Imaging Science in Dentistry 2025
https://doi.org/10.5624/isd.20240237

Integration of artificial intelligence in orthodontic imaging: A bibliometric analysis of research trends and applications

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ABSTRACT

Purpose: This study employs bibliometric analysis to evaluate research trends, key contributors, and applications of artificial intelligence (AI) models in orthodontic imaging. It highlights the impact and evolution of AI in this field from 1991 to 2024.

Materials and Methods: A total of 130 documents were extracted from the Scopus database, spanning 33 years of research. The analysis examined annual growth rates, citation metrics, AI model adoption, and international collaborations. Network visualization was performed using VOSviewer to map research trends and co-authorship networks.

Results: The study analyzed 96 publications from 47 sources, revealing exponential growth in AI research—particularly after 2010, with a peak in 2023. The findings show a steady annual growth rate of 9.66% and a maximum citation count of 138 for an AI-based cephalometric analysis study. Convolutional neural networks (CNNs) and artificial neural networks (ANNs) dominate AI applications in orthodontic image analysis. An h-index of 23 and a g-index of 38 reflect the field's significant research impact. Strong international collaborations were observed, with 28.12% of studies involving cross-border research.

Conclusion: This analysis highlights the growing influence of AI in orthodontic imaging and emphasizes the need for larger datasets, improved model interpretability, and seamless clinical integration. Addressing these challenges will further enhance AI-driven diagnostics and treatment planning, guiding future research and broader clinical applications. ***(Imaging Sci Dent 20240237)***

KEY WORDS: Artificial Intelligence; Orthodontics; Diagnostic Imaging; Machine Learning

Introduction

Artificial intelligence (AI) has rapidly emerged as a transformative force across various industries, and dentistry is no exception. Over recent years, there has been a significant increase in the development and application of AI-powered tools and techniques to enhance dental care. This trend is particularly evident in the fields of medical imaging, orthodontics, and digital health. AI-driven medical imaging approaches, such as convolutional neural networks (CNNs) and artificial neural networks (ANNs), have revolutionized the accuracy and efficiency of image analysis.[1] In personalized orthodontics, machine learning algorithms have enabled more precise diagnoses and treatment planning,

This research was financially supported by the Prototype Research Grant Scheme PRGS/1/2023/SKK07/UITM/02/1.
Received November 22, 2024; Revised March 4, 2025; Accepted March 7, 2025
Published online April 10, 2025
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leading to more effective and tailored orthodontic care.[2] The integration of AI-powered digital tools, including ChatGPT, has opened new avenues for patient communication, education, and support.[3] Collectively, these advancements point to a future where dentistry becomes increasingly personalized, efficient, and technologically advanced. As AI continues to evolve, its impact on orthodontic care is expected to grow, resulting in improved patient outcomes and a more streamlined orthodontic experience.

Recently, researchers have increasingly employed bibliometric analysis to gain deeper insights into the current state and future directions of scientific research within their fields.[4,5] This approach tracks the development of knowledge on specific topics and identifies key sources, authors, organizations, and countries involved in the research. Several studies have specifically examined the use of AI in dental research.[4] These investigations provide valuable insights into the quantity, diversity, and quality of AI-related scientific output in dentistry, serving as a resource for clinical treatment planning and decision-making. Moreover, they help shape future research directions in this area. By leveraging this information, journal editors, peer reviewers, and publishers can prioritize submissions that address AI-related topics.

To fully understand the scope and nature of scientific literature on AI in dentistry, it is essential to perform a thorough analysis of these articles. This study aims to evaluate the current state of research on AI in orthodontic imaging using bibliometric methods. The analysis is intended to provide valuable insights for the dental research community and offer a comprehensive understanding of how researchers are employing AI in this field.

