



DOI: <https://doi.org/10.69648/DOXW3661>

International Journal of Natural and Technical
Sciences (IJTNS), 2026; 6(1): 49-58.

ijtns.ibupress.com

Online ISSN: 2671-3519



Application: 15.04.2026

Revision: 20.05.2026

Acceptance: 21.06.2026

Publication: 26.06.2026



Dimovska, R. (2026). Artificial Intelligence in
Orthodontics: From Algorithms to Aligners Interna-
tional Journal of Technical and Natural Sciences,
6(1), 49-58. <https://doi.org/10.69648/DOXW3661>



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Artificial Intelligence in Orthodontics: From Algorithms to Aligners

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Abstract

Artificial intelligence (AI) has become an important component of modern orthodontics, significantly influencing diagnostics, treatment planning, and patient monitoring. This review paper examines the current applications of artificial intelligence (AI) and digital technologies in orthodontic practice, with particular focus on cephalometric analysis, clear aligner therapy, predictive tooth movement, and digital treatment workflows. Relevant scientific literature was retrieved from PubMed, Scopus, Web of Science, and Google Scholar, focusing on machine learning (ML), deep learning (DL), cone-beam computed tomography (CBCT), intraoral scanning, and artificial intelligence (AI)-assisted orthodontic software systems. The reviewed studies demonstrate that AI improves diagnostic accuracy, accelerates cephalometric analysis, enhances treatment simulations, and supports individualized orthodontic care. AI-assisted aligner systems and remote monitoring technologies also improve treatment efficiency, patient compliance, and communication. Despite these advantages, orthodontic treatment remains dependent on biological variability and clinical expertise. Artificial intelligence (AI) should therefore be regarded as a supportive tool rather than a replacement for the clinician. The future of orthodontics will likely depend on the balanced integration of advanced digital technologies and professional clinical judgment.

Keywords: Artificial intelligence, digital orthodontics, orthodontics, clear aligners, treatment planning

Introduction

Orthodontics has always relied heavily on the careful analysis of diagnostic data. From manual cephalometric tracings to the digital technologies introduced in the early 2000s, the primary objective has remained unchanged: achieving controlled and predictable tooth movement within the craniofacial complex. Modern diagnostic techniques now generate enormous amounts of information, including cone beam computed tomography (CBCT), three-dimensional (3D) intraoral scans, and high-resolution facial photographs. The volume and complexity of these datasets often exceed the capacity of traditional manual analysis.

Artificial intelligence (AI), particularly machine learning (ML) and deep learning (DL), offers powerful tools for processing and integrating complex clinical data. In contemporary orthodontics, artificial intelligence (AI) is increasingly used to support clinicians in diagnosis, treatment planning, and the customized creation of orthodontic appliances (Ye et al., 2025).

The development of digital orthodontics has accelerated significantly in recent years due to improvements in computational technologies, imaging systems, and software algorithms. Orthodontic practice is transitioning from conventional analog methods toward digital workflows that rely on virtual simulations and predictive modeling. Artificial intelligence (AI)-assisted systems are now capable of performing cephalometric analysis, predicting tooth movement, analyzing radiographs, and supporting clear aligner therapy with a degree of speed and precision that was previously unattainable.

Despite these advancements, orthodontic treatment remains fundamentally biological. Tooth movement depends on the response of the periodontal ligament, alveolar bone remodeling, patient cooperation, and individual anatomical variability. Therefore, while artificial intelligence (AI) can improve efficiency and analytical precision, clinical expertise and professional judgment remain essential for successful treatment outcomes.

The purpose of this review paper is to examine the current applications of artificial intelligence in orthodontics, with particular emphasis on diagnostics, treatment planning, clear aligner systems, and patient monitoring. In addition, the paper evaluates the benefits, limitations, and future implications of artificial intelligence (AI) integration in contemporary orthodontic practice.

