University J Dent Scie 2024; Vol. 10, Issue 4

Shaping smiles with AI: a comprehensive review of artificial intelligence in orthodontics

Abstract:
The application of artificial intelligence (AI) to orthodontics is transforming the discipline by making it possible to plan treatments, make diagnoses, and monitor patients with greater accuracy. The use of AI technologies in orthodontic practice, including computer vision, deep learning, and machine learning, is examined in this paper. Personalized therapy protocols, predictive modeling for treatment results, and automated cephalometric analysis are important areas of emphasis. Current issues including data privacy, algorithmic bias, and the requirement for standardized data sets are explored alongside AI's promise to increase productivity, improve patient outcomes, and support clinical decision-making. The paper also provides a research roadmap and discusses current developments in AI-driven orthodontic tools. Orthodontics can gain from increased workflow automation and more accurate treatments by using AI into clinical practice.

Key-words: Artificial intelligence, orthodontics, machine learning, deep learning, cephalometric analysis, predictive modeling, treatment outcomes, personalized orthodontics, clinical decision-making, AI-driven tools.

Introduction:

Definition and scope of AI in Orthodontics:

In orthodontics, artificial intelligence (AI) is being utilized to enhance clinical effectiveness, treatment planning, and diagnostic precision. Robust dental image analysis, treatment outcomes, and task automation are achieved by the application of machine learning, deep learning, and computer vision techniques.[1] This includes real-time patient progress tracking, customized treatment programs, and automatic malocclusion diagnosis. Traditional orthodontic treatment is being transformed by the use of AI in orthodontic practice, which increases accuracy, improves patient outcomes, and simplifies clinical workflows.

Historical context and evolution of AI in dentistry:

Since the late 20th century, dentistry has incorporated AI, initially focusing on expert systems that emulate human decision-making.[3] The 1990s witnessed the emergence of advanced AI algorithms, enabling the examination of more extensive datasets and intricate patterns. These algorithms were employed to automatically analyze dental X-rays, detecting cavities and gum disease with improved accuracy.[4] The 21st century has experienced a swift increase in AI adoption across dental fields, propelled by

[1]SAVEEN NELLIKOTTU SOMAN, [2]NADEER THOMMANCHERI, [3]SAJNA MANKADAVATHU PUTHENVEETIL, [4]AMRIC MUKUNDAN, [5]NAVEDHA SURENDRAN, [6]AKHIL SAJITH KUMAR
[4]Consultant Orthodontist, Ambaloor, Trichur, Kerala
[1,2,3,5]Department of Orthodontics and Dento facial Orthopaedics, Royal Dental College College, Challisery, Palakkad, Kerala
[6]Chief Dental Surgeon, White Petals Dental Clinic, Pampakuda, Ernakulam, Kerala.

Address for Correspondence: Dr. Akhil S
Chief Dental Surgeon
White Petals Dental Clinic Pampakuda
PO MuvattupuzhaTaluk
Ernakulam dist., Kerala, India-686667.
Email: whitepetalsdentalclinic@gmail.com

Received : 2 Nov., 2024, **Published :** 31 Dec., 2024

How to cite this article: Nellikottu Soman, S., Thommancheri, N., Mankadavathu Puthenveetil, S., Mukundan, A., Surendran, N., & Akhil S. (2024). Shaping smiles with AI: a comprehensive review of artificial intelligence in orthodontics. UNIVERSITY JOURNAL OF DENTAL SCIENCES, 10(4).

Access this article online
Website: www.ujds.in
Quick Response Code
DOI: https://doi.org/10.21276/ujds.2024.10.4.16

progress in deep learning, computer vision, and natural language processing. AI has transformed cephalometric analysis, tooth movement forecasting, and the creation of personalized orthodontic devices. The capacity to process and interpret 3D imaging data has also improved the accuracy of orthodontic treatments.[2] AI continues to advance, with ongoing research combining it with cutting-edge technologies such as augmented and virtual reality, promising to reshape orthodontic practice by offering immersive treatment simulations and enhancing patient education.[5]

Objectives of this review:

The implementation of AI in orthodontics is examined in this review, with particular focus paid to how it might improve patient management, clinical effectiveness, treatment planning, and diagnostic procedures. It explores how developments in AI technology, such as computer vision, deep learning, and machine learning, have revolutionized orthodontic treatment. Additional topics covered in the review include possible biases, data privacy, and ethical issues. This review aims to provide light on how AI could enhance orthodontics' accuracy, effectiveness, and patient results.

Ai Technologies and Methods:

AI technologies have grown in importance in the orthodontics field because of their ability to improve clinical efficiency, treatment planning, and diagnostic accuracy. Machine learning, deep learning, computer vision, and natural language processing are important AI technologies employed in orthodontics.[6]

Machine learning in orthodontics:

In orthodontics, machine learning (ML) is a branch of artificial intelligence that relies on data analysis to make decisions. By processing large patient data sets, ML algorithms can detect patterns and forecast outcomes, reducing errors and time. In addition, ML can predict patient responses to treatments and dental misalignments, enabling more effective treatment strategies. The integration of ML technology improves clinical decision-making, which in turn leads to better patient outcomes and streamlined clinical processes.[7]

Deep learning in orthodontics:

