Artificial Intelligence in Orthodontics: Transforming Diagnosis, Treatment Planning, and Predictive Precision

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Artificial intelligence (AI) is rapidly transforming the diagnostic and therapeutic framework of contemporary orthodontics. The increasing digitization of orthodontic records—lateral cephalograms, cone-beam computed tomography (CBCT), intraoral scans, and 3-dimensional facial images—has created an ideal ecosystem for the application of machine learning and deep learning algorithms. These technologies are enabling automated diagnosis, predictive modeling of tooth movement, individualized treatment planning, and growth forecasting, thereby shifting orthodontics toward precision-driven and data-guided clinical care [1-3].

One of the most extensively investigated applications of AI in orthodontics is automated cephalometric analysis. Conventional landmark identification is time-intensive and subject to intra- and inter-examiner variability. Deep learning algorithms, particularly convolutional neural networks (CNNs), have demonstrated high accuracy in detecting cephalometric landmarks with performance comparable to experienced orthodontists while significantly reducing analysis time [4-6]. AI-based systems not only improve reproducibility but also allow rapid large-scale data processing, which is valuable for both clinical decision-making and research applications. Recent systematic reviews report that most AI models achieve landmark detection errors within clinically acceptable limits (<2 mm), highlighting their reliability in routine orthodontic practice [5,6].

AI is also redefining the predictability of orthodontic biomechanics through tooth movement prediction models. By training on extensive datasets of treated cases, machine learning algorithms can estimate the rate, direction, and pattern of tooth movement under specific force systems. These predictive models are particularly relevant in clear aligner therapy, where discrepancies between virtual setups and clinical outcomes remain a challenge. AI-driven simulations have been shown to improve staging protocols, optimize attachment design, and enhance the accuracy of complex movements such as torque, rotation, and intrusion [7,8]. Such developments contribute to reduced treatment duration, improved efficiency, and better control of anchorage.

Another significant advancement is the use of AI in treatment planning and outcome simulation. AI-enabled platforms can integrate skeletal, dental, and soft-tissue parameters to generate multiple treatment scenarios and predict post-treatment facial and occlusal outcomes. This facilitates extraction versus non-extraction decisions, orthognathic surgery planning, and customized biomechanics based on patient-specific characteristics [2,9]. Moreover, visual simulations derived from AI improve patient communication, compliance, and informed consent by providing realistic projections of treatment results.

In growing patients, AI has demonstrated promising applications in growth prediction and extraction decision support. Machine learning models trained on longitudinal datasets can assess skeletal maturation using cervical vertebral morphology, hand-wrist radiographs, and cephalometric variables with accuracy comparable to traditional methods [10,11]. These tools assist clinicians in determining the optimal timing for growth modification procedures and in predicting treatment response. Similarly, AI-based decision support systems can analyze arch length discrepancy, soft-tissue profile, and skeletal relationships to provide evidence-based guidance for extraction planning, thereby improving long-term stability and esthetic outcomes [2,12].

Despite its transformative potential, the integration of AI into orthodontic practice raises important concerns regarding data security, algorithm transparency, ethical responsibility, and medico-legal accountability. AI should be considered an adjunct to, rather than a replacement for, clinical expertise. The orthodontist's role in interpreting AI-generated outputs within the biological and psychosocial context of the patient remains indispensable [1,3].

In conclusion, artificial intelligence is ushering orthodontics into an era of precision, efficiency, and personalized care. From automated cephalometric analysis to intelligent treatment simulations and growth forecasting, AI has the potential to enhance diagnostic accuracy, optimize biomechanics, and improve treatment outcomes. The future of orthodontics will depend on a synergistic integration of human clinical judgment and machine intelligence, ensuring that technological advancements translate into meaningful improvements in patient care.

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