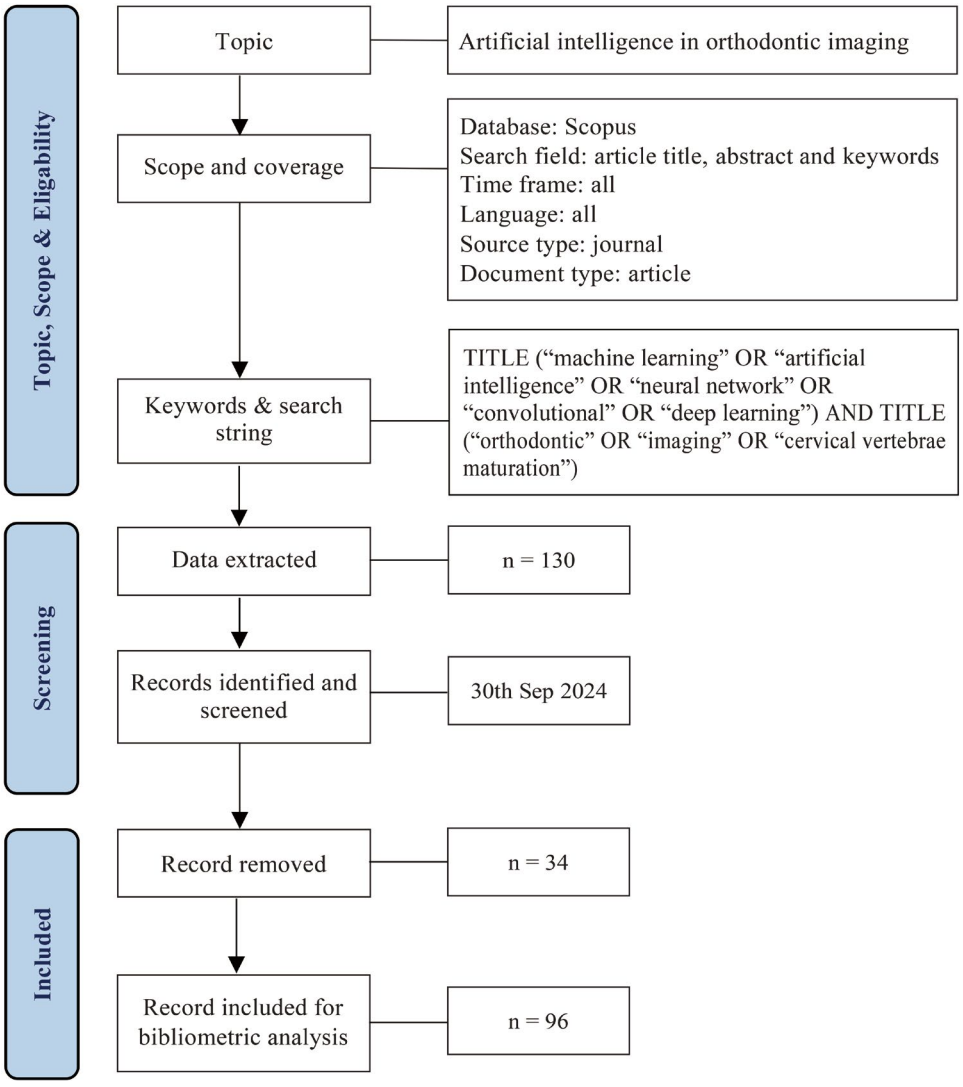

Fig. 1. Flow diagram of the search strategy.

Materials and Methods

A rigorous electronic search strategy was implemented using the Scopus database (Elsevier) to include articles published from its inception until September 30, 2024, exclusively in English.[6] The search utilized a combination of keywords, synonyms, and Medical Subject Headings (MeSH) related to AI applications in orthodontics (Fig. 1). Studies were included if they explicitly discussed AI-driven orthodontic imaging techniques, including machine learning applications. Editorials, letters, and non-research publications were excluded.

To identify and analyze pertinent studies, a 2-tiered approach was employed. Initially, 2 independent reviewers screened titles and abstracts to exclude irrelevant articles. Any disagreements were resolved through consensus and discussion with a third investigator.

The selection process included original scientific papers, case studies, and review articles published in reputable dental, scientific, or multidisciplinary journals. All selected articles were required to include relevant AI terminology in their titles, abstracts, or keywords. Editorials, letters, news articles, and other non-research publications were excluded.

To evaluate the impact of documents related to AI in orthodontic imaging, a citation analysis was conducted, which involved assessing the number of times each work was cited by other publications.[7] Harzing's "Publish or Perish" and Scientopy tools were used to calculate citation metrics,[8] while VOSviewer software[9] was employed to analyze research trends through co-citation and keyword mapping, thereby visualizing relationships among influential publications. The data, extracted from Scopus in CSV format, underwent association-based normalization and density-based clustering to improve analytical accuracy.[10]

After data extraction and selection, the research questions were analyzed using co-occurrence networks of significant phrases[11] in research on AI and orthodontic imaging. This comprehensive bibliometric analysis aimed to elucidate the role of AI in orthodontics research, identifying prevailing trends and potential avenues for future inquiry.

Results

A total of 130 literature titles were extracted from the Scopus database. Of these, 34 were excluded due to language constraints or because the articles were not available in full text. After applying all selection criteria, the final dataset consisted of 96 documents, predominantly journal articles (77%) complemented by 22 review articles (23%), reflecting a mix of original research and critical evaluations of AI in orthodontics. This bibliometric analysis, conducted using Scientopy software, yields significant insights into the integration of AI within the field of orthodontics, elucidating research trajectories and identifying potential domains for future inquiry (Table 1).

Table 1. Summary of relevant data

	Description	Results
Main information about data	Timespan (33 years)	1991:2024
	Sources (journals, books, etc)	47
	Documents	96
	H-index	23
	G-index	38
	Annual growth rate %	9.66
	Document average age	2.32
	Citations	1680
	Average citations per doc	17.5
	Average citations per year	50.91
	References	3513
Document contents	Keywords plus	431
	Author's keywords	174
Authors	Authors	450
	Authors of single-authored docs	2
	Authors per paper	5.52
Authors collaboration	Single-authored documents	2
	Co-authors per document	5.8
	International co-authorships %	28.12
Document types	Article	74
	Review	22

Table 1 provides a comprehensive snapshot of research trends and collaborations in the field as of September 30, 2024. Over a span of 33 years, 96 documents were published across 47 journals, with an annual growth rate of 9.66%, indicating increasing interest in AI and orthodontic imaging research. An h-index of 23 and a g-index of 38 reflect the impact of this research; specifically, 23 documents have been cited at least 23 times each, while the g-index highlights the most highly cited publications. The total citation count is 1,680, averaging 17.5 citations per document and 50.91 citations per year. This suggests that the published works have received moderate attention, contributing to the field's development. The average age of the documents is 2.32 years, underscoring that much of the research is relatively recent, likely driven by the rise of AI technologies in healthcare. A total of 174 author keywords were identified, reflecting the diversity and specificity of

