International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 13s, 2025
https://www.theaspd.com/ijes.php

Artificial Intelligence And Augmented Reality In Orthodontics: Current Applications And Future Prospects

Rasiga Gandhi[1], Janani Ravi[2], Shreya Kishore[3], Suman M Mathew[4], Sushil Chakravarthi N.C[5]
[1,2,3] Senior Lecturer, Department of Orthodontics, SRM Dental College, Ramapuram, Bharathi Salai, Chennai-600089.
[4]Tutor, Department of Orthodontics, SRM Dental College, Ramapuram, Bharathi Salai, Chennai-600089.
[5]Reader, Department of Orthodontics, SRM Dental College, Ramapuram, Bharathi Salai, Chennai-600089.
Corresponding Author: Rasiga Gandhi,Senior Lecturer, Department of Orthodontics, SRM Dental College, Ramapuram, Bharathi Salai, Chennai-600089.

ABSTRACT
Artificial Intelligence (AI) and Augmented Reality (AR) are emerging as transformative technologies in orthodontics, reshaping diagnostic workflows, treatment planning, and patient engagement. AI enables enhanced diagnostic accuracy, predictive modeling, and personalized treatment strategies through machine learning and deep learning applications, while AR improves patient communication and education by overlaying digital simulations onto real-world views. This review comprehensively explores the current applications of AI and AR in orthodontics, evaluating their clinical effectiveness, technological underpinnings, and potential for future integration into patient-centered care. Additionally, the paper discusses the regulatory, ethical, and practical considerations involved in adopting these technologies. As digital innovation accelerates, AI and AR are poised to play a pivotal role in optimizing orthodontic outcomes and improving the overall treatment experience.
Keywords: *Artificial Intelligence, Augmented Reality, Orthodontics, Machine Learning, Deep Learning, Cephalometrics, Predictive Modeling*

INTRODUCTION

Artificial Intelligence (AI) is a field of computer science enabling machines to simulate human intelligence. Augmented Reality (AR) overlays digital elements on real-world environments, allowing interactive experiences that aid in both patient communication and treatment planning. In orthodontics, AI has been applied to various diagnostic and treatment planning tools, leveraging complex algorithms to simulate human intelligence in data analysis, outcome prediction, and even automated decision-making.(1) AR, on the other hand, allows orthodontic practitioners to overlay digital elements onto real-world settings, creating immersive visual experiences for patients. This enhances patient communication by allowing patients to visualize potential treatment outcomes through simulations.(2)
The rise of digital technologies, particularly AI and AR, has profoundly impacted healthcare by enhancing the accuracy and efficiency of medical processes, including the field of orthodontics. This dual advancement allows for unprecedented precision in orthodontic care and a more interactive approach to patient engagement. These technologies, though still evolving, are ushering in a new era of orthodontics characterized by increased efficiency and patient-centered care. This review aims to discuss AI and AR applications in orthodontics, their current status, and their future potential.

1.AI - OVERVIEW

Artificial Intelligence (AI), a branch of computer science, focuses on developing intelligent machines capable of performing tasks that traditionally require human cognition. While AI may seem like a modern innovation, its origins date back to the 1950s. The term "Artificial Intelligence" was coined by John McCarthy in 1956 during a historic meeting at Dartmouth College, marking the beginning of formal AI research.(3)
Over the decades, AI has been extensively integrated into various industries, revolutionizing fields such as speech recognition, internet search engines, online assistance, facial recognition on social media platforms, and autonomous vehicles.(4) In orthodontics, AI leverages machine learning (ML) algorithms

and neural networks to enhance traditional workflows by automating repetitive tasks, minimizing human error, and accelerating clinical decision-making.(5) Neural networks, especially convolutional neural networks (CNNs), are instrumental in analyzing complex data like X-rays and 3D scans. These advancements have significantly improved diagnostic accuracy, treatment planning, and patient management, positioning AI as a transformative tool in modern orthodontic practice.

2.HOW DOES AI WORK?

Artificial Intelligence (AI), in its current form, consists of a set of algorithms and computational models designed to simulate human-like behaviors and decision-making processes. These systems integrate vast amounts of data from multiple sources, enabling outcomes that often surpass human capabilities in efficiency and accuracy.

AI is a broad field encompassing various methodologies, but it is primarily categorized into Symbolic AI and Machine Learning (ML).(6) (Figure 1) In orthodontics, AI applications predominantly rely on ML and deep learning, leveraging extensive datasets to refine diagnostics and treatment planning. Understanding the fundamental types and mechanisms of AI is crucial for appreciating its role in orthodontics.