Cephalometric Analysis

Cephalometric analysis has traditionally been a time-consuming procedure requiring manual identification of anatomical landmarks. Artificial intelligence (AI)-based systems are now capable of automatically identifying skeletal and dental reference points with remarkable speed and accuracy (Cao et al., 2022). Recent studies have demonstrated that artificial intelligence (AI)-assisted landmark detection can achieve accuracy within approximately 2 mm of manually determined positions, which is generally considered clinically acceptable. Advanced deep learning algorithms have shown promising results in both two-dimensional and three-dimensional cephalometric analysis. Song et al. (2024) reported that convolutional neural network (CNN)-based systems significantly improved the reliability of 3D cephalometric landmark identification. Similarly, Lee et al. (2023) demonstrated that automated landmark detection systems could achieve performance comparable to that of experienced orthodontists.

The implementation of artificial intelligence (AI)-assisted cephalometric analysis substantially reduces the time required for diagnosis. Procedures that previously required 15–20 minutes of manual tracing may now be completed within seconds, improving efficiency and reducing interobserver variability.

Detection of Pathology and Bone Assessment

Artificial intelligence (AI) has also demonstrated significant potential in the detection of pathological findings on panoramic and periapical radiographs. Artificial intelligence (AI)-assisted radiographic interpretation contributes to improved diagnostic precision by identifying dental caries, cystic lesions, impacted teeth, and other pathological conditions. Another important application involves skeletal maturity assessment using hand-wrist radiographs and cervical vertebral maturation analysis. Artificial intelligence (AI)-based systems provide more consistent and reproducible evaluations compared with conventional methods (Kavasoglu et al., 2025). Such assessments are particularly important in orthodontic treatment planning because growth prediction influences the timing of orthopedic and functional interventions.

Digital Scanning and Virtual Treatment Planning

The connection between diagnostic algorithms and clinical treatment becomes evident during digital treatment planning. Artificial intelligence (AI) systems transform static diagnostic information into dynamic simulations of tooth movement. Modern orthodontic software automatically segments intraoral scans by identifying individual teeth and separating them from surrounding gingival tissues (Turner, 2025). This process allows the creation of digital setups in which teeth can be moved independently within a virtual three-dimensional environment. In many systems, digital models can be integrated with cone-beam computed tomography (CBCT) data, enabling orthodontists to visualize not only the crowns but also the roots and surrounding alveolar bone structures during treatment planning (Ahn et al., 2024). This integration improves the ability to evaluate root proximity, cortical bone limitations, and potential risks associated with orthodontic tooth movement.

Predictive Tooth Movement

Predicting biological responses to orthodontic forces remains one of the greatest challenges in orthodontics. By analyzing large datasets from previously treated patients, artificial intelligence (AI) models are now capable of estimating potential movement patterns and treatment outcomes (Liu et al., 2023; Nordblom et al., 2024). These systems assist clinicians in evaluating root proximity, predicting treatment duration, and optimizing force distribution for movements such as intrusion, extrusion, distalization, and rotation (Alhazmi, 2025). Although artificial intelligence (AI) cannot fully account for individual biological variability, predictive models provide valuable support during treatment planning and risk assessment.

Clear Aligner Systems and AI Personalization

Clear aligner therapy represents one of the most visible clinical applications of artificial intelligence (AI) in orthodontics. Unlike conventional fixed appliances, aligner therapy depends largely on digitally planned treatment sequences.

CAD/CAM Technology

The fabrication of aligners relies on computer-aided design (CAD) and computer-aided manufacturing (CAM). Artificial intelligence (AI)-assisted algorithms optimize the staging of tooth movement by determining the number of aligners and

treatment steps required to achieve the desired outcome (Alhazmi, 2025). Recent technological developments have introduced the possibility of directly 3D-printing aligners, potentially eliminating traditional thermoforming procedures (Khijmatgar et al., 2022). These advancements may improve manufacturing precision and reduce material distortion during production.