Table 2. Summary of key characteristics of the included papers

	Classification	Total publication	Percentage (N = 96)
Country	United States	21	21.9%
	China	15	15.6%
	Turkey	12	12.5%
	India	10	10.4%
	Saudi Arabia	8	8.3%
	South Korea	6	6.3%
	Germany	5	5.2%
	United Arab Emirates	5	5.2%
Subject area	Dentistry	60	62.5%
	Medicine	33	34.4%
	Biochemistry, genetics, and molecular biology	12	12.5%
	Computer science	7	7.3%
	Engineering	7	7.3%
	Chemical engineering	6	6.3%
	Material science	4	4.2%

topics within the field, with a strong focus on AI, machine learning, and deep learning applications in orthodontics. The involvement of 450 authors—averaging 5.52 authors per paper—indicates significant collaboration, and 28.12% of the publications involved international co-authorship, highlighting cross-border research efforts. This data underscores the increasing relevance of AI in orthodontic imaging, the collaborative nature of the field, and the growing citation impact of its research outputs.

Table 2 presents the characteristics of publications by country and subject domains. Research has been conducted across both developed and developing nations. Developed countries, including the United States (21.9%), South Korea (6.3%), and Germany (5.2%), contribute 33.4% of the total publications. Meanwhile, developing nations such as China (15.6%), Turkey (12.5%), India (10.4%), and Saudi Arabia (8.3%) collectively account for nearly half (46.8%) of the top 10 countries with the highest publication counts.

Research interest has been led by the United States, which accounted for the highest number of publications (n = 21, 21.9%), followed by China (n = 15, 15.6%) and Turkey (n = 12, 12.5%). India, Saudi Arabia, and South Korea—representing Asian countries—each contributed a comparable share of publications (10.4%, 8.3%, and 6.3%, respectively), while developed countries such as Germany and the United Arab Emirates each accounted for 5.2% of the publications (n = 5).

Although American institutions currently dominate the landscape of recent publications, increasing contributions from Asian universities—especially in South Korea and China—underscore the expanding global perspective in this field. Collaborative efforts among these productive institutions could yield valuable insights and further accelerate advancements in AI-driven orthodontic research.

Publication trend analysis

Publication trend analysis reveals that the inaugural article on "AI in Orthodontic Imaging" was published in English in 1991. Between 1991 and September 30, 2024, the Scopus database catalogued a cumulative total of 96 publications and 1,680 associated references on this subject. During this period, the annual publication growth rate was calculated at 9.66% (Fig. 2). Notably, the trend experienced a significant upsurge after 2018, with publication numbers peaking in 2023.

The initial exploration of AI in orthodontic imaging dates back to 1991 with the publication of "Artificial intelligence in the dental surgery: an orthodontic expert system, a dental tool of tomorrow" in *Dental Update*.[12] However, following this pioneering work, the field experienced a prolonged lull, with minimal academic contributions over the next 2 decades.

A renewed interest in AI for orthodontic applications emerged in the 2010s. The 2010 article by Xie et al. in *Angle Orthodontist*, which focused on predicting the need for extractions using neural networks, marked a significant milestone.[13] Nonetheless, the field remained relatively understudied until 2020.

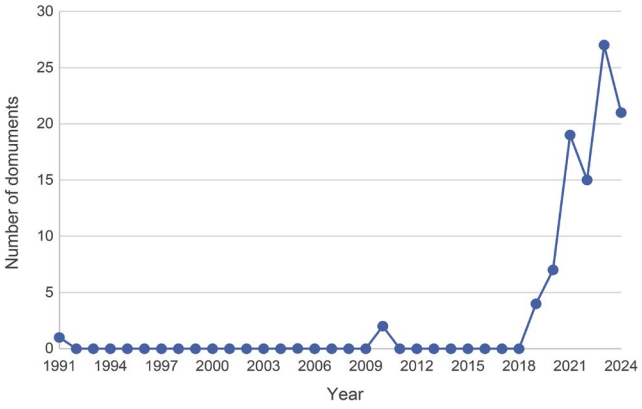

Fig. 2. Publication trends.

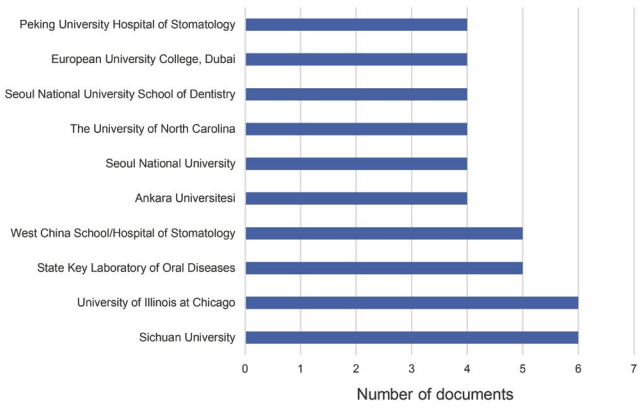

Fig. 3. Documents by institutional affiliation.

A turning point occurred in 2020 with the introduction of a deep learning-based approach for detecting early gingivitis in orthodontic patients by Alalharith et al.[14] This breakthrough catalyzed a substantial increase in academic publications, rising from 7 articles in 2020 to 19 in 2021 (Fig. 2). This upward trend has continued, indicating growing momentum in the application of AI to orthodontic practice.