In orthodontics, deep learning (DL) is being employed as an advanced ML technique to evaluate complex data, especially in image analysis tasks such as the interpretation of three-dimensional images and dental radiographs.[8] Convolutional neural networks (CNNs) are very useful for analyzing bone structures, identifying and categorizing dental abnormalities, and assessing tooth alignment. In-depth virtual models of patients' dental structures may also be generated from these models, allowing for exact treatment planning and the creation of unique orthodontic appliances. Because of this, deep learning is a very useful technique in orthodontics, allowing for more precise diagnosis and customized treatment plans.[9]

Applications and impact:

Orthodontics is using ML and DL to enhance patient management and clinical efficacy. By predicting the length and complexity of a therapy, machine learning algorithms can improve appointment scheduling and minimize wait times.[10] By comparing the expected outcomes with dental scans, deep learning algorithms can track the progress of a therapy. Orthodontists can more effectively adapt their approach with the use of AI-driven predictive analytics, which offer insights into patient behavior and treatment adherence. These technological advancements improve patient outcomes and experiences by streamlining healthcare procedures and increasing precision and efficacy.[11]

3D imaging and reconstruction:

Computer vision technology also plays a crucial role in processing and analyzing 3D imaging data.With the development of 3D scanning technologies such as cone-beam computed tomography (CBCT), orthodontists may now acquire comprehensive three-dimensional representations.[12]

AI IN DIAGNOSTIC PROCESS:

Automated image analysis in orthodontics:

AI powered automated image analysis in orthodontics improves diagnostic and treatment planning processes by analyzing dental images without human interference. With the use of this technology, anatomical features can potentially be accurately identified and measured, enabling orthodontists to treat patients according to their needs and make educated judgments.[2]

Cephalometric analysis:

For cephalometric analysis in orthodontics, which necessitates locating and measuring specific anatomical landmarks on radiographs, automated image processing is crucial. Manual tracing is necessary for traditional approaches, which can be unreliable and time-consuming. CNNs, an AI-driven automated image processing technique,

may be used to precisely identify landmarks, streamline diagnostics, enhance measurement accuracy, and enhance treatment planning and result prediction.[13]

Detection of dental anomalies:

Dental abnormalities such caries, periodontal disease, and impacted teeth may be detected through automated image analysis utilizing AI algorithms. By spotting relatively small radiographic indicators of early-stage dental decay or bone loss, these devices might possibly avert serious consequences and enable swift action, both of which improve patient outcomes.[4]

3D imaging and segmentation

3D imaging technologies like CBCT and intraoral scanners have revolutionized orthodontics by enabling automated image analysis. With the use of AI algorithms, patients' dental and craniofacial anatomy may be accurately reconstructed in three dimensions, enabling accurate evaluation of tooth alignment and jaw connections. Custom orthodontic appliance design and virtual treatment simulations are also made feasible by this techniques.[12]

Workflow optimization:

In orthodontics, automated image analysis increases diagnostic precision and optimizes clinical processes. It boosts landmark recognition and picture interpretation, enabling orthodontists to concentrate on patient care.[11] Ensuring current patient records through integration with electronic health record systems (EHR) expedites the clinical process and enhances productivity.[14]

Detection and classification of malocclusions in orthodontics using AI:

The diagnosis and classification of malocclusions have been significantly enhanced by the application of AI in orthodontics, increasing accuracy, efficiency, and consistency. AI is capable of properly classifying various malocclusion categories, identifying trends in massive amounts of dental data, and analyzing it all via ML and DL algorithms.[1]

ML algorithms for malocclusion detection:

CNNs, which use large datasets of labeled dental pictures to identify certain traits, have demonstrated significant effectiveness in the automated detection of malocclusions. These algorithms may identify problems including crowding, overbite, underbite, and crossbite by analyzing radiographs and 3D images. While doing so, human error and inter-operator variability are decreased, guaranteeing accurate diagnosis and prompt intervention.[15]

Classification of malocclusions using AI

AI may use deep learning models, like Angle's classification system, to categorize malocclusions into several categories. By examining the relationships between teeth and jaws in dental images, these classifications are accurate.[16] In addition, subcategories and particular traits within each class may be identified by AI algorithms, generating a comprehensive diagnostic profile. By customizing treatment programs to each patient's needs, orthodontists are able to improve treatment outcomes.[2]

Advantages of AI in malocclusion detection and classification

Benefits of AI integration in malocclusion detection and classification include reduced diagnosis times, objective assessments, and ongoing learning. It reduces subjectivity, caters to various patient groups and changing orthodontic procedures, and allows orthodontists to concentrate on patient engagement and treatment planning. Over time, AI systems also improve the accuracy of diagnoses.[1]

Clinical applications and benefits

Numerous therapeutic advantages are provided by AI in cephalometric landmark recognition, such as reliable measurements, rapid processing of high radiograph volumes, better workflow, and improved patient experience. Better patient outcomes result from this accuracy, which facilitates precise diagnosis and individualized therapy planning.[13] AI-powered solutions also decrease the duration of diagnostic procedures, improving patient satisfaction and lowering the procedure time.[16]

Enhanced diagnostic capabilities

AI systems, in particular deep learning models, are capable of effortlessly recognizing and segmenting anatomical features such as teeth, bones, and soft tissues from complicated 3D imaging data.[18] More precise dental diagnosis is made possible by convolutional CNN's ability to identify teeth and other features in digital dental impressions and CBCT images. This improves treatment planning by assisting orthodontists in identifying problems overlooked in 2D imaging when paired with 3D visualization.[3]