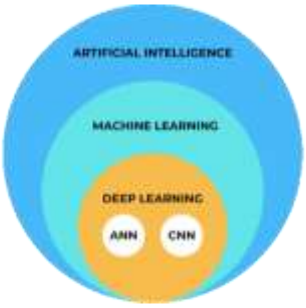

Figure 1: Paradigms of AI

2.1 Two major paradigms of AI

(A) Symbolic AI

This category was the foundation of AI research until the late 1980s and is also known as traditional AI or "Good Old-Fashioned AI" (GOFAI). Symbolic AI operates on predefined rules and logic, making it effective in structured environments. It was the earliest form of AI, developed to handle rule-based reasoning tasks by relying on pre-established human-defined rules, often using "if-then" logic statements to solve straightforward problems. Despite its structured approach, symbolic AI is less effective in orthodontics due to the complexity and variability of human anatomy and pathology, which require more adaptive and flexible algorithms. Since it focuses on human-readable symbols (such as logic statements) and rule-based reasoning, its efficiency in healthcare is low, given the intricate nature of medical problems, multiple interacting variables, and the limitations of predefined rule sets.(7)

(B) Machine Learning (ML)

ML enables AI systems to learn from data patterns without explicit programming. A term first phrased by Arthur Samuel in 1952 is the current paradigm in AI. Unlike symbolic AI, ML enables systems to learn from data without relying on rule-based instructions. Instead, ML models learn from past examples to detect patterns, make predictions, and improve as new data becomes available. For orthodontics, ML applications include predicting growth patterns, assessing the likelihood of impacted teeth, and providing automated measurements in cephalometrics. In ML, the models learn from examples rather than a set of rules established by a human. By utilizing a mixture of statistical and probabilistic tools, machines can learn from previous models and improve their actions when new data is introduced. This could be in the form of predictions, identifying new patterns, or classifying new data.(7) It can be categorized into traditional machine learning and deep learning.(8)

i. **Traditional Machine Learning-** It is further classified into supervised, unsupervised and reinforcement learning.(Figure 2)

a. **Supervised Learning:** Uses labeled datasets to train models for predictions and classifications, commonly applied in cephalometric landmark detection. Commonly used for classification and regression tasks, supervised learning in orthodontics may involve feeding algorithms with labeled data,

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 13s, 2025
https://www.theaspd.com/ijes.php

such as radiographs with annotated cephalometric landmarks, to train models on how to identify specific structures.

b. **Unsupervised Learning**: Identifies hidden patterns within data, aiding in patient classification and growth prediction. (e.g., clustering, anomaly detection). This learning type is beneficial for finding hidden patterns in data without labeled outcomes. For instance, unsupervised learning can help identify unique patient patterns, which might lead to more personalized treatment planning.

c. **Reinforcement Learning**: Enhances decision-making by rewarding optimal treatment strategies based on trial-and-error learning. By maximizing reward feedback, reinforcement learning is instrumental in cases where orthodontic systems need to adapt dynamically, such as optimizing force levels for personalized aligner treatment.

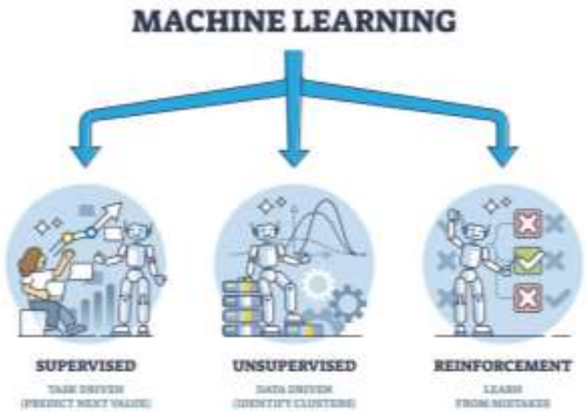

Figure 2: Classification of Machine Learning

ii. Deep Learning (DL)

A sub-domain of machine learning (ML), deep learning uses neural networks with multiple layers to automatically learn and extract complex features from input data without the need for manual feature engineering by humans.(Figure 3) DL is particularly suited for analyzing large and intricate datasets such as 3D scans, radiographs, and Cone Beam Computed Tomography (CBCT) images, making it highly valuable in orthodontics.

