

AI Precision in Orthodontics: Applications, Evidence, and Future Directions A Narrative Review

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Abstract

Artificial Intelligence (AI) is transforming orthodontic diagnosis, treatment planning, and monitoring by enabling faster, more consistent, and more individualized clinical decision-making. This narrative review synthesizes current peer-reviewed literature on AI applications across the orthodontic care pathway, including automated cephalometric landmark detection, extraction and treatment-planning decision support, clear aligner design and tooth-movement prediction, biomechanical finite element simulation, real-time remote patient monitoring, face-driven soft-tissue analysis, and airway screening. Across these domains, AI systems built on convolutional neural networks and related deep-learning architectures have demonstrated accuracy that frequently approaches or matches experienced clinicians, while substantially reducing analysis time and inter-examiner variability. Key limitations persist, including dataset diversity, generalizability across imaging systems, algorithmic bias, data privacy, and the continued need for clinician oversight. We conclude that AI is best positioned as a decision-support tool that enhances precision throughout orthodontic care rather than a replacement for clinical judgment.

Keywords: artificial intelligence; orthodontics; precision medicine; cephalometric analysis; clear aligners; machine learning; deep learning.

INTRODUCTION

Artificial Intelligence (AI) is increasingly reshaping the practice of orthodontics, moving the specialty from largely manual, experience-based diagnosis and planning toward data-driven, highly personalized care. AI systems built on machine learning and deep learning are now capable of analyzing large volumes of dental records, radiographs, and three-dimensional scans to support diagnosis, treatment planning, and monitoring with a level of consistency that is difficult for the human eye to match on its own¹. This shift toward "precision orthodontics" mirrors a broader movement across healthcare, in which algorithms trained on large datasets help clinicians individualize treatment rather than apply generalized protocols to every patient². Central to this transformation is the ability of AI models, particularly convolutional neural networks (CNNs), to process complex imaging data such as lateral cephalograms and cone-beam computed tomography (CBCT) scans far faster than manual methods, while reducing inter-examiner variability^{3,4}. As these tools mature, they are being integrated across nearly every stage of orthodontic care: diagnosis, treatment simulation, appliance design, biomechanical planning, and remote patient monitoring. Figure 1 depicts this as a continuous, cyclic process rather than a one-directional pipeline, since remote monitoring data feeds back into ongoing treatment planning. This review summarizes the current evidence on AI-driven precision in orthodontics and outlines the principal clinical applications, limitations, and future directions reported in the peer-reviewed literature.

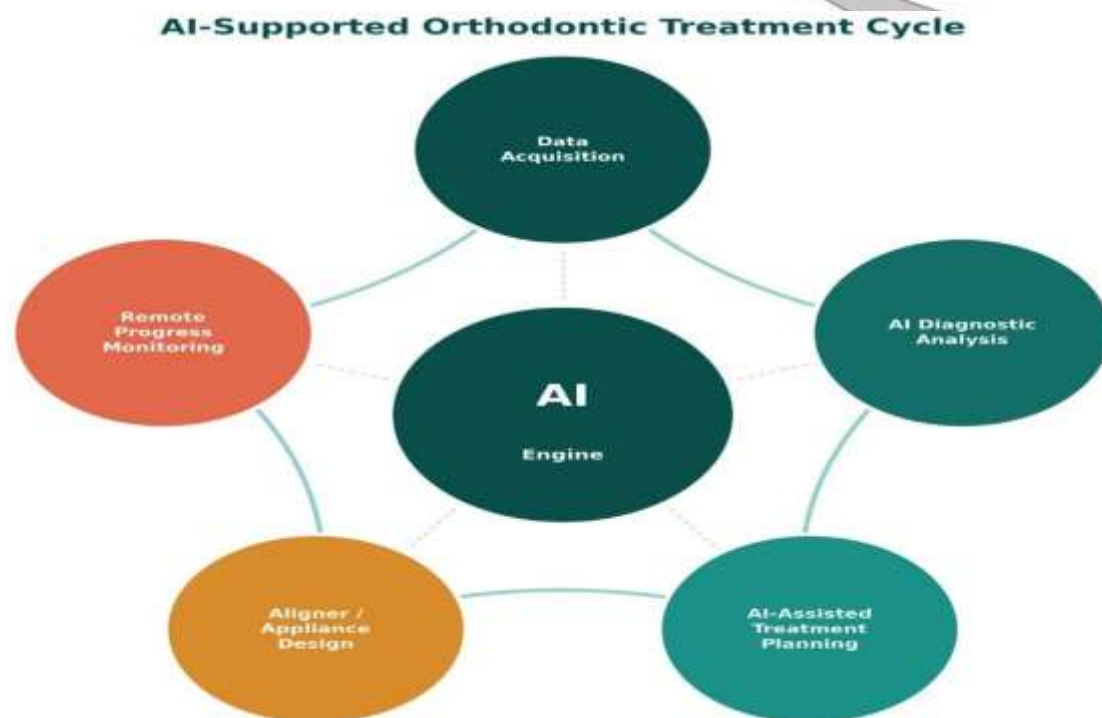


Figure 1. AI-supported orthodontic treatment cycle: a continuous loop connecting data acquisition, diagnostic analysis, treatment planning, appliance design, and remote monitoring around a central AI engine.