In summary, although early exploration of AI in orthodontic imaging was limited, recent years have witnessed a remarkable surge in research and development. This exponential growth suggests that AI is poised to play an increasingly significant role in the future of orthodontic treatment and patient care.

Institutional analysis

Figure 3 delineates the 10 top institutions publishing scholarly articles on this subject. Notably, Sichuan University[15-20] and the University of Illinois at Chicago[21-26] have each produced the highest research output on AI in orthodontic imaging, with a total of 6 publications apiece. Their recent contributions establish them as the preeminent institutions in Asia and America, respectively, currently advancing academic inquiry in this domain.

Tied for the second-most prolific positions are 2 Sichuan institutions closely affiliated with Sichuan University: the State Key Laboratory of Oral Disease and the West China School of Stomatology/Hospital of Stomatology. Each of these institutions produced 5 papers during the period from 2016 to 2024. Their research focused on topics such as automated diagnosis and treatment planning, cervical vertebral maturation (CVM) assessment, facial morphology prediction, 3D imaging analysis, patient monitoring, ethical implications, and tele-orthodontics.

In third place, with 4 publications each, are 6 institutions as illustrated in Figure 3. The research focus of these institutions emphasizes the integration of AI across various orthodontic domains to enhance clinical practice. Key areas include diagnostic imaging and analysis, where AI improves the interpretation of orthodontic imaging data and automates assessments such as cervical vertebral maturation; treatment planning, which uses AI algorithms for personalized treatment and predictive analytics; and patient compliance and behavior prediction, aimed at forecasting adherence and personalizing engagement strategies. Additionally, facial aesthetic assessments utilize AI to predict aesthetic outcomes and analyze post-treatment facial changes, while the integration of digital technologies merges AI with digital tools for enhanced diagnostics and tele-orthodontics. Finally, the ethics and challenges of AI adoption highlight the need to address data privacy, algorithmic biases, and reliability to ensure responsible clinical implementation.[27-45]

Journal analysis

Table 3 presents a detailed overview of the 10 most influential active journals in this domain. In the field of orthodontics, the journal *Orthodontics and Craniofacial Research* published the most articles on AI, with 10 articles. The next most productive journals were the *American Journal of Orthodontics and Dentofacial Orthopedics* and *Seminar in Orthodontics*, each recording 7 publications. It is noteworthy that the former is classified as Q1 with strong metrics, whereas the latter lacks comparable citation metrics.

Progress in Orthodontics was identified as the journal with the highest impact based on various evaluative metrics, having published 4 relevant articles. This journal has a 2023 Cite Score of 7.3, an Scimago journal rank (SJR) of 1.392, a source normalized impact per paper (SNIP) of 1.962, and is classified within the first quartile according

Table 3. Most active sources

Source titles, publisher (number)	Cite score 2023	SJR 2023	SNIP 2023	JCI	CQ	IF
Orthodontics and Craniofacial Research, Wiley (10)	5.3	0.97	1.68	0.92	Q2	2.4
American Journal of Orthodontics and Dentofacial Orthopedics, Mosby-Elsevier (7)	4.8	1.28	1.566	1.22	Q1	2.7
Seminar in Orthodontics, WB Saunders (7)	NA	0.41	NA	NA	NA	NA
Angle Orthodontist, Research Foundation (4)	6.4	1.45	1.998	1.5	Q1	3.0
APOS Trends in Orthodontics, Scientific Scholar (4)	0.8	0.174	0.261	0.20	Q4	0.5
Korean Journal of Orthodontics, Korean Association of Orthodontists (4)	3.5	0.685	1.300	1.03	Q1	2.6
Progress in Orthodontics, Springer (4)	7.3	1.392	1.962	0.67	Q1	3.5
Applied Sciences (Basel), MDPI (3)	5.3	0.508	0.924	0.56	Q2	2.5
Diagnostics, MDPI (3)	4.7	0.667	0.912	0.87	Q1	3.0
Healthcare Switzerland, MDPI (3)	3.5	0.606	0.784	0.95	Q2	2.4

SJR: SCImago journal rank, SNIP: source normalized impact per paper, JCI: journal citation indicator, CQ: category quartile, IF: impact factor, NA: not available, MDPI: multidisciplinary digital publishing institute

to its journal citation indicator (JCI). Another significant publication is *Angle Orthodontist*, which also published 4 articles and has a Cite Score of 6.4, an SJR of 1.45, and a SNIP of 1.998, placing it in the top quartile. It is important to note that these journals are highly rated within the field of orthodontics.

APOS Trends in Orthodontics contributed 4 papers to the literature, though with lower quartile rankings within the dataset, while other Swiss journals each contributed 3 articles and exhibited higher citation metric impact. In conclusion, this analysis offers a comprehensive overview of the journals involved in this discourse, highlighting that orthodontic journals are the most prolific and that the leading journals contribute substantially in terms of both publication volume and citation influence.

Impact analysis with top-cited articles

Table 4 presents the 10 most cited academic publications related to AI in orthodontic imaging from previous research efforts. The article with the highest citation count, "Artificial intelligence in orthodontics: Evaluation of fully automated cephalometric analysis using customized convolutional neural network" by Kunz et al.[46] (2020), received 138 citations. These authors were among the first to develop an AI algorithm that analyzes cephalometric X-rays with expert-level accuracy and can be easily integrated into clinical workflows on standard computers. They suggest that future work should expand training data diversity, improve user interfaces, and explore broader diagnostic applications.