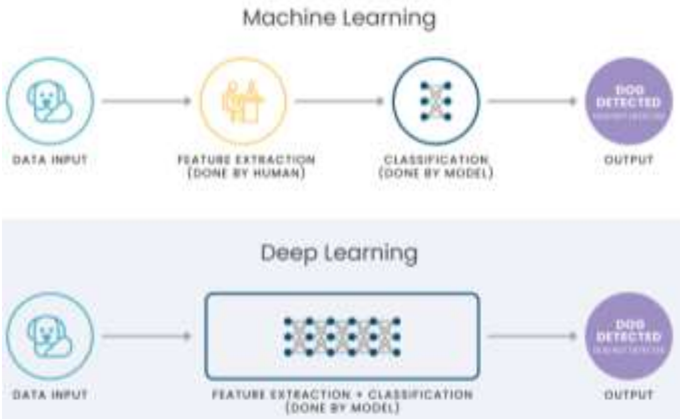

Figure 3: Difference between Machine Learning and Deep Learning

Neural Networks: Artificial neural networks (ANNs) developed in the 1990s which draw inspiration from the biological neural system of the human brain. They consist of layers of interconnected nodes (or "neurons") that process vast amounts of data.(9)(Figure 4) Key neural network architectures in DL include

- **Artificial Neural Networks (ANNs):** Inspired by biological neurons, useful for general pattern recognition.
- **Convolutional Neural Networks (CNNs):** Optimized for image processing tasks like diagnostic imaging and cephalometric analysis.

- **Recurrent Neural Networks (RNNs):** Effective for handling sequential data such as speech or time-series records.

The evolution from traditional ML to deep learning has allowed AI to play an increasingly autonomous role in orthodontic diagnosis and treatment planning, improving precision, reducing human error, and optimizing clinical workflows. In the field of medical imaging, DL algorithms predominantly utilize CNNs with high diagnostic accuracy. Recent advancements in computational technology have allowed researchers to construct more complex neural networks, referred to as "deeper" networks, to handle increasingly challenging tasks. In orthodontics, deep learning has been applied to automate cephalometric landmark detection and tracing, predict treatment outcomes, and segment or classify dental and skeletal structures from radiographic or 3D imaging data, thereby enhancing diagnostic precision and reducing reliance on manual assessments.(10)

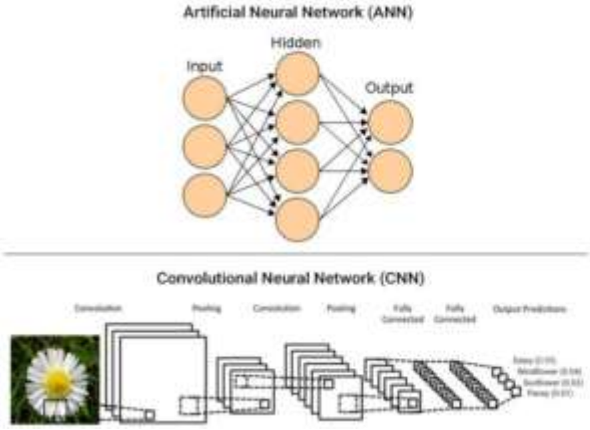

Figure 4: Neural networks

2.2 Mechanism of ai in orthodontic applications

AI systems in orthodontics work by recognizing patterns in large datasets and applying these learned patterns to new cases. For instance, in cephalometric analysis, ML algorithms are trained on large volumes of labeled radiographic images, enabling them to accurately identify landmarks. A practical example of AI's mechanism in orthodontics is the use of neural networks to improve cephalometric accuracy.(Figure 5) Neural networks, modeled after the human brain's neuron structure, process inputs through layers of nodes or "neurons," with each layer extracting progressively complex features from the data. In cephalometric tracing, the neural network's ability to recognize spatial relationships and patterns makes it a powerful tool for identifying cephalometric points, reducing human error and saving time.(11)

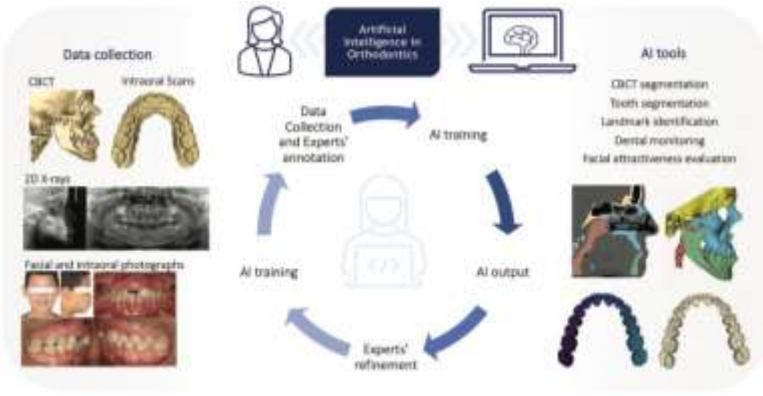

Figure 5: AI Training for Orthodontics

3.APPLICATIONS OF AI IN ORTHODONTICS

AI is increasingly being integrated into various aspects of orthodontic practice, enabling more efficient workflows, enhancing diagnostic accuracy, and facilitating personalized treatment planning.