REVIEW METHODOLOGY

This is a narrative review synthesizing recent peer-reviewed literature (2023-2026) identified through PubMed/MEDLINE, Scopus, Web of Science, and ScienceDirect, using combinations of the terms "artificial intelligence", "machine learning", "deep learning", "orthodontics", "cephalometric", "clear aligner", and "precision". Priority was given to systematic and scoping reviews, narrative reviews, and validation studies reporting quantitative accuracy outcomes. The aim was to characterize the breadth of current clinical applications rather than to conduct a formal systematic review with meta-analysis.

1. Overview of AI Applications in Orthodontics

Table 1 summarizes the principal domains in which AI is currently applied in orthodontic practice, the underlying technique, and the key reported outcomes from the reviewed literature.

Table 1. Summary of AI applications across the orthodontic care pathway.

Domain	AI Technique	Key Reported Outcome	Ref.
Diagnostic imaging	CNN-based landmark detection on lateral cephalograms / CBCT	Accuracy within 2 mm clinical threshold in most studies; lower inter-examiner variability than manual tracing	5-8
Treatment planning	Decision-support algorithms; large language models	Assists extraction vs. non-extraction decisions, arch expansion, deep-bite planning, facial growth simulation	10
Clear aligner design	Predictive force-response modeling	Individualized aligner staging; improved digital treatment planning precision	1, 11
Biomechanical simulation	AI-driven finite element models (FEM)	Optimizes bracket/aligner force design prior to clinical placement	4
Remote monitoring	Automated image analysis of patient-submitted photos	Reduces in-person visits; earlier detection of treatment deviation	2, 4, 11
Face-driven orthodontics	Facial and soft-tissue AI analysis	Integrates facial aesthetics with occlusal treatment goals	12
Airway / OSA screening	CBCT-based deep learning segmentation	Automated adenoid/airway volumetric analysis; sensitivity comparable to experts	9

2. Diagnostic Imaging and Cephalometric Analysis

The most extensively studied application of AI in orthodontics is automated landmark detection on lateral cephalograms. CNN-based models trained on large image datasets can locate cephalometric landmarks with accuracy that frequently matches, or shows less variability than, experienced examiners, while completing the analysis in a fraction of the time^{5,6}. Studies comparing AI-generated tracings with manual tracings report deviations within the clinically accepted 2 mm threshold for most landmarks, with some systems achieving landmark prediction errors below 1 mm^{7,8}. Three-dimensional CBCT-based landmarking is advancing rapidly but currently remains less accurate than 2D cephalometric analysis⁹.

AI-Based Cephalometric Landmark Identification (Schematic)

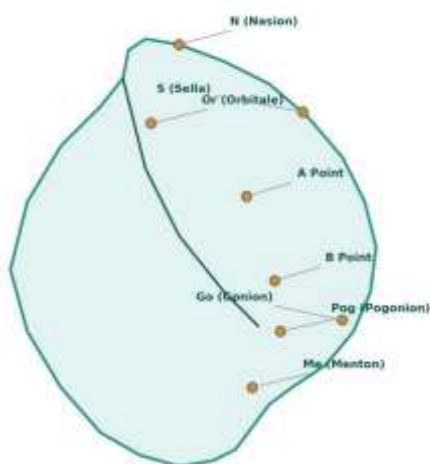


Figure 2. Schematic of AI-based cephalometric landmark identification on a lateral profile.