The second most cited manuscript, "Artificial neural network modelling for deciding if extractions are necessary prior to orthodontic treatment" by Xie et al. (2010), amassed 119 citations.[13] This study was among the first to use ANNs to enhance orthodontic decision-making regarding extractions by accurately predicting key treatment factors. The authors recommended validation with larger datasets, improvements to the ANN model, and exploration of other orthodontic applications while addressing limitations such as sample size and long-term clinical outcomes.

The third most cited article, by Kok et al. (2019), investigated 7 AI classifiers for determining cervical vertebrae stages using cephalometric radiographs from 300 individuals, analyzing 19 reference points and 20 linear distances.[47] The study found that ANNs were the most reliable algorithm, highlighting AI's potential in orthodontic imaging. The authors recommended improving algorithm training with larger datasets, developing user-friendly software for orthodontists, and conducting comparative studies with other skeletal maturation methods.

Several highly cited papers on AI in orthodontic imaging focus on the use of ANNs and CNNs to enhance diagnostic capabilities and treatment planning. These studies demonstrate that AI can achieve accuracy levels comparable to those of experienced clinicians while providing valuable support to less experienced practitioners. Although some reviews highlight methodological issues and selection biases, they emphasize AI's potential to improve clinical decision-making and streamline orthodontic procedures.[42,48]

However, AI applications in orthodontic imaging are still in the early stages of development with limited clinical implementation. Machine learning models often struggle to address the specific causes of orthodontic issues and may not fully account for oral diseases in treatment plans. Deep learning models also face challenges related to transparen-

Table 4. Highly cited articles (minimum 40 citations)

Authors	Title	Publication	Cites/author	Cites/year	Type
Kunz et al.[46]	Artificial intelligence in orthodontics: evaluation of fully automated cephalometric analysis using customized convolutional neural network	*Journal of Orofacial Orthopedics*	138	34.5	Original article
Xie et al.[13]	Artificial neural network modeling for deciding if extractions are necessary prior to orthodontic treatment	*Angle Orthodontist*	119	8.5	Original article
Kök et al.[47]	Usage and comparison of artificial intelligence algorithms for determination of growth and development by cervical vertebrae stages in orthodontics	*Progress in Orthodontics*	94	18.8	Original article
Khanagar et al.[48]	Scope and performance of artificial intelligence technology in orthodontic diagnosis, treatment planning, and clinical decision-making - a systematic review	*Journal of Dental Sciences*	87	29	Review
Li et al.[20]	Orthodontic treatment planning based on artificial neural networks	*Scientific Reports*	86	17.2	Original article
Bichu et al.[42]	Applications of artificial intelligence and machine learning in orthodontics: a scoping review	*Progress in Orthodontics*	79	26.3	Review
Amasya et al.[28]	Cervical vertebral maturation assessment on lateral cephalometric radiographs using artificial intelligence: comparison of machine learning classifier models	*Dentomaxillofacial Radiology*	56	14	Original article
Mohammad-Rahimi et al.[49]	Machine learning and orthodontics, current trends and the future opportunities: a scoping review	*American Journal of Orthodontics and Dentofacial Orthopedics*	50	16.7	Review
Chen et al.[35]	Machine learning in orthodontics: introducing a 3s auto-segmentation and auto-landmark finder of CBCT images to assess maxillary constriction in unilateral impacted canine patients	*Angle Orthodontist*	48	12	Original article
Tanikawa and Yamashiro[64]	Developmental of novel artificial intelligence systems to predict facial morphology after orthognathic surgery and orthodontic treatment in Japanese patients	*Scientific Reports*	47	15.7	Original article
Suhail et al.[61]	Machine learning for the diagnosis of orthodontic extractions: a computational analysis using ensemble learning	*Bioengineering*	47	11.75	Original article
Monill-González et al.[75]	Artificial intelligence in orthodontics: where are we now? a scoping review	*Orthodontics and Craniofacial Research*	45	15	Review
Gandedkar et al.[76]	Role of virtual reality (VR), augmented reality (AR) and artificial intelligence (AI) in tertiary education and research of orthodontics: an insight	*Seminars in Orthodontics*	40	13.33	Original article

cy and interpretability, necessitating clinicians' reliance on their judgment. These reviews call for further research to strengthen AI's role in early detection, personalized treatment, and interdisciplinary collaboration within orthodontic practice.[49]

Topic analysis utilizing trending keywords

A comprehensive co-occurrence analysis of author keywords was performed using VOSviewer to delineate the intellectual framework of the literature (Fig. 4). An initial corpus of 568 keywords, extracted from the selected scholarly articles, was refined by merging singular and plural forms, resulting in 56 prevalent terms that met the criterion of at least 5 occurrences. The resulting network map, comprising 24 of these keywords, was categorized into 3 clusters based on their co-occurrence frequencies. This classification facilitates the identification of the principal themes and interconnections among keywords used in research on AI in orthodontic imaging.

The visualization of the network map assigned different colors to 3 distinct clusters, each representing a particular theme.