3.1 Diagnosis and Predictive Modeling

- **Radiographic Analysis**: AI-driven tools, particularly those using deep learning and convolutional neural networks (CNNs), have advanced radiographic analysis in orthodontics. Studies have shown that these AI tools can reduce human error and offer consistent results, making them reliable for routine diagnostic use. AI in detecting maxillofacial fractures has been analysed, emphasizing its diagnostic potential in orthognathic and trauma-related cases.(12)

i. **Cephalometric Landmark Detection**: AI based landmark detection traces back to as early as 1985 where algorithms based on organized set of rules and simple interpreter were used. (13) AI-powered software, like WEBceph™, AudaxCeph™, Cephio™, CephX™, DentaliQ- Ortho™, EYES.OF.AI™ and FPT-Software™ which are trained to recognized points in cephalometric radiographs to facilitate cephalometric analyses. They use supervised learning to assist in identifying cephalometric landmarks, achieving accuracies comparable to those of human examiners and has significantly advanced cephalometric analysis by automating landmark detection.(14) By identifying key points on cephalometric radiographs, these AI tools reduce the time required for manual tracing, minimize human error, and provide consistent results.(15)

ii. **CBCT Imaging**: CBCT imaging is indispensable in complex orthodontic cases, particularly for assessing craniofacial structures in three dimensions. AI enhances CBCT analysis by automating segmentation processes, thereby reducing segmentation times from hours to seconds. For example, Preda et al. reported that AI-assisted CBCT analysis tools can reach dice coefficients as high as 96% for craniofacial structures, underscoring the technology's efficiency and accuracy.(16)

iii. **Growth Prediction:** AI models evaluate skeletal maturity using wrist radiographs or cervical vertebral maturation (CVM) stages. Neural networks, like those used by Kok et al., accurately assess growth phases to guide optimal treatment timing, often outperforming traditional assessment methods.(17) While AI in CVM assessments shows promise, accuracy can vary, especially around growth peaks. Caution is needed due to potential discrepancies.

iv. **Tooth and Anomaly Detection:** AI algorithms can detect dental caries and structural anomalies in radiographs and intraoral scans with high sensitivity identifying caries that may be missed by the human eye. When used alongside traditional methods, AI improves the accuracy of early diagnosis and enables preventive interventions, especially valuable in orthodontic planning.

v. **TMD Classification**

In the absence of an expert, AI can assist in the diagnosis of temporomandibular disorders (TMD), such as TMJ osteoarthritis. Shoukri et al., applied neural network to stage condylar morphology in temporomandibular joint osteoarthritis (TMJOA). The neural network was trained on 259 condyles to detect and classify TMJOA stages, showing strong agreement with expert classifications. (18) Kim et al. developed an expert system using R-CNN and CNN for mandibular condyle detection and osteoarthritis classification on panoramic images.(19)

3.2 Treatment Planning and Outcome assessment

- **Dental analysis :** Peer Assessment Rating (PAR) evaluates orthodontic treatment outcomes by comparing pre- and post-treatment misalignment and occlusion scores. Zarei et al. used ANN to predict outcomes in Class II and III patients, accurately predicting final PAR scores.(20) Kim et al. introduced a feature wrapping system to predict Class III treatment prognosis with high accuracy.(21)
- **Impaction and Eruption Predictions** AI models contribute significantly to predicting tooth impactions and eruption timelines, aiding early and effective intervention.

i. **Canine Impaction Prediction:** Machine learning models like Bayesian networks and random forests have shown up to 83% accuracy in predicting impacted canine eruption, helping orthodontists preemptively plan treatment strategies.(22)

ii. **Size Prediction of Unerupted Teeth:** Predicting unerupted tooth size is critical for managing occlusion during the mixed dentition period. Neural networks and genetic algorithms show higher accuracy than traditional methods. Moghimi et al. found AI techniques more effective for predicting unerupted canine and premolar sizes.(23)

- **Soft Tissue Analysis and Facial Aesthetic Prediction** AI is increasingly used for aesthetic evaluations and treatment simulations, especially in cases involving soft tissue and surgical considerations.

i. **Facial Photograph Analysis:** AI tools using facial photographs have been proposed to assess facial attractiveness after treatment, classify clinical orthodontic photos, and determine treatment needs. CNN algorithms predict age and facial attractiveness after treatment, showing improvements.

ii. **Soft Tissue Outcome Assessment:** Assessing the relationship between the nose, lips, and chin is important for achieving an aesthetic facial profile. Nanda SB et al. used an artificial neural network (ANN) to predict changes in lip curvature following orthodontic treatment with or without extractions. The predicted changes in the upper and lower lips were 29.6% and 7%, respectively, closely aligning with actual results.(24)

iii. **AI in Evaluation for Cleft Patients:** Zhang used machine learning on 43 Single Nucleotide Polymorphisms (SNPs) to assess cleft lip/palate risk. Logistic regression performed best in predicting risk, identifying significant genetic variants in *MTHFR* and *RBP4*.(25) Patcas et al. compared AI and human ratings on facial attractiveness of treated cleft patients. AI performed comparably to humans for cleft patients but rated controls lower, suggesting AI needs improvement in cleft aesthetics interpretation.(26)