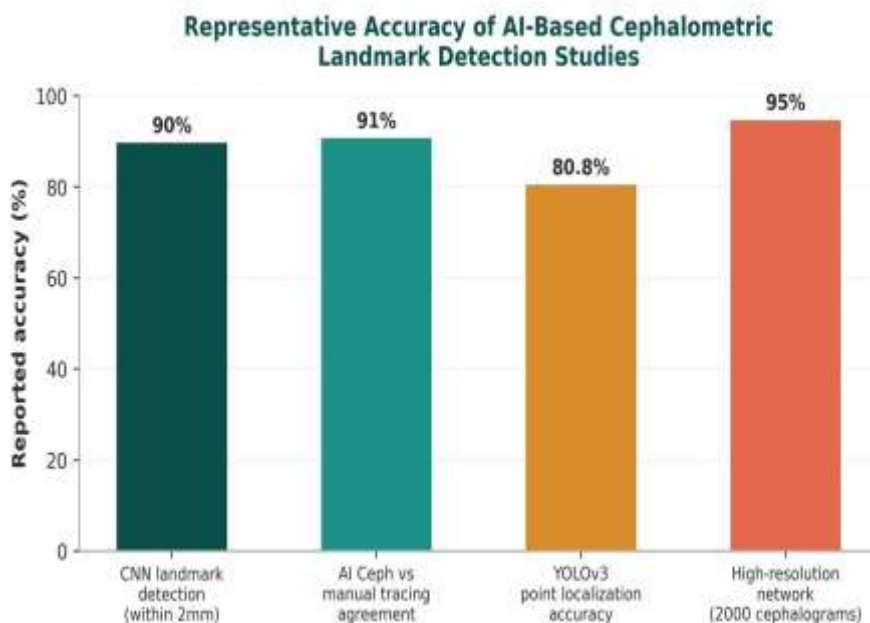


Figure 3. Illustrative accuracy figures reported across representative AI cephalometric landmark-detection studies (approximate midpoints of ranges reported in the cited literature; for illustration only).

3. Treatment Planning and Extraction Decision Support

AI-based decision-support tools are being used to assist orthodontists with extraction versus non-extraction decisions, arch expansion planning, and deep-bite management, particularly in mixed dentition cases. A scoping review of commercially available and academically validated tools found that most focus on AI-driven decision-making for extractions and appliance design, with additional emerging applications in large language

models used to answer orthodontic clinical questions¹⁰. AI is also applied to simulate long-term treatment outcomes through facial growth prediction, giving clinicians a forward-looking view of how a treatment plan may affect facial development¹⁰.

4. Clear Aligner Design and Tooth Movement Prediction

AI plays a substantial role in clear aligner therapy, where predictive models help streamline workflow, enhance the precision of digital treatment planning, and enable greater customization based on each patient's dental characteristics¹¹. AI-driven systems analyze intraoral scans and prior treatment data to predict how individual teeth will respond to applied forces, allowing aligners and fixed appliances to be designed for optimal force delivery, which can reduce treatment time and patient discomfort¹.

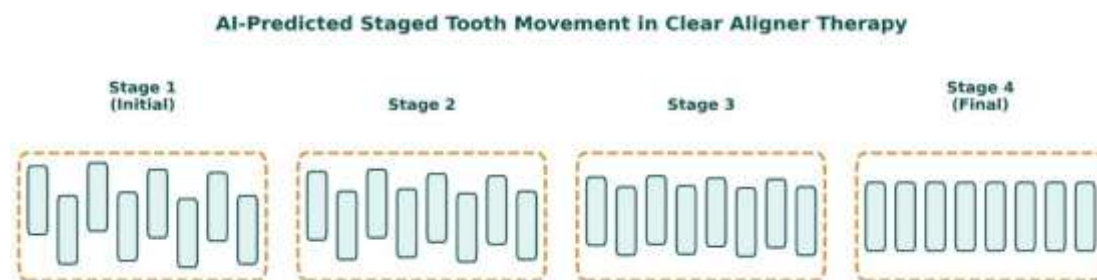


Figure 4. AI-predicted staged tooth movement across sequential clear aligner stages.

5. Biomechanical Simulation

AI-driven finite element models (FEMs) simulate the biomechanical effects of orthodontic forces on teeth and their surrounding periodontal structures, allowing bracket and aligner designs to be optimized before clinical placement. By reducing subjectivity in treatment planning, deep learning approaches are helping refine predictive precision across a range of malocclusions⁴.

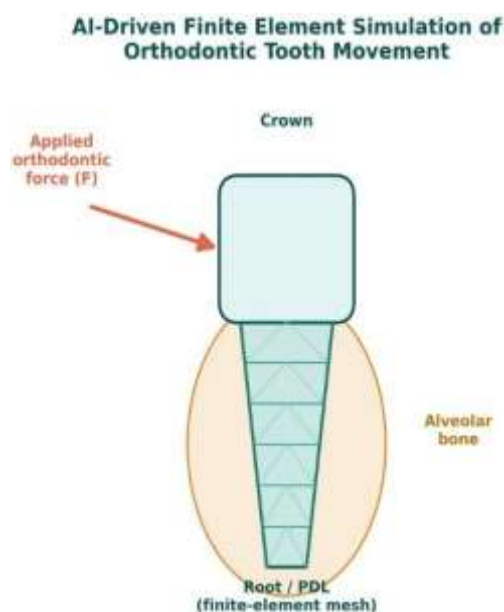


Figure 5. AI-driven finite element simulation of force distribution through the root and periodontal ligament during orthodontic tooth movement.