Cluster 1 (Red): AI-driven skeletal growth assessment and imaging

The red cluster emphasizes the early applications of AI in orthodontic imaging during the mid-2020s, focusing particularly on smart learning concepts and the use of CNNs for assessing skeletal maturity and diagnostic imaging. Deep learning methods, especially CNNs, play a critical role in analyzing cephalometric data and lateral cephalograms.[50,51] Key topics within this cluster include bone maturation, cephalometric analysis, and cervical vertebrae evaluation, all of which are essential for estimating a patient's growth phase.[27,52] By leveraging AI models, orthodontists can significantly enhance the accuracy of growth stage predictions based on skeletal and radiographic data, leading to more informed treatment planning.

Additionally, this cluster addresses the application of ANNs and machine learning techniques to overcome challenges in tooth segmentation within both 2D and 3D dental radiography.[53] It highlights AI applications in teeth segmentation and lateral cephalography landmark detection, marking the emergence of semi- and fully automated models in orthodontic imaging that further support diagnostic accuracy and treatment planning.[46,51,54-56]

Cluster 2 (Green): AI in clinical orthodontic procedures and treatment planning

The green cluster focuses on the crucial role of AI in improving clinical procedures within orthodontics, showcasing its applications in complex treatments such as cone-beam computed tomography (CBCT) imaging,[57,58] tooth extractions,[59,60] and orthognathic surgery. By harnessing AI, orthodontists can analyze intricate data derived from dental procedures, which leads to improved treatment planning

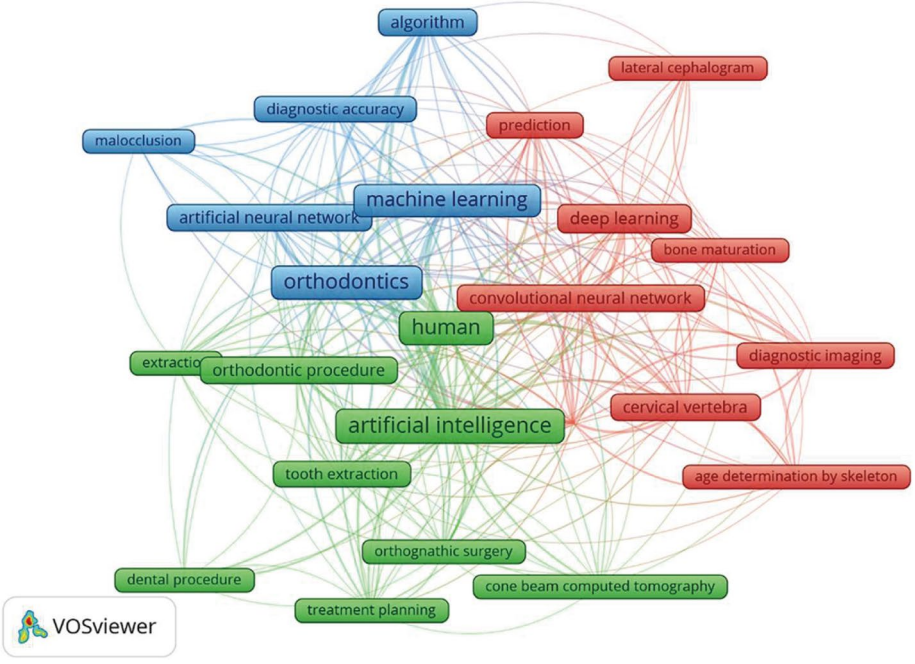

Fig. 4. Network visualisation map of co-occurrence of author keywords.

and better patient outcomes. For example, AI algorithms can process and interpret imaging data with increased speed and accuracy, enabling more precise diagnoses and personalized treatment strategies.

Moreover, AI's influence extends beyond diagnostics; it significantly informs surgical interventions and treatment decisions by providing orthodontists with valuable insights. Despite these advancements, final treatment planning decisions still heavily rely on the clinician's expertise, highlighting the collaborative nature of AI in clinical practice.[61] This cluster also explores automation, examining how AI can streamline clinical decision-making processes and optimize orthodontic treatment planning.[13,38] In doing so, it addresses challenges related to automating AI models, including the need for extensive training data and ensuring system reliability and transparency. Additionally, the integration of AI into daily practice is a critical focus, as orthodontists navigate the complexities of incorporating advanced technologies while maintaining high standards of patient care.[62] Ultimately, Cluster 2 underscores the transformative potential of AI in orthodontic imaging, aiming to enhance both the efficiency and effectiveness of clinical procedures while fostering collaboration between technology and clinical expertise.[20,63]

Cluster 3 (Blue): machine learning and diagnostic accuracy in orthodontics

This blue cluster highlights the transformative potential of machine learning and ANNs in the field of orthodontic imaging, specifically aiming to increase diagnostic accuracy and treatment efficacy.[12,18] This cluster of research harnesses advanced algorithms to address the critical need for precise identification of malocclusion, a common orthodontic condition that can significantly impact both aesthetic outcomes and functional performance.[33,64] Improving diagnostic capabilities through machine learning not only helps clinicians make more informed decisions but also plays a pivotal role in optimizing treatment strategies tailored to individual patient needs.