- **AI in Extraction vs. Non-Extraction Therapy :** Xie et al. Developed an AI system using backpropagation ANN to decide extraction in orthodontics trained on 200 patients (120 extraction, 80 non-extraction), achieving 80% accuracy. The Key factors were lip incompetence and IMPA that contributed most to decisions.(27) Jung et al. created an AI system to decide extraction and pattern using cephalometric data and achieved 93% accuracy for extraction decision and 84% for extraction pattern selection. They used validation data to prevent overfitting for more reliable results.(28) All reports are predictive in essence totally, but the authors warn that the validity of their findings is dependent on the training received by the neural network.
- **Orthognathic Surgery Planning**

AI has significantly advanced orthognathic surgery planning by enabling highly accurate simulations, predictive modeling, and aesthetic evaluations. Knoops et al. developed a 3D morphable model (3DMM) that achieved over 95% sensitivity and specificity for determining surgical referrals, allowing clinicians to make precise pre-operative decisions.(29) Weichel et al. leveraged computed tomography (CT), cephalometric data, and AI to automatically generate expert-level surgical plans, minimizing human dependency in complex planning processes.(30) Predictive models developed by Choi et al. used ANN with 96% success for surgical planning and Niño-Sandoval predicted mandibular morphology using AI for craniofacial reconstruction.(31,32) Moreover, AI has played a critical role in assessing facial aesthetics post-surgery. Patcas et al. used AI algorithms to evaluate changes in facial attractiveness following orthognathic procedures and reported a 66.4% improvement in appearance, emphasizing AI's value in both functional and aesthetic treatment outcomes.(33)

3.3 Treatment Optimization

- **Automated Aligner Design:** AI facilitates the customization of aligners by simulating tooth movement and applying optimal force vectors. Platforms like Invisalign's iTero™ use AI to visualize alignment progression and allow dynamic treatment adjustments. It creates precise, patient-specific aligners by simulating tooth movement, reducing manual work. AI-driven tools predict and simulate tooth alignment over time, helping orthodontists plan more accurate treatment. It allows for on-the-fly changes in treatment plans based on progress.
- **Automated Case Setup for Indirect Bonding:** AI systems automate bracket placement using digital models, improving accuracy and consistency. AI determines the ideal bracket position to optimize tooth movement and treatment outcomes tailored to each patient's unique needs, ensuring personalized orthodontic care. Benefits include reduced manual error, customized bracket positioning, and a streamlined workflow.
- **AI-Driven Orthodontic Devices:** New orthodontic devices powered by AI are being developed to independently move teeth.

i. **Force System Prediction:** In orthodontics, force system plays a major role to attain desirable tooth movement. Kazem et al. used ANNs to evaluate the force system of T-retraction springs. Neural networks proved effective in mapping input-output force characteristics, aiding in optimal appliance design.(34)

ii. **Independent Tooth Movers (TM):** orthodontic devices powered by AI algorithms are designed to individually control the movement of each tooth. AI technology helps predict tooth movement patterns and automatically adjusts force application for optimal outcomes, personalizing treatment based on individual patient needs.(35)

3.4 Patient Monitoring and Remote Care

AI enables effective remote monitoring, improving patient compliance and reducing the frequency of in-person visits.

- **Remote Monitoring Platforms:** Applications like Dental Monitoring (DM), Virtual Care AI, GoLive® and 3D Monitoring Light allow orthodontists to track treatment progress remotely through photos or scans. These tools reduce chairside visits by up to 23% and maintain high accuracy in evaluating tooth movement and appliance fit. Homsi et al. demonstrated that digital models generated by DM are as accurate as intraoral scans.(36) Moylan supported this by comparing DM-generated models to plaster models for intercanine and intermolar width measurements.(37) However, recent studies have highlighted concerns regarding the consistency and reliability of AI-generated recommendations, particularly in complex cases. Additionally, the rationale behind DM's instructions for clear aligner replacement remains unclear.(38) As a result, orthodontists may need to approach the widespread use of AI-driven remote monitoring tools with caution to ensure proper patient care.

4. EXPLORING AUGMENTED REALITY IN ORTHODONTICS

Augmented Reality (AR) offers a unique advantage in orthodontics by enabling both practitioners and patients to visualize treatment outcomes, thereby enhancing communication, patient engagement, and treatment satisfaction. AR is gaining momentum in various aspects of orthodontic practice including treatment planning, bracket placement, patient communication, and professional training. AR technology superimposes digital information onto real-world environments through devices such as smartphones, tablets, and smart glasses. By integrating AR with orthodontic systems, practitioners can offer real-time visualizations that support patient understanding and enhance treatment planning.