Remote Monitoring and Patient Compliance

Artificial intelligence (AI)- supported mobile applications allow patients to perform regular scans of their dentition using smartphone cameras. The acquired images are analyzed by software that evaluates aligner fit and treatment progress (Fawaz et al., 2023). Remote monitoring systems may reduce the frequency of clinical visits while still allowing orthodontists to identify deviations from treatment plans and intervene when necessary. In addition, these technologies improve patient engagement and communication throughout treatment.

Materials and Methods

This review paper was conducted as a comprehensive literature-based study aimed at analyzing the integration of artificial intelligence in modern orthodontics, with particular focus on cephalometric analysis, clear aligner therapy, digital workflows, and predictive treatment planning.

A structured literature search was performed using PubMed, Scopus, Web of Science, and Google Scholar databases. The search included scientific articles published up to 2025. The following keywords and combinations were used: “orthodontics,” “artificial intelligence,” “machine learning,” “deep learning,” “digital orthodontics,” “clear aligners,” “CBCT,” “cephalometric analysis,” and “treatment planning.”

Approximately 100 peer-reviewed articles were initially identified. Studies were selected based on relevance, methodological quality, scientific impact, and clinical applicability. Both original research articles and systematic reviews were included to provide a broad overview of diagnostic, predictive, and therapeutic applications of artificial intelligence (AI) in orthodontics.

The inclusion criteria consisted of:

1. Studies evaluating artificial intelligence (AI) applications in orthodontic diagnosis and treatment planning.

2. Research involving digital orthodontic workflows, cone-beam computed tomography (CBCT) analysis, and aligner therapy.
3. Peer-reviewed articles.
4. Studies demonstrating clinical or practical relevance to orthodontic treatment.

The exclusion criteria included:

1. Studies unrelated to orthodontics.
2. Purely technical computer science studies without clinical applicability.
3. Non-peer-reviewed publications and unpublished data.
4. Duplicate studies and conference abstracts lacking full scientific data.

Data extraction focused on the following areas:

- Artificial intelligence (AI)-assisted cephalometric analysis and radiographic interpretation.
- Digital treatment planning and virtual tooth movement simulation.
- Clear aligner therapy and predictive treatment modeling.
- Remote monitoring systems and patient compliance.
- Clinical outcomes, limitations, and ethical considerations.

The selected literature was analyzed and carefully read to qualitatively identify current trends, reported clinical accuracy, advantages, limitations, and future perspectives regarding the integration of artificial intelligence into orthodontic workflows.

Discussion

The integration of artificial intelligence (AI) into orthodontics represents one of the most significant technological developments in contemporary dental medicine. Nevertheless, despite the impressive capabilities of modern software systems, orthodontic treatment remains fundamentally a biological process. Tooth movement occurs within living tissues, and the response of the periodontal ligament and surrounding bone structures is influenced by numerous patient-specific factors. Consequently, artificial intelligence (AI) should be considered a supportive clinical tool rather than a replacement for professional judgment.

One of the greatest contributions of artificial intelligence (AI) is its ability to process and organize large amounts of diagnostic information. Modern orthodontic workflows frequently combine cone-beam computed tomography (CBCT) imaging, intraoral scans, facial photographs, and digital models. Manual analysis of these datasets may be time-consuming and prone to variability between clinicians. AI-assisted systems can rapidly integrate these data and provide structured diagnostic support, thereby improving efficiency and consistency.

The reviewed literature demonstrates that artificial intelligence (AI)-assisted cephalometric analysis significantly reduces the time required for landmark identification while maintaining clinically acceptable accuracy. This improvement not only enhances efficiency but also minimizes human error and interobserver variability. Similar findings have been reported regarding artificial intelligence (AI)-assisted radiographic interpretation and skeletal maturity assessment.

At the same time, it is essential to recognize the limitations of algorithm-based predictions. Artificial intelligence systems (AI) rely on previously collected datasets and statistical models. Although such systems can identify patterns across large populations, they may not accurately predict the biological response of every individual patient. Variations in bone density, periodontal health, age, genetics, and patient compliance can influence treatment outcomes in ways that algorithms cannot fully anticipate.