In addition to increasing diagnostic accuracy, the research in cluster 3 emphasizes the development of algorithms designed to automate various orthodontic tasks, thereby streamlining workflows and improving overall efficiency in clinical settings.[65] This automation covers a range of procedures, from initial assessments to ongoing monitoring, ultimately creating a more cohesive treatment experience for patients.[66] However, the cluster also recognizes the challenges of AI model interpretability, which is essential for ensuring that clinicians can effectively understand and trust AI-driven recommendations.[67] Furthermore, integrating these sophisticated models into existing clinical practice remains a critical hurdle that requires ongoing research and collaboration among orthodontic professionals, data scientists, and policymakers.[68] By addressing these challenges, the research in cluster 3 aims to pave the way for more effective, AI-enhanced orthodontic care that is grounded in both technological innovation and practical applicability.

Each cluster highlights a distinct dimension of AI's expanding role in orthodontic imaging, encompassing image analysis, clinical procedures, and algorithm-driven decision-making. Overall, the network map offers a comprehensive overview of the key themes and their interconnections in research on AI in orthodontic imaging research, providing researchers and scholars with deeper insights into the multifaceted nature of the field.

Discussion

The study aimed to address several research questions regarding publications on AI in orthodontic imaging. Scopus was selected as the database for this study because of its comprehensive author and institution profiles, which are generated through advanced profiling algorithms and expert curation. This approach ensures high precision and recall in the data. Owing to its reliability, Scopus is widely used as a bibliometric data source for research reviews, landscape studies, scientific policy evaluations, and university rankings. The database compiles journals, conference proceedings, and book series submitted by editors and publishers, and prospective content undergoes a rigorous review process based on scientific quality and integrity. The analysis addressed the following research questions (RQs):

1. RQ1: How have publication trends in AI in orthodontic imaging evolved over time?

Publication trends in AI in orthodontic imaging have evolved significantly since the inception of the field, reflecting a growing convergence of multiple disciplines. The first recorded work in 1991 explored AI as an orthodontic tool, but the field saw minimal academic contributions for nearly 2 decades.[12] Renewed interest in the 2010s brought some key developments, including research using neural networks to predict the need for orthodontic extractions in 2010.[13,59] However, AI in orthodontic imaging remained relatively underexplored until 2020.

A significant turning point occurred in 2019, when machine learning and AI techniques began being applied in orthodontics for facial image analysis, cervical vertebrae growth

assessment, and treatment planning using ANNs.[20,47,53,69] Research output increased notably, from 7 publications in 2020 to 19 in 2021, reflecting growing momentum in AI applications for orthodontic practice.[14,37,43,57,64,70] By September 2024, a total of 96 publications and 1680 references had been recorded in the Scopus database, with an annual growth rate of 9.66%. The trend reached its peak in 2023 and is expected to exceed this level by the end of 2024.[21,37]

While early progress was slow, recent years have witnessed rapid growth in AI research in orthodontic imaging, with diverse applications spanning multiple disciplines. This trend suggests that AI will play an increasingly significant role in shaping the future of orthodontic treatment and patient care.

2. RQ2: Which countries lead in research on this topic based on publication output?

The United States is at the forefront of research on AI in orthodontic imaging, contributing the highest number of publications. Following the U.S., China and Turkey are significant contributors, with China demonstrating a particularly strong presence. Developed countries such as South Korea and Germany also play notable roles, collectively accounting for a substantial portion of the total output.

Conversely, developing nations, including China, India, Turkey, and Saudi Arabia, form a significant part of the research landscape, reflecting an increasing emphasis on AI in orthodontic imaging in these regions. This indicates a notable shift towards heightened research activity, especially among Asian countries.

Although American institutions currently dominate the publication landscape, rising contributions from Asian universities, particularly in South Korea and China, underscore a broader global perspective in this field. Collaborative efforts among these institutions could yield valuable insights and accelerate advancements in AI-driven orthodontic research, suggesting that the research landscape is becoming increasingly diverse and interconnected.

3. RQ3: What are the top cited articles on this topic globally?

The most-cited article in AI in orthodontic imaging focuses on the evaluation of semi-automated cephalometric analysis using customized CNNs.[46] This study developed an AI algorithm capable of analyzing cephalometric X-rays with expert-level accuracy and underscores the need for more diverse training data, improved user interfaces, and broader diagnostic applications in future research. Another significant study employed ANNs to refine decision-making regarding extractions before orthodontic treatment, representing a considerable advancement in orthodontic decision-making through accurate predictions based on key treatment factors.[13]

Others among the most highly cited studies compare ANN and CNN techniques to achieve accurate diagnoses and support various orthodontic applications—including treatment planning, extractions, tooth segmentation, and facial analysis—with the aim of identifying the most effective algorithm while progressing toward full automation without manual segmentation.[54,56]

Additionally, comprehensive reviews examining AI's role in enhancing diagnostic capabilities and treatment planning reveal that AI can achieve accuracy levels comparable to those of experienced practitioners while also providing valuable support to less experienced clinicians. Despite some methodological issues and selection biases, these studies collectively underscore the promising potential of AI to improve clinical decision-making and streamline orthodontic procedures.

4. RQ4: Which journals have published the most on this topic?

Within the field of orthodontics, *Orthodontics and Craniofacial Research* emerged as the leading journal for publications on AI, featuring a notable volume of articles. Following this, the *American Journal of Orthodontics and Dentofacial Orthopedics* and *Seminars in Orthodontics* have also made significant contributions; however, while the former is recognized as a Q1 journal with robust metrics, the latter lacks comparable citation metrics, reflecting differences in academic impact.