4.1 Devices and AR Platforms:

AR in orthodontics primarily utilizes mobile devices and specialized platforms like iTero's TimeLapse and Dental Monitoring. These tools provide real-time visual feedback by overlaying proposed or actual treatment results on the patient's current state. iTero's TimeLapse technology, for instance, enables practitioners to correlate historical 3D scans with current ones, allowing for evaluation of orthodontic movement, gingival recession, and tooth wear. These devices overlay digital images onto the real-world environment, enabling orthodontists to present a clear picture of treatment progress or anticipated results.

4.2 Applications of AR in Patient Communication

- **Visualizing Treatment Outcomes:** AR enhances patient communication by offering interactive and realistic visualizations of treatment outcomes. Patients can preview their post-treatment smiles, which can positively influence their motivation and adherence to the treatment plan. By showing potential treatment results, AR fosters patient engagement and understanding, helping to manage patient expectations more effectively. Studies have shown that patients exposed to AR simulations feel more confident in their treatment decisions, as the visual demonstrations clarify complex orthodontic procedures.(39)
- **Educational Support:** AR also plays a crucial role in patient education by offering visual explanations of the orthodontic process. For example, AR apps can simulate tooth movement, allowing patients to understand the mechanics behind their treatment plans. This not only empowers patients with knowledge but also builds trust in their orthodontist's recommendations.

4.3 Educational Applications of AR

- **Orthodontic Training and Education:** AR-based simulations offer trainees the opportunity to practice procedures, such as bracket placement, in a controlled environment. The use of AR-assisted bracket navigation systems increases bracket placement accuracy and decreases lab-stage procedure time. These systems help guide bracket positioning within a clinically acceptable error margin of approximately 0.5 mm. (40) The utilization of AR systems increases accuracy in all spatial directions, which is particularly helpful for novice orthodontists.
- **AR in Real-Time Treatment Planning:** Orthodontic practices have started to incorporate AR tools that assist clinicians in planning and performing treatments. Real-time tools, such as AR bracket navigation systems, allow practitioners to visualize ideal bracket positioning, significantly enhancing

accuracy and reducing procedural errors. This is particularly beneficial for early-career orthodontists, who may gain confidence and precision through AR guidance.

5. INTEGRATION AND FUTURE PERSPECTIVES IN AI AND AR FOR ORTHODONTICS

The integration of Artificial Intelligence (AI) and Augmented Reality (AR) into orthodontics is transforming clinical workflows and patient experiences. Together, these technologies enable more accurate diagnoses, personalized treatment plans, and enhanced patient communication. AI supports clinicians through data-driven predictions and automation, while AR brings a new level of visualization to both education and treatment delivery.

5.1 Preventative Orthodontics and Personalized Care

AI's predictive capabilities hold significant promise in shifting orthodontics toward a preventative model. Early identification of malocclusions, impacted teeth, or skeletal discrepancies allows for minimally invasive interventions. By analyzing growth patterns and genetic data, AI enables orthodontists to anticipate changes and tailor treatments to the individual.

- **Early Screening and Intervention:** AI tools facilitate the early detection of developmental abnormalities in young patients. Growth prediction models can guide the timing and approach of interventions for optimal results.
- **Genetic Risk Prediction and Personalized Treatment:** AI can analyze genetic, lifestyle, and environmental data to predict susceptibility to certain conditions. For example, AI models have been used to assess cleft lip and palate risk, offering a glimpse into truly personalized orthodontic care.

5.2 Regulatory and Ethical Considerations

- **Regulatory Approval and Clinical Maturity:** Most AI tools in orthodontics have not yet received full regulatory approval. Developers must demonstrate safety, reliability, and unbiased performance before widespread clinical use.
- **Data Privacy and Security:** The use of large datasets raises concerns about patient confidentiality. Developers must adhere to strict data protection standards and ensure their models do not perpetuate demographic biases.
- **Ethical Decision-Making:** AI should assist, not replace, clinical expertise. Some deep learning models operate as "black boxes," with limited transparency in how decisions are made. Orthodontists must ensure AI recommendations are validated against clinical experience.

5.3 The Future of Patient-Centered Orthodontics

- **AI and AR as Complementary Tools:** AI enhances diagnostics and automates routine planning, while AR supports visual communication. Their integration allows orthodontists to focus on complex decisions and individualized care.
- **Innovations in Patient Engagement:** Future AR tools may offer interactive features through VR headsets or mobile apps, allowing patients to explore treatment options and progress remotely. This could deepen patient trust and involvement.

6. LIMITATIONS OF AI AND AR IN ORTHODONTICS

Despite their promise, AI and AR technologies face several limitations.