Another important aspect involves digital treatment planning systems used in clear aligner therapy. Artificial intelligence (AI)-assisted software allows clinicians to visualize predicted tooth movements and treatment outcomes before therapy begins. However, clinical experience indicates that *in vivo* tooth movement does not always correspond precisely to virtual simulations. Movements such as extrusion, rotation of rounded teeth, and bodily translation may occur more slowly or less predictably than expected. Consequently, orthodontists often incorporate overcorrections and refinement stages into aligner therapy.

The expansion of digital orthodontics has also created new possibilities for remote patient monitoring. Smartphone-based applications and artificial intelligence (AI)-supported monitoring systems allow patients to submit photographs and scans that can be evaluated remotely. Although these technologies improve convenience and communication, they should not replace direct clinical examination entirely. Evaluation of occlusion, periodontal health, temporomandibular joint function, and patient comfort still requires professional clinical assessment.

Ethical considerations represent another important dimension of artificial intelligence (AI) integration in healthcare. The use of artificial intelligence (AI) requires careful attention to patient privacy, data security, algorithm transparency, and professional responsibility. Clinicians must ensure that artificial intelligence (AI)-generated outputs are interpreted responsibly and that patient care remains individualized and biologically safe. Furthermore, the legal responsibility for treatment decisions still rests entirely with the clinician, as artificial intelligence (AI) tools function only as supportive systems and not autonomous decision-makers.

The role of the orthodontist is gradually evolving within this highly digital environment. Traditionally, orthodontics relied heavily on manual procedures such as model analysis, wire bending, and cephalometric tracing. With increasing digitalization, the clinician's role is shifting toward interpretation, treatment strategy, and supervision of technologically assisted workflows. In this context, the orthodontist becomes not merely a technician but a clinical strategist responsible for integrating digital information with biological understanding and patient-centered care.

Despite rapid technological advancement, the human aspect of orthodontic treatment remains irreplaceable. Successful treatment depends not only on technical precision but also on communication, trust, motivation, and empathy between clinician and patient. Artificial intelligence (AI) can support treatment monitoring and predictive analysis, but it cannot replace the clinical intuition and ethical responsibility of the orthodontist.

Ultimately, the future of orthodontics will likely depend on a balanced integration of advanced technology and clinical expertise. Artificial intelligence (AI) offers powerful analytical capabilities that improve precision and efficiency; however, its greatest value lies in complementing—not replacing—the knowledge, experience, and judgment of the clinician.

Conclusion

The integration of artificial intelligence (AI) into orthodontics represents a transformative advancement in contemporary dental medicine. Evidence from recent scientific literature demonstrates that artificial intelligence (AI)-assisted systems improve diagnostic precision, optimize treatment planning, and enhance efficiency in orthodontic workflows. Applications such as automated cephalometric analysis, cone-beam computed tomography (CBCT) interpretation, predictive tooth

movement modeling, and clear aligner staging have significantly reduced the time required for routine clinical procedures while maintaining high levels of accuracy. In addition, remote monitoring technologies and smartphone-based applications contribute to improved patient communication, compliance, and treatment supervision. Despite these advancements, orthodontic treatment remains fundamentally dependent on biological principles and individualized patient responses. Artificial intelligence (AI) cannot fully predict the complexity of tissue adaptation, patient cooperation, and anatomical variability. Therefore, clinical expertise and professional judgment remain essential in interpreting artificial intelligence (AI)-generated data and ensuring biologically safe treatment outcomes.

The reviewed literature suggests that the future of orthodontics will involve a synergistic relationship between artificial intelligence (AI) and clinician expertise. Artificial intelligence (AI) should be regarded as a powerful adjunctive tool that enhances efficiency, precision, and personalization rather than as a replacement for the orthodontist.

In conclusion, the successful integration of artificial intelligence (AI) into orthodontics requires a balanced approach that combines advanced digital technologies with evidence-based clinical practice, ethical responsibility, and patient-centered care. Orthodontists who effectively integrate artificial intelligence (AI) into their workflows will likely define the future standards of modern orthodontic treatment.

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