AI IN TREATMENT PLANNING:

Predictive analytics for treatment outcomes in orthodontics using AI:

By enabling data-based insights into patient outcomes, predictive analytics driven by AI is transforming orthodontic therapy. AI improves precision and customization by evaluating demographics, clinical characteristics, and prior records. This enables physicians to customize therapies to meet the needs of specific patients.[2]

Enhancing treatment planning and patient communication

Treatment planning is enhanced by predictive analytics, which provides orthodontists valuable knowledge. Based on individual traits and treatment histories, AI-driven projections determine which patients would respond best to a given therapy or care. This aids in creating individualized treatment programs. By offering concise, fact-based explanations of possible outcomes, predictive analytics also improves patient communication by enhancing trust and adherence to the suggested treatment strategy.[19]

Reducing risks and improving efficiency

By examining historical data, AI driven predictive analytics aids in recognizing and reducing orthodontic treatment risks. It helps orthodontists to proactively address the problems that are causing challenges or inconsistent outcomes. This is particularly helpful in complicated instances when there are significant skeletal or dental anomalies. It enhances therapeutic effectiveness by allocating resources as efficiently as possible.[20]

Virtual treatment planning and simulation in orthodontics using AI

By improving treatment planning and simulation virtually, artificial intelligence is transforming orthodontic care. With the goal of helping orthodontists envision and simulate treatment possibilities prior to implementation, AI algorithms generate comprehensive digital models of patients' dentition and structures. Clinicians and patients together gain from this enhanced predictability, precision, and efficiency of orthodontic treatments.[21]

Customization and precision

A distinctive advantage in customizing therapies to meet the demands of each patient is provided by AI-driven virtual therapy planning. To generate exact treatment plans, it can process large amounts of data, such as age, dental history, and anatomical variances. This improves orthodontic procedures' accuracy, resulting in more successful, efficient treatments with fewer challenges and better results.[22]

Improving patient engagement and compliance:

Improving patient involvement and compliance requires the use of virtual treatment planning and simulation. They aid patients in understanding the advantages and difficulties of therapy by giving a visual depiction of the procedure and anticipated results. AI-driven simulations enable patients see how their teeth will move and align over time, which enhances patient compliance and happiness, builds confidence, and eventually produces superior overall outcomes.[23]

Custom appliance design in orthodontics using AI:

By developing accurate, customized tools, AI is transforming orthodontic therapy. Conventional appliances need to be adjusted several times depending on the distinctive dental anatomy of each patient. AI technology makes treatments more effective and efficient when paired with cutting-edge manufacturing and imaging methods.[2]

Personalized Treatment Plans:

Personalized treatment plans for every patient are made possible by AI-driven personalized appliance design. Appliances can provide the proper pressure because AI algorithms anticipate how teeth will shift in response to orthodontic pressures. With clear aligners, teeth may be moved precisely in small steps, requiring fewer manual corrections and resulting in more effective treatment. By minimizing discomfort and time, this modifying guarantees that patients receive the best possible care.[24]

Real-time monitoring and feedback

AI technology makes it possible to use sensors, intraoral scanners, and imaging tools to monitor orthodontic treatments in real time.[21] Algorithms that use ML recognize patterns in data and can spot possible problems before they become significant. With the use of this data-driven feedback, orthodontists may promptly modify appliances to ensure that treatment proceeds smoothly, reducing delays and increasing overall efficacy.[25]

AI IN CLINICAL PRACTICE

Automating routine tasks:

AI in orthodontics automates repetitive processes, giving orthodontists and their teams greater flexibility.[13]It manages

clinical and administrative tasks like appointment scheduling, patient data management, and reminder sending.[26] By automatically evaluating dental images, AI also helps with diagnosis. This lowers administrative load and error risk, allowing up time for patient treatment.[15]

Improving Communication and Collaboration:

By facilitating better cooperation and communication between orthodontic teams and patients, AI improves workflow. It reduces misunderstandings and mistakes by enabling the smooth exchange of patient data, treatment plans, and progress reports. By offering clear visual descriptions of treatment regimens, AI also improves patient communication, resulting in higher compliance and satisfaction rates.[2]

Automated Scheduling in Orthodontics Using AI:

By automating scheduling procedures, AI is transforming orthodontic centers. Manual input is a common component of traditional approaches, which can result in mistakes and inefficient use of time. AI-driven scheduling systems examine variables including appointment kinds, patient preferences, practitioner availability, and treatment schedules using machine learning algorithms. These technologies are able to generate schedules that reduce wait times and enhance efficiency. Additionally, they are adaptable, which lessens the administrative strain on employees. Additionally, automated reminders lower the number of cancellations.[26]

AI-Driven Inventory Management in Orthodontics:

With real-time tracking and predictive analytics, AI is transforming inventory management in orthodontic centers. When stock hits a particular limit, these systems automatically restock supplies by keeping an eye on inventory levels and consumption trends. In order to avoid shortages and guarantee efficiency, they may also forecast future inventory needs based on scheduled visits and treatment schedules. AI also maximizes the turnover of inventory, cutting down on waste and guaranteeing that goods are used before they expire, all of which contribute to better patient care.[27]

AI in Inventory and Resource Management in Orthodontics:

By automating processes, maximizing inventory levels, and offering useful insights, AI is fundamentally altering resource and inventory management in clinics. Maintaining patient care and assuring effective and economical operations depend on this. AI-driven solutions improve practice management overall by streamlining the allocation of people and physical resources.[26]

Integration with Practice Management Systems:

Practice management software and AI-driven inventory and resource management systems may be used to provide a single platform for managing every facet of an orthodontic practice. Better communication between scheduling, invoicing, inventory control, and patient care is made possible by this. The technology can accelerate operations, set off alarms or reorder procedures, and automatically monitor inventory levels for particular treatments.[11]

AI-Powered Communication Platforms:

By providing immediate responses to numerous needed queries, appointment reminders, and pre-treatment instructions, AI-powered communication systems are enhancing interactions in the orthodontics field. Routine communication is automated by these technologies, giving staff members more time to concentrate on sophisticated patient care. By customizing messages to each patient's requirements, AI can evaluate patient feedback and communication patterns to improve the overall patient experience.[28]

Facilitating Collaborative Treatment Planning:

By enabling orthodontists to instantly communicate patient information, 3D models, and treatment plans with other experts, artificial intelligence (AI) improves collaborative treatment planning in orthodontics. This encourages a multidisciplinary approach and enables every healthcare practitioner share their knowledge.[29] AI also combines diverse data sets, like as patient histories and CBCT scans, into a single platform so that team members may make well-informed decisions.[12]

PATIENT CENTRIC APPLICATIONS OF AI:

AI-Driven Monitoring and Real-Time Adjustments in Orthodontics:

One of the biggest benefits of AI in orthodontics is the ability to make real-time treatment modifications. AI can offer instant adjustments to the treatment plan, such as modifying the force exerted by aligners, modifying the timing of appliance changes, or even suggesting additional treatments to address unforeseen concerns, based on the data gathered from continuous monitoring.[30]

Gamification and Engagement Tools:

Strategies for patient engagement which includes gamification and engagement technologies are also being integrated into orthodontics. With their constant reminders and instructional help, AI-driven virtual assistants are quickly proving to be indispensable tools for improving patient compliance. Being accessible around-the-clock allows these systems to modify their reminders and instructional materials to better suit the patient's changing requirements as their treatment progresses.[23]

CHALLENGES AND LIMITATIONS:

Data Privacy and Security Concerns in AI-Driven Orthodontics:

The use of AI in orthodontics has sparked worries regarding the security and privacy of patient data.[6] AI is largely dependent on the gathering, storing, and processing of vast amounts of patient data, including private health information, imaging data, and unique identifiers. While these data are essential for AI to deliver precise diagnosis, customized treatment regimens, and real-time monitoring, they also carry significant risks if not properly safeguarded. Maintaining patient confidence and complying by legal and ethical requirements depend on the security and privacy of patient data.[31]

The Risks of Data Breaches and Unauthorized Access:

The possibility of data breaches and unauthorized access to private patient data is one of the primary challenges with AI in healthcare. Cloud-based processing and storage can expose patient data to cyberattacks, which can have serious repercussions including identity theft, monetary loss, and harm to a practice's reputation. Unauthorized access has the potential to compromise patient care by undermining the integrity of AI algorithms and resulting in erroneous treatment recommendations.[32]

Compliance with Data Protection Regulations:

AI-driven health practices must abide by stringent data privacy laws, such as the General Data privacy Regulation (GDPR) in the European Union and the Health Insurance Portability and Accountability Act (HIPAA) in the United States, in order avoid these dangers. Strong security measures, like as encryption, access limits, and frequent security audits, are required under these standards to safeguard patient data.[33]

Ethical Considerations in Data Handling:

Since patients need to know how their data will be used, who will have access to it, and what safeguards are in place to preserve their privacy, ethical issues in data management are also crucial. Given that AI has the ability to significantly improve patient care while maintaining the highest standards of care, striking a balance between innovation and security is imperative.[34]

Bias and Fairness in AI Algorithms in Orthodontics:

The data used to train AI systems, such as patient demographics, medical histories, imaging results, and treatment outcomes, often includes bias.[35] The AI system may provide biased findings if the training data is not representative of the various patient groups found in clinical practice. An AI model may not be able to predict results for patients from different ethnic origins, for instance, if it was trained only using data from one ethnic group. Similar to this, the AI system may not be able to offer treatments that are equally appropriate for various patient populations if the data is not representative of certain age groups or socioeconomic levels.[36]

Ensuring Fairness through Diverse and Representative Data:

It is essential to use representative and varied data when developing and training AI systems in order to reduce bias and guarantee fairness in AI algorithms.[35] This entails gathering and combining information from a variety of patient demographics, such as various age groups, genders, ethnic groups, and socioeconomic statuses. The relevance and equity of the AI models should be preserved throughout time by routinely updating these datasets to reflect emerging trends and modifications in patient populations.[37]

Technical and Operational Challenges in AI-Driven Orthodontics:

There are a number of operational and technological difficulties in implementing artificial intelligence (AI) in orthodontics.[2] A major technical obstacle is to ensure that there is complete, high-quality data for operation and training. Large patient data sets, including imaging results, medical histories, and treatment outcomes, are necessary for AI systems to perform properly. However, it might be challenging to compile and standardize the data for AI training since orthodontic clinics sometimes have fragmented, inconsistent, or missing data accessible.[6]