- **Complexity and Unpredictability:** AI models, especially deep learning networks, are complex and sometimes lack transparency. Their predictions must be interpreted cautiously.
- **Limited Clinical Maturity:** Many AI applications are still in development and require more evidence to validate their effectiveness in diverse clinical settings.
- **Dependence on Data Quality:** AI performance is heavily reliant on the quality and size of the training data. Incomplete or biased data can lead to inaccurate outputs.
- **User Adaptability and Training:** Orthodontists must undergo training to effectively use these technologies. The learning curve can be steep, especially for practices new to digital workflows.

CONCLUSION

Artificial Intelligence (AI) and Augmented Reality (AR) are revolutionizing orthodontics by enhancing diagnostic accuracy, streamlining treatment planning, and improving patient engagement. Together, they offer transformative possibilities for delivering personalized and preventive orthodontic care. However, their use must be guided by clinical judgment, with ongoing validation, ethical implementation, and professional oversight.

As the field continues to evolve, AI and AR will play an increasingly vital role in shaping patient-centered orthodontics. With continued innovation and responsible integration, these technologies will empower orthodontists to meet rising demands for precision and efficiency, supporting but never replacing the clinician's expertise.

REFERENCES:

1. Khanagar SB, Al-Ehaideb A, Vishwanathaiah S, Maganur PC, Patil S, Naik S, et al. Scope and performance of artificial intelligence technology in orthodontic diagnosis, treatment planning, and clinical decision-making - A systematic review. J Dent Sci. 2021 Jan 1;16(1):482–92.
2. Dhopte A, Bagde H. Smart Smile: Revolutionizing Dentistry With Artificial Intelligence. Cureus. 2023 Jun;15(6):e41227.
3. Mintz Y, Brodie R. Introduction to artificial intelligence in medicine. Minim Invasive Ther Allied Technol. 2019 Apr;28(2):73–81.
4. Malik S, Muhammad K, Waheed Y. Artificial intelligence and industrial applications—A revolution in modern industries. Ain Shams Eng J. 2024 Sep 1;15(9):102886.
5. Albalawi F, Alamoud KA. Trends and application of artificial intelligence technology in orthodontic diagnosis and treatment planning—A review. Appl Sci. 2022 Jan;12(22):11864.
6. Williams M. Artificial Intelligence: The Very Idea by John Haugeland. Technol Cult. 1987;28(3):706–7.
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. Prog Orthod. 2021 Dec;22(1):18.
8. 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;13(2):344.
9. 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.
10. Retrouvey JM. The role of AI and machine learning in contemporary orthodontics. 2021.
11. Miranda F, Barone S, Gillot M, Baquero B, Anchling L, Hutin N, et al. Artificial intelligence applications in orthodontics. J Calif Dent Assoc. 2023;51(1):2195585.
12. Babu B, Vinayachandran D, Ganesh C, Shanthi M, Krithika C. Bibliometric analysis of the role of artificial intelligence in detecting maxillofacial fractures. Cureus. 2024;16(12).
13. Levy-Mandel A, Venetsanopoulos A, Tsotsos J. Knowledge-based landmarking of cephalograms. Comput Biomed Res. 1986;19(3):282–309.
14. Prince ST, Srinivasan D, Duraisamy S, Kannan R, Rajaram K. Reproducibility of linear and angular cephalometric measurements obtained by an artificial-intelligence assisted software (WebCeph) in comparison with digital software (AutoCEPH) and manual tracing method. Dent Press J Orthod. 2023 Apr 3;28(01):e2321214.
15. Hwang HW, Park JH, Moon JH, Yu Y, Kim H, Her SB, et al. Automated identification of cephalometric landmarks: Part 2—Might it be better than human? Angle Orthod. 2020;90(1):69–76.
16. Preda F, Morgan N, Van Gerven A, Nogueira-Reis F, Smolders A, Wang X, et al. Deep convolutional neural network-based automated segmentation of the maxillofacial complex from cone-beam computed tomography: A validation study. J Dent. 2022;124:104238.
17. Kök H, Acilar AM, İzgi MS. Usage and comparison of artificial intelligence algorithms for determination of growth and development by cervical vertebrae stages in orthodontics. Prog Orthod. 2019;20:1–10.
18. Shoukri B, Prieto J, Ruellas A, Yatabe M, Sugai J, Styner M, et al. Minimally invasive approach for diagnosing TMJ osteoarthritis. J Dent Res. 2019;98(10):1103–11.
19. Kim D, Choi E, Jeong HG, Chang J, Youm S. Expert system for mandibular condyle detection and osteoarthritis classification in panoramic imaging using R-CNN and CNN. Appl Sci. 2020;10(21):7464.
20. Zarei A, El-Sharkawi M, Hairfield M, King G. An intelligent system for prediction of orthodontic treatment outcome. In: IEEE; 2006. p. 2702–6.
21. Kim BM, Kang BY, Kim HG, Baek SH. Prognosis prediction for Class III malocclusion treatment by feature wrapping method. Angle Orthod. 2009 Jul;79(4):683–91.
22. Chelliah BJ. Prediction of favorability of maxillary canine impaction using artificial intelligence algorithm. J Indian Orthod Soc. 2024;58(3):291–302.
23. Moghimi S, Talebi M, Parisay I. Design and implementation of a hybrid genetic algorithm and artificial neural network system for predicting the sizes of unerupted canines and premolars. Eur J Orthod. 2012;34(4):480–6.
24. Nanda SB, Kalha AS, Jena AK, Bhatia V, Mishra S. Artificial neural network (ANN) modeling and analysis for the prediction of change in the lip curvature following extraction and non-extraction orthodontic treatment. J Dent Spec. 2015;3(2).
25. Zhang SJ, Meng P, Zhang J, Jia P, Lin J, Wang X, et al. Machine learning models for genetic risk assessment of infants with non-syndromic orofacial cleft. Genomics Proteomics Bioinformatics. 2018;16(5):354–64.