The journal with the highest overall impact was found to be *Progress in Orthodontics*, which has published several key articles in this area and is distinguished by its impressive citation metrics, indicating substantial influence within the academic community. Additionally, *Angle Orthodontist* has published a significant number of articles, supported by robust citation figures that position it among the top-tier journals in the field.

Overall, this analysis offers a comprehensive overview of the key journals engaged in the discourse on AI in orthodontic imaging. It shows that orthodontic journals are among the most prolific in this research area and highlights the leading publications that contribute significantly based on both article volume and citation influence. These insights are essential for understanding the research landscape in orthodontic imaging and identifying the journals shaping its future.

5. RQ5: What are the commonly utilized author keywords or topics in research related to AI in orthodontic imaging?

Research on AI in orthodontic imaging frequently employs keywords and topics that emphasize the transformative role of AI in various aspects of the field. A key area of focus is skeletal growth assessment and diagnostic imaging, where AI algorithms significantly enhance the analysis of cephalometric data, enabling orthodontists to estimate skeletal maturity with greater accuracy.[32,65,67] These AI-driven tools improve predictions of growth stages based on radiographic data, thereby facilitating informed, patient-specific treatment decisions.

In addition, the integration of AI in clinical procedures is a common theme, particularly in streamlining complex treatments such as imaging and surgical planning. Advancements in imaging techniques have improved outcomes by enabling the analysis of extensive data from dental procedures.[71] AI not only supports diagnostic processes but also aids in treatment decisions involving tooth extractions and orthognathic surgeries, while still relying on clinician expertise for final judgments. The use of machine learning further enhances diagnostic accuracy, especially in identifying malocclusion and optimizing treatment strategies. Overall, these keywords and topics reflect a growing recognition of AI's multifaceted contributions to orthodontics, underscoring the need for continued research and development in this rapidly evolving field.[63]

6. RQ6: How far has research in AI in orthodontic imaging progressed?

Key thematic areas in AI applications within orthodontic imaging include diagnosis, treatment planning, and patient management. One significant focus is the development of automated diagnosis and treatment planning tools, where AI algorithms analyze diagnostic images—such as cephalograms—to support clinical decision-making. Additionally, AI is used for automated assessment of cervical vertebral maturation (CVM) stages, which is critical for determining the optimal timing of orthodontic interventions.[72-74] Furthermore, AI techniques are employed to predict changes in facial morphology following orthodontic treatments or orthognathic surgery, thereby aiding in pre-treatment planning and patient consultations. The processing and analysis of 3D imaging data, particularly from CBCT scans, further enhance diagnostic accuracy and treatment strategies.[35]

Beyond clinical applications, the integration of AI in orthodontic imaging raises important ethical and social considerations. These include issues of data privacy, algorithmic bias, and the necessity for human oversight in AI-driven decision-making processes. Another critical area is the development of AI systems for patient monitoring and compliance prediction, which enables remote tracking of orthodontic patients and anticipates adherence to treatment regimens based on behavioral data. Moreover, the role of AI in teleorthodontics is gaining traction, particularly with the growth of digital health services that support remote consultations and monitoring. Collectively, these themes illustrate the transformative potential of AI in orthodontic imaging while emphasizing the need to carefully consider its broader implications in practice.

7. RQ7: What issues obstruct research on AI in orthodontics imaging?

Research on AI in orthodontic imaging faces several significant obstacles that hinder progress and publication. One primary challenge is the limitation of available datasets, which often restricts the ability to train and validate AI models effectively. These limited datasets can result in automated models that fail to match the performance and accuracy of human observers, thereby complicating outcome validation. This discrepancy can lead to difficulties in publishing findings in reputable databases such as Scopus, which uphold rigorous standards for data quality and model performance.

Additionally, the pursuit of fully automated models presents another major hurdle.[63,71] Developing such models requires comprehensive training and testing datasets that accurately represent the diverse clinical scenarios encountered in orthodontics. Without sufficient and varied data, the effectiveness of AI tools in supporting clinicians with diagnosis and treatment planning remains limited. Addressing these issues through expanded datasets and continued research into model performance is crucial for advancing the field and achieving meaningful integration of AI into orthodontic practice.[45,75]

This bibliometric analysis highlights the growing impact of AI in orthodontic imaging, driven by advancements in machine learning and an expanding global research output. The United States leads in contributions, while emerging studies from China and South Korea highlight the need for stronger international collaboration. Key research themes include AI applications in skeletal growth assessment, diagnostic imaging, and clinical decision-making, although ethical considerations and clinician-patient dynamics remain underexplored. AI research is disseminated through leading journals such as *Orthodontics and Craniofacial Research* and *Progress in Orthodontics*, with opportunities for broader

interdisciplinary engagement. Despite significant progress, challenges persist regarding dataset availability, model interpretability, and clinical implementation. Addressing these issues through expanded datasets, enhanced methodological rigor, and closer collaboration between AI developers and clinicians will further integrate AI into clinical practice. Future research should focus on ethical considerations, diverse methodologies, and stakeholder-driven innovations to optimize AI-driven diagnostics and treatment planning, ultimately improving patient outcomes in orthodontic care.

Conflicts of Interest: None

Acknowledgments

The authors would like to express their gratitude to Univeristi Teknologi MARA and its affiliations for their support and resources provided during this study. Special thanks to team members for their invaluable contributions and guidance throughout this research.

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