Complexity in Algorithm Development and Validation:

Another major technological problem is the creation and validation of AI systems. Complex algorithms trained on large datasets are needed to create an AI model that can correctly diagnose illnesses, predict treatment outcomes, or recommend the best course of action.[p\[38] This procedure requires in-depth knowledge of orthodontic concepts and clinical practice in addition to technical proficiency in AI and machine learning. In order to guarantee these algorithms' correctness and dependability in actual clinical situations, they need to undergo extensive validation after development.[39]

Integration into Clinical Workflows:

Operational issues arise upon integration into current orthodontic workflows. It could be necessary for clinicians to receive training in new software systems or modifications to decision-making procedures in order to understand how to evaluate and act upon AI-generated suggestions. Achieving interoperability and reducing interference with workflow are essential for the effective integration of AI in orthodontics. Another operational issue preventing AI from being widely used in orthodontics is scalability. Practices need to be sure that their AI systems can develop with them without sacrificing accuracy or performance as they employ AI technology more and more.[6]

Limitations in Current AI Technologies in Orthodontics

The complete use and efficacy of existing AI technologies in clinical practice are hindered by a number of constraints, despite the significant progress and potential advantages of AI in orthodontics. These restrictions include the need for human oversight and knowledge, generalization and model transferability issues, interpretability and transparency issues, and data availability and quality limits. Improving AI models' interpretability and openness is essential to their successful use in orthodontic practice.[40]

ETHICAL AND REGULATORY CONSIDERATIONS:

Ethical Implications of AI Use in Orthodontics:

There is a lot of promise for increasing clinical effectiveness, optimizing treatment plans, and providing better patient care when AI is integrated into orthodontics.[1] But it also brings up ethical issues that practitioners, researchers, and governments need to take extremely seriously. The preservation of patient autonomy and informed consent, addressing bias in decision-making procedures, accountability and openness, data security and privacy, and the effect on the patient-clinician relationship are some of these worries.[41]

Patient Autonomy and Informed Consent:

As AI systems have a more and growing effect on diagnosis and treatment decisions, patient autonomy is crucial. Providing patients thorough explanations of AI technology's workings and how they may affect their course of therapy is necessary to provide informed consent. If a patient would rather take a more conventional approach, they should have the freedom to decline AI-driven therapies.[42]

Impact on the Patient-Clinician Relationship:

The connection between a patient and a health practitioner, which is based on trust, communication, and individualized treatment, may be impacted by the introduction of AI . An over-reliance on technology may result in a depersonalized approach to treatment, wherein the function of the physician is reduced. A balanced strategy that capitalizes on AI's advantages while maintaining the human aspects of care which are essential to patient results and satisfaction is needed for ethical medical practice.[43]

Regulatory Framework and Compliance in AI-Driven Orthodontics:

Compliance and a regulatory framework are necessary for the ethical application of AI in healthcare. Under the FDA's medical device framework, AI technologies applied in healthcare including orthodontics are categorized as medical devices in several jurisdictions. Adherence to these standards is vital for obtaining authorization and preserving the confidence of healthcare providers and patients who depend on these artificial intelligence technologies for crucial healthcare decision-making.[44]

International Standards and Harmonization:

The effective application of AI in clinical practice requires the harmonization of regulatory frameworks across international borders. Global organizations, such the World Health Organization (WHO) and the International Medical Device Regulators Forum (IMDRF), are striving to develop uniform standards that may be implemented in many legal contexts. Developers and practitioners still have a great deal of difficulty negotiating these changing requirements, which calls for ongoing communication with regulatory agencies and a proactive approach to compliance.[45,46]

Regulatory and Legal Framework Development:

In order to handle the particular issues posed by the application of AI in dentistry, regulatory and legal frameworks must be developed. This involves updating laws pertaining to healthcare, establishing norms for transparency, and drafting legislation to guarantee equity and restrict discrimination. Working together, AI developers, legal specialists, ethicists, and healthcare professionals may create a regulatory framework that supports innovation and safeguards patient rights. The legal and ethical frameworks regulating AI usage must evolve as the technology does.[47]

FUTURE DIRECTIONS:

Emerging Trends and Technologies in AI-Driven Orthodontics:

With the introduction of AI, the area of orthodontics is fast changing. This has resulted in an outburst of new trends and technologies that are revolutionizing the provision of orthodontic treatment. By stretching the bounds of conventional methods, these advances have opened up more individualized, effective, and efficient treatment possibilities.[7,20]

Integration of AI with AR and VR Technologies in Orthodontics:

By combining AI with augmented reality (AR) and virtual reality (VR) technology, orthodontics is expanding its horizons and gaining access to revolutionary equipment that improve patient care and clinical practice.[48]

Immersive Treatment Planning with AI-Driven VR:

The process of designing and simulating orthodontic treatments is being revolutionized by the combination of AI, VR, and other cutting-edge technology. By creating intricate, 3-D models of the oral cavity, VR technologies enable orthodontists to virtually visualise a patient's mouth and investigate different treatment options in a collaborative setting. These simulations are dynamic tools for ongoing treatment planning since they are not static but rather update continually depending on the most recent patient data.[48,49]

Patient Education and Engagement through AI-Integrated AR and VR:

Patient education and engagement in orthodontics are also being revolutionized by the combination of AI with AR and VR. Patients may examine dynamic, 3D representations of their treatment plans on their smartphones or tablets thanks to AR applications driven by artificial intelligence. With the use of these technologies, patients may visualize the movement of their teeth over time, get a glimpse of their smile post-treatment, and gain insight into the functioning of their orthodontic appliances. By simplifying and making the treatment process more palpable, these interactive and visual explanations can greatly improve patient comprehension and compliance.[48,50]

Enhanced Training and Education for Orthodontists

In addition, AR and VR technologies are showing to be quite useful for orthodontic professionals' education and training. AI-powered VR simulations give orthodontists a risk-free, controlled environment in which to investigate complex circumstances, sharpen their abilities, and practice treatments without having to deal with patients in person. Training modules incorporating AI algorithms that provide real-time feedback and recommendations depending on the user's activities can be customized to imitate a variety of clinical circumstances.[21,51]

Future Directions: AI, AR, and VR in Collaborative Orthodontic Care:

Future directions for AI, AR, and VR in collaborative orthodontic care include remote consultations and real-time collaboration between orthodontists and other dental specialists, regardless of their physical presence. This could lead to more comprehensive treatment plans, faster decision-making, and ultimately, better patient outcomes.[48]

Recommendations for Future Research in AI-Driven Orthodontics:

The science of orthodontics might undergo a revolution if AI-driven orthodontics is explored further in a few important fields. These involve creating complex AI algorithms, investigating cutting-edge clinical practice applications, and assessing the effects of AI on patient outcomes and safety.[45] The creation of reliable and broadly applicable AI models that can be utilized in a variety of therapeutic contexts and patient groups is one of the main recommendations. Researchers ought to concentrate on building more extensive and varied datasets and investigating methods to enhance the applicability of AI models.[52]

Interdisciplinary Collaboration and Education:

Research on AI in orthodontics must also be advanced by promoting multidisciplinary collaboration and education.

Collaborations between engineers, data scientists, computer scientists, and orthodontists can result in the development for innovative applications and more complex algorithms suited to the unique requirements of orthodontic practices.[1,2]

Conclusion

By evaluating complicated information, automating repetitive procedures, and offering individualized treatment alternatives, AI has the potential to completely transform the orthodontics field. This technology will enhance treatment planning, increase the accuracy of diagnoses, and simplify clinical operations. But it has to contend with issues like algorithmic bias, data privacy, and the requirement for strong regulatory frameworks. In order to train orthodontists for this quickly changing world, multidisciplinary collaboration and educational activities are needed due to the continual development of AI. The development of AI will propel important advancements in orthodontic research and practice, including the investigation of cutting-edge uses like 3D printing, augmented reality, and virtual reality. In addition to enhancing clinical results, these technologies will help orthodontics become more individualized, effective, and patient-centered. AI has the potential to revolutionize the sector, even in its early stages. Through a thoughtful and ethical approach, the orthodontic community may leverage AI to improve patient outcomes, streamline procedures, and enhance comprehension of orthodontic science.

References:

1. Liu J, Zhang C, Shan Z. Application of artificial intelligence in orthodontics: Current state and future perspectives. Healthcare (Basel). 2023 Oct 18;11(20):2760. doi: 10.3390/healthcare11202760.
2. Kazimierczak N, Kazimierczak W, Serafin Z, Nowicki P, Nożewski J, Janiszewska-Olszowska J. AI in orthodontics: revolutionizing diagnostics and treatment planning-a comprehensive review. J Clin Med. 2024 Jan 7;13(2):344. doi: 10.3390/jcm13020344.
3. Alzaid N, Ghulam O, Albani M, Alharbi R, Othman M, Taher H, et al. Revolutionizing dental care: A comprehensive review of artificial intelligence applications among various dental specialties. Cureus. 2023 Oct 14;15(10):e47033. doi: 10.7759/cureus.47033.
4. Anil S, Porwal P, Porwal A. Transforming dental caries diagnosis through artificial intelligence-based techniques. Cureus. 2023 Jul 11;15(7):e41694. doi: 10.7759/cureus.41694.
5. Aichert, A.; Wein, W.; Ladikos, A.; Reichl, T.; Navab, N. Image-based tracking of the teeth for orthodontic augmented reality. *Comput. Vision* **2012**, *15*, 601–608.
6. Nordblom NF, Büttner M, Schwendicke F. Artificial intelligence in orthodontics: critical review. J dent res. 2024 jun;103(6):577-584. doi: 10.1177/00220345241235606.
7. Bichu YM, Hansa I, Bichu AY, Premjani P, Flores-Mir C, Vaid NR. Applications of artificial intelligence and machine learning in orthodontics: a scoping review. ProgOrthod. 2021 Jul 5;22(1):18. doi: 10.1186/s40510-021-00361-9.
8. S. Bhat, G. K. Birajdar and M. D. Patil, "A comprehensive survey of deep learning algorithms and applications in dental radiograph analysis", *Healthcare Analytics*, vol. 100282, 2023.
9. Wang X, Alqahtani KA, Van den Bogaert T, Shujaat S, Jacobs R, Shaheen E. Convolutional neural network for automated tooth segmentation on intraoral scans. BMC Oral Health. 2024 Jul 16;24(1):804. doi: 10.1186/s12903-024-04582-2.
10. Li X, Liu W, Kong W, Zhao W, Wang H, Tian D, et al. Prediction of outpatient waiting time: using machine learning in a tertiary children's hospital. TranslPediatr. 2023 Nov 28;12(11):2030-2043. doi: 10.21037/tp-23-58.
11. Mahesh Batra A, Reche A. A new era of dental care: harnessing artificial intelligence for better diagnosis and treatment. Cureus. 2023 Nov 23;15(11):e49319. doi: 10.7759/cureus.49319.
12. Kapila S, Conley RS, Harrell WE Jr. The current status of cone beam computed tomography imaging in orthodontics. DentomaxillofacRadiol. 2011 Jan;40(1):24-34. doi: 10.1259/dmfr/12615645.
13. Subramanian AK, Chen Y, Almalki A, Sivamurthy G, Kafle D. Cephalometric analysis in orthodontics using artificial intelligence-a comprehensive review. Biomed Res Int. 2022 Jun 16;2022:1880113. doi: 10.1155/2022/1880113.
14. Aguirre RR, Suarez O, Fuentes M, Sanchez-Gonzalez MA. Electronic health record implementation: a review of resources and tools. Cureus. 2019 Sep 13;11(9):e5649. doi: 10.7759/cureus.5649.
15. Hung KF, Yeung AWK, Bornstein MM, Schwendicke F. Personalized dental medicine, artificial intelligence, and their relevance for dentomaxillofacial imaging. DentomaxillofacRadiol. 2023 Jan 1;52(1):20220335. doi: 10.1259/dmfr.20220335.

