diverse populations constrains generalisability [27, 172, 173]. In addition, a structural concentration of studies within single-centre datasets and a small number of institutions may introduce dataset and institutional bias, potentially inflating reported performance.

Importantly, these findings suggest that AI in dentistry has achieved substantial technical maturity but remains at an intermediate stage of evidence maturity. Despite encouraging diagnostic performance and rapid publication growth, important translational challenges persist, including inconsistent methodological reporting in systematic reviews, limited prospective validation, insufficient evaluation of patient-centred outcomes, methodological heterogeneity, and restricted external validation. Future research should therefore prioritise high-quality multi-centre clinical studies, diversified datasets, rigorous evidence synthesis, and transparent methodological reporting to strengthen the evidence base and support the safe and effective implementation of AI in routine dental practice.

Limitations

This study has several limitations that should be acknowledged. Only English-language publications were included, which may have resulted in the exclusion of relevant studies published in other languages and potentially introduced language bias. However, English remains the predominant language of scientific communication, particularly in high-impact journals indexed in international databases, and its use is consistent with established practices in bibliometric research to ensure consistency in data extraction and analysis.

Furthermore, the bibliometric analysis was conducted using the Scopus database only. However, Scopus is one of the largest and most comprehensive multidisciplinary citation databases, providing extensive coverage of peer-reviewed literature across dentistry, medicine, engineering, and computer science. Its broad coverage and high-quality citation indexing make it particularly suitable for bibliometric analyses involving interdisciplinary fields such as artificial intelligence in dentistry.

The search strategy also employed broad AI-related terms, including “artificial intelligence”, “machine learning”, and “deep learning”. Consequently, studies referring exclusively to specific algorithms or model architectures (e.g., Transformers, Random

Forest, U-Net, EfficientNet, or YOLO) without explicitly using these broader terms may not have been retrieved. However, the selected search strategy was designed to maximise retrieval sensitivity while maintaining consistency with previous bibliometric studies and capturing the majority of AI-related research in dentistry.

Moreover, bibliometric indicators such as citation counts and total link strength primarily reflect research productivity and scholarly influence rather than methodological quality or direct clinical impact. However, these indicators remain widely accepted measures for evaluating scientific influence and mapping the evolution of research landscapes.

In addition, although the methodological quality of systematic reviews was evaluated using the ROBIS tool, the assessment relied on the completeness of methodological reporting within the published reviews. Consequently, reviews with insufficient reporting may have been classified as having an unclear rather than a low risk of bias despite the absence of major methodological flaws. Furthermore, ROBIS evaluates the methodological quality of systematic reviews rather than the quality of individual primary studies; therefore, the findings should be interpreted as reflecting the robustness of the available evidence syntheses rather than the methodological quality of the underlying AI studies.

Despite these limitations, the integration of bibliometric analysis with a comprehensive ROBIS assessment of 75 systematic reviews provides a broad overview of research development while simultaneously evaluating the methodological quality and trustworthiness of the current evidence base. These findings offer valuable insights into the evolution, evidence maturity, and translational readiness of AI in dentistry and may serve as a useful reference for future research, evidence synthesis, and clinical implementation.

CONCLUSION

This bibliometric and thematic analysis provides a comprehensive overview of AI research in dentistry between 2015 and 2025, while integrating a methodological quality assessment of systematic reviews using the ROBIS tool to evaluate the strength and trustworthiness of the current evidence base. The findings indicate rapid growth in publication output, increasing international collaboration, and a clear thematic progression from methodological development to diagnostic applications, digital workflow integration, and clinical translation. The ROBIS assessment further demonstrated that, although only a small proportion of systematic reviews exhibited a high risk of bias, the predominance of reviews with an unclear risk of bias highlights the need for improved methodological transparency and reporting in evidence synthesis. Although current evidence demonstrates strong technical performance, limitations related to retrospective study designs, heterogeneity, limited real-world validation, and inconsistent methodological reporting suggest that the field remains at an intermediate stage of evidence maturity. Collectively, these findings indicate that the future advancement of AI in dentistry should be driven not only by continued technological innovation but also by the production of robust, transparent, and clinically relevant evidence. Future research should focus on multicentre validation, standardised evaluation frameworks, high-quality systematic reviews, and clinically relevant outcomes to strengthen translational readiness and support broader clinical implementation of AI in dentistry.

DATA AVAILABILITY

All study related data are reported within the manuscript in the methods and results sections. Any further queries or clarifications may be sought by contacting the corresponding author.

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AUTHOR CONTRIBUTIONS

MYPMY, RA, NHKA, NM, MMR, and IWM conceptualised the study. INAR, NO, and NZ performed the methodology. INAR managed the software and visualisation. Validation was carried out by INAR, NO, and NZ. Formal analysis was conducted by

INAR, NO, and NZ, and the investigation was performed by INAR, NO, and NZ. Resources were provided by MYPMY, RA, NHKA, NM, and MMR. Data curation was completed by INAR, NO, NZ, and INAR prepared the original manuscript draft. MYPMY, RZ, and INAR reviewed and edited the manuscript. Supervision was provided by MYPMY, RA, NHKA, NM, MMR, and IWM. Project administration was conducted by MYPMY, RA, NHKA, NM, MMR, and IWM. Funding acquisition was secured by MYPMY, RA, NHKA, NM, and MMR. All authors reviewed and approved the final manuscript.

COMPETING INTERESTS

All authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ADDITIONAL INFORMATION

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