26. Patcas R, Timofte R, Volokitin A, Agustsson E, Eliades T, Eichenberger M, et al. Facial attractiveness of cleft patients: A direct comparison between artificial-intelligence-based scoring and conventional rater groups. Eur J Orthod. 2019 Aug 8;41(4):428–33.
27. Xie X, Wang L, Wang A. Artificial neural network modeling for deciding if extractions are necessary prior to orthodontic treatment. Angle Orthod. 2010 Mar;80(2):262–6.
28. Jung SK, Kim TW. New approach for the diagnosis of extractions with neural network machine learning. Am J Orthod Dentofac Orthop. 2016 Jan;149(1):127–33.
29. Knoops PG, Papaioannou A, Borghi A, Breakey RW, Wilson AT, Jeelani O, et al. A machine learning framework for automated diagnosis and computer-assisted planning in plastic and reconstructive surgery. Sci Rep. 2019;9(1):13597.
30. Weichel F, Eisenmann U, Richter S, Hagen N, Rückschloß T, Freudlsperger C, et al. A computer-assisted optimization approach for orthognathic surgery planning. Curr Dir Biomed Eng. 2019;5(1):41–4.
31. Choi HI, Jung SK, Baek SH, Lim WH, Ahn SJ, Yang IH, et al. Artificial intelligent model with neural network machine learning for the diagnosis of orthognathic surgery. J Craniofac Surg. 2019 Oct;30(7):1986–9.
32. Niño-Sandoval TC, Guevara Pérez SV, González FA, Jaque RA, Infante-Contreras C. Use of automated learning techniques for predicting mandibular morphology in skeletal class I, II and III. Forensic Sci Int. 2017 Dec;281:187.e1–7.
33. Patcas R, Bernini DAJ, Volokitin A, Agustsson E, Rothe R, Timofte R. Applying artificial intelligence to assess the impact of orthognathic treatment on facial attractiveness and estimated age. Int J Oral Maxillofac Surg. 2019 Jan;48(1):77–83.
34. Kazem BI, Ghaib NH, Grama NMH. Experimental investigation and neural network modeling for force system of retraction T-spring for orthodontic treatment. 2010.
35. Peikar M. AI driven orthodontic devices: Independent tooth movers (ITM). Semin Orthod. 2023 Mar 1;29(1):85–9.
36. Homsi K, Snider V, Kusnoto B, Atsawasuwan P, Viana G, Allareddy V, et al. In-vivo evaluation of artificial intelligence driven remote monitoring technology for tracking tooth movement and reconstruction of 3-dimensional digital models during orthodontic treatment. Am J Orthod Dentofacial Orthop. 2023 Nov 1;164(5):690–9.
37. Moylan H. Accuracy of a smartphone-based orthodontic treatment monitoring application. 2018.
38. Ferlito T, Hsiou D, Hargett K, Herzog C, Bachour P, Katebi N, et al. Assessment of artificial intelligence–based remote monitoring of clear aligner therapy: A prospective study. Am J Orthod Dentofacial Orthop. 2023;164(2):194–200.
39. Mani S, Manerikar R, Arimbur A, Khurdal AS. Evaluation of augmented reality and social media on patient motivation to undergo fixed orthodontic treatment. APOS Trends Orthod. 2024;14:124–9.
40. Lo YC, Chen GA, Liu YC, Chen YH, Hsu JT, Yu JH. Prototype of augmented reality technology for orthodontic bracket positioning: an in vivo study. Appl Sci. 2021;11(5):2315.