16. afala, I.; Bourzgui, F.; Othmani, M.B.; Azmi, M. Automatic classification of malocclusion. Procedia Comput. Sci. 2022, 210, 301–304.
17. Bajwa J, Munir U, Nori A, Williams B. Artificial intelligence in healthcare: transforming the practice of medicine. Future Healthc J. 2021 Jul;8(2):e188-e194. doi: 10.7861/fhj.2021-0095.
18. Khalifa M, Albadawy M. AI in diagnostic imaging: revolutionising accuracy and efficiency. Comput Methods Programs Biomed Updat.2024;5:100146. doi:10.1016/j.cmpbup.2024.100146
19. Prasad J, Mallikarjunaiah DR, Shetty A, Gandedkar N, Chikkamuniswamy AB, Shivashankar PC. Machine learning predictive model as clinical decision support system in orthodontic treatment planning. Dent J (Basel). 2022 Dec 20;11(1):1. doi: 10.3390/dj11010001..
20. Albalawi F, Alamoud KA. Trends and application of artificial intelligence technology in orthodontic diagnosis and treatment planning—A review. ApplSci 2022;12(22):11864. DOI: 10.3390/ app122211864.
21. Tomášik, J.; Zsoldos, M.; Oravcová, Ľ.; Lifková, M.; Pavleová, G.; Strunga, M.et al. Ai and face-driven orthodontics: a scoping review of digital advances in diagnosis and treatment planning. *AI* **2024**, *5*, 158–176.
22. Surendran A, Daigavane P, Shrivastav S, Kamble R, Sanchla AD, Bharti L, Shinde M. The future of orthodontics: deep learning technologies. Cureus. 2024 Jun 10;16(6):e62045. doi: 10.7759/cureus.62045.
23. Thorat V, Rao P, Joshi N, Talreja P, Shetty AR. Role of artificial intelligence (ai) in patient education and communication in dentistry. Cureus. 2024 May 7;16(5):e59799. doi: 10.7759/cureus.59799.
24. Thurzo A, Kurilová V, Varga I. Artificial Intelligence in Orthodontic Smart Application for Treatment Coaching and Its Impact on Clinical Performance of Patients Monitored with AI-TeleHealth System. Healthcare (Basel). 2021 Dec 7;9(12):1695. doi:10.3390/healthcare9121695.
25. Cunha TMAD, Barbosa IDS, Palma KK. Orthodontic digital workflow: devices and clinical applications. Dental Press J Orthod. 2021 Dec 15;26(6):e21spe6. doi: 10.1590/2177-6709.26.6.e21spe6.
26. Maleki Varnosfaderani S, Forouzanfar M. The role of ai in hospitals and clinics: transforming healthcare in the 21st century. Bioengineering (Basel). 2024 Mar 29;11(4):337. doi: 10.3390/bioengineering11040337.
27. Kumar A, Mani V, Jain V, Gupta H, Venkatesh VG. Managing healthcare supply chain through artificial intelligence (AI): A study of critical success factors. Comput Ind Eng. 2023 Jan;175:108815. doi: 10.1016/j.cie.2022.108815.
28. Dhopte A, Bagde H. Smart Smile: Revolutionizing Dentistry With Artificial Intelligence. Cureus. 2023 Jun 30;15(6):e41227. doi: 10.7759/cureus.41227. PMID: 37529520; PMCID: PMC10387377.
29. Lämmermann L, Hofmann P, Urbach N. Managing artificial intelligence applications in healthcare: Promoting information processing among stakeholders. Int J Inf Manage. 2024 Apr;75:102728. doi: 10.1016/j.ijinfomgt.2023.102728.
30. Woo H., Jha N., Kim Y.-J., Sung S.-J. Evaluating the accuracy of automated orthodontic digital setup models. Semin. Orthod. 2023;29:60–67.
31. Murdoch B. Privacy and artificial intelligence: challenges for protecting health information in a new era. BMC Med Ethics. 2021 Sep 15;22(1):122. doi: 10.1186/s12910-021-00687-3.
32. Williamson, S.M.; Prybutok, V. Balancing privacy and progress: A review of privacy challenges, systemic oversight, and patient perceptions in ai-driven healthcare. Appl. Sci. **2024**, *14*, 675.
33. Yadav N, Pandey S, Gupta A, Dudani P, Gupta S, Rangarajan K. Data privacy in healthcare: in the era of artificial intelligence. Indian Dermatol Online J. 2023 Oct 27;14(6):788-792. doi: 10.4103/idoj.idoj_543_23.
34. Chiruvella V, Guddati AK. Ethical issues in patient data ownership. Interact J Med Res. 2021 May 21;10(2):e22269. doi: 10.2196/22269.
35. Ferrara E. Fairness and bias in artificial intelligence: a brief survey of sources, impacts, and mitigation strategies. Sci. 2024;6(1):3.
36. Norori N, Hu Q, Aellen FM, Faraci FD, Tzovara A. Addressing bias in big data and AI for health care: A call or open science. Patterns (N Y). 2021 Oct 8;2(10):100347. doi: 10.1016/j.patter.2021.100347.
37. Obermeyer Z, Powers B, Vogeli C, Mullainathan S. Dissecting racial bias in an algorithm used to manage the health of populations.Science.2019;366:447–453. doi: 10.1126/science.aax2342.
38. Al-Antari MA. Artificial intelligence for medical diagnostics-existing and future ai technology. Diagnostics (Basel). 2023 Feb 12;13(4):688. doi: 10.3390/diagnostics13040688.
39. Auconi P, Gili T, Capuani S, Saccucci M, Caldarelli G, Polimeni A et al. The validity of machine learning