6. Real-Time and Remote Patient Monitoring

AI-powered mobile applications allow patients to photograph their teeth at home; automated image-analysis algorithms then assess tooth position and treatment progress remotely, reducing the need for frequent in-person visits and supporting earlier detection of deviations from planned tooth movement^{2,11}. This kind of

dynamic, AI-supported monitoring is increasingly used for real-time treatment tracking and risk prediction within clinical workflows⁴.

AI-Powered Remote Monitoring of Orthodontic Treatment

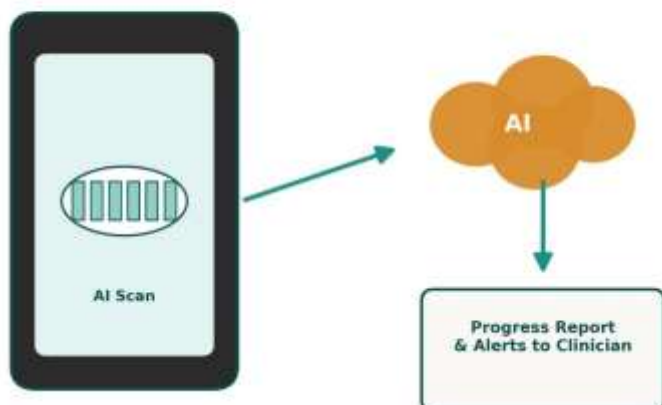


Figure 6. AI-powered remote monitoring workflow: patient-submitted scans are analyzed and summarized for the clinician.

7. Face-Driven Orthodontics and Airway Screening

Beyond occlusion, AI is used to integrate facial analysis and dynamic soft-tissue evaluation into treatment planning, supporting "face-driven" orthodontics that aims to optimize facial balance and aesthetic harmony alongside bite correction, in response to growing patient demand for aesthetic outcomes¹². Separately, deep learning models applied to CBCT scans can perform automated airway segmentation and volumetric analysis, supporting detection of adenoid hypertrophy and early screening for obstructive sleep apnoea (OSA) in pediatric patients, with some models achieving sensitivity and specificity comparable to human experts at markedly reduced processing time⁹.

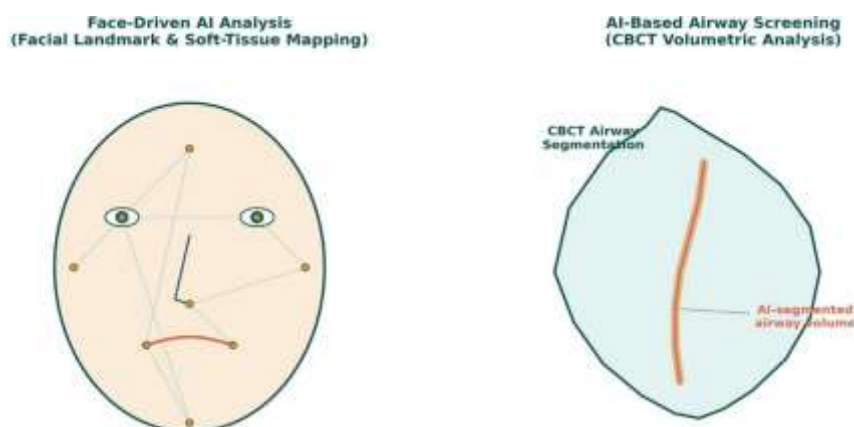


Figure 7. Left: facial landmark mapping for face-driven orthodontic planning. Right: AI-segmented airway volume from CBCT for screening purposes.

8. Challenges and Limitations

Despite this progress, AI tools in orthodontics remain decision-support systems rather than replacements for clinical judgment. Model performance can vary across patient populations, imaging equipment, and image quality, and most systems are trained using expert opinion as the reference standard, which carries forward some inherent variability^{9,10}. Ongoing concerns include data privacy, algorithmic bias from insufficiently diverse training datasets, domain shift between imaging devices, and the cost of adopting AI systems into practice^{1,3}. Continued human supervision, larger and more diverse training datasets, and long-term clinical

validation are widely cited as prerequisites for wider adoption⁹.

9. Future Directions

Looking ahead, the literature points to the integration of AI with robotics for performing selected orthodontic procedures, predictive orthodontics for earlier interceptive intervention, and on-demand 3D printing to fabricate orthodontic appliances directly from AI-generated treatment plans¹. Continued convergence of AI with sustainable, eco-friendly manufacturing technologies is also an emerging area of interest for the specialty³.

CONCLUSION

AI is steadily becoming embedded across the orthodontic workflow, from cephalometric diagnosis and extraction decision-support to aligner design, biomechanical simulation, remote monitoring, and facial-aesthetic planning. The consistent theme across the current literature is precision: AI helps standardize measurements, reduce examiner variability, and personalize treatment to the individual patient. Realizing its full potential will depend on rigorous validation, diverse training data, and orthodontists retaining oversight of AI-generated recommendations as a decision-support tool rather than an autonomous one.

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