procedures in orthodontics: what is still missing? J Pers Med. 2022 Jun 11;12(6):957. doi: 10.3390/jpm12060957.

40. Wang F., Preininger A. AI in health: state of the art, challenges, and future directions. *Yearb. Med. Inform.* 2019;28:16–26. doi: 10.1055/s-0039-1677908.
41. Naik N, Hameed BMZ, Shetty DK, Swain D, Shah M, Paul R, et al. Legal and ethical consideration in artificial intelligence in healthcare: who takes responsibility? Front Surg. 2022 Mar 14;9:862322. doi: 10.3389/fsurg.2022.862322.
42. Richardson JP, Smith C, Curtis S, Watson S, Zhu X, Barry B, et al. Patient apprehensions about the use of artificial intelligence in healthcare. NPJ Digit Med. 2021 Sep 21;4(1):140. doi: 10.1038/s41746-021-00509-1.
43. Nagy M, Sisk B. How will artificial intelligence affect patient-clinician relationships? AMA J Ethics. 2020 May 1;22(5):E395-400. doi: 10.1001/amajethics.2020.395.
44. US FDA. Artificial Intelligence and Machine Learning (AI/ML)-Enabled Medical Devices. 2023. https://www.fda.gov/medical-devices/software-medical-device-samd/artificial-intelligence-and-machine-learning-aiml-enabled-medical-devices.
45. Larson DB, Harvey H, Rubin DL, Irani N, Tse JR, Langlotz CP. Regulatory frameworks for development and evaluation of artificial intelligence-based diagnostic Imaging Algorithms: Summary and Recommendations. J Am CollRadiol. 2021 Mar;18(3 Pt A):413-424. doi: 10.1016/j.jacr.2020.09.060.
46. Geneva: World: Health Organization; 2023. Regulatory considerations on artificial intelligence for health. License: CC BY-NC-SA 3.0 IGO.https://iris.who.int/handle/10665/373421, accessed 30 July 2024.
47. Duggal I, Tripathi T. Ethical principles in dental healthcare: Relevance in the current technological era of artificial intelligence. J Oral BiolCraniofac Res. 2024 May-Jun;14(3):317-321. doi: 10.1016/j.jobcr.2024.04.003.
48. Gandedkar NH, Wong MT, Darendeliler MA: *Role of virtual reality (vr), augmented reality (ar) and artificial intelligence (ai) in tertiary education and research of orthodontics: an insight.* Elsevier;2021;69–77.
49. Moussa R, Alghazaly A, Althagafi N, Eshky R, Borzangy S. Effectiveness of virtual reality and interactive simulators on dental education outcomes: systematic review. Eur J Dent. 2022 Feb;16(1):14-31. doi: 10.1055/s-0041-1731837.
50. Farronato, M., Maspero, C., Lanteri, V. *et al.* Current state of the art in the use of augmented reality in dentistry: a systematic review of the literature. *BMC Oral Health. 2019* July; **19**, 135 .https://doi.org/10.1186/s12903-019-0808-3.
51. Strunga M, Urban R, Surovková J, Thurzo A. Artificial intelligence systems assisting in the assessment of the course and retention of orthodontic treatment. Healthcare (Basel). 2023 Feb 25;11(5):683. doi: 10.3390/healthcare11050683.
52. Javaid M, Haleem A, Pratap Singh R, Suman R, Rab S. Significance of machine learning in healthcare: features, pillars andapplications. Int J IntellNetw. 2022;3:58–73.