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## Review Article



# A New Perspective on Developments in Orthodontics: Artificial Intelligence

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## **A New Perspective on Developments in Orthodontics: Artificial Intelligence**

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### **Abstract**

The rapidly increasing advances in technological developments, the importance of economic gains, and the need to carry out business processes in a shorter and more efficient manners increased the demand for digital systems in order to enable the rapid collection and analysis of large amounts of data. In this respect, artificial intelligence (AI) has emerged, and played an important role in the digitalization of societies. Recently, AI applications have become popular in dentistry, which are also evident in orthodontics to provide guidance in diagnosis, treatment planning, and/or prediction of prognosis. There are large standardized data sets for patient follow-ups in orthodontics, which pose great potential for the application of AI due to their longitudinal and multimodal dataset structures. Therefore, the aim of this review was to give a general definition of artificial intelligence and provide a perspective on orthodontic diagnosis, treatment planning and ethical limitations.

**Keywords:** Artificial intelligence, diagnosis, machine-learning, orthodontics, treatment planning.

### **Introduction**

Artificial intelligence (AI) has been defined by a Stanford Professor John McCarthy in 1955 as the science and engineering of making intelligent machines to mimic the cognitive abilities of humans. Fundamentally, most of their behavior arises learning from data or experience by using algorithms (1). There are different AI systems, such as machine learning (ML), convolutional neural networks (CNN), genetic algorithms (2). ML focuses on computer agents to improve their perception, knowledge, or actions based on experience or data. Deep learning is a subset of ML in which artificial neural networks (algorithms modeled to work like the hierarchically organized neurons in human brain) learn from large amounts of data, and perform the required tasks such as classification, regression and representation learning (3).

In the field of orthodontics, AI systems were declared to provide benefits in detecting cephalometric landmarks, in treatment-decision stages, remote-monitoring of patients, or in data archiving and documentation, which are all important steps that need to be performed carefully (4). This review aimed to evaluate the advances in the field of AI in orthodontics based on the current literature knowledge.

### **Orthodontic diagnosis**

Digitalization in orthodontics provided benefits, especially in accelerating diagnostic steps, enabling more accurate and predictable results to be interpreted with clinical data. In this respect, three-dimensional (3D) images, computer-aided diagnosis and treatment planning, 3D based manufacturing systems (CAD/CAM) and 3D printing technologies are being used more frequently. The large amount of data and differences in observer experiences can lead to differences in orthodontic diagnosis and treatment planning, so AI systems aimed to speed up these stages and eliminate variations. One of the most common strategies in ML is visual learning, where an algorithm is exposed to pairs of data. During the model training phase, these data pairs are repeatedly shown to the algorithm to minimize the error in the DL model's preliminary predictions. The DL model learns to represent the statistical structure of the input data and its relationship to the given label and can eventually predict a label on the data (images). DL-based cephalometric software applications from different companies are available to orthodontists all over the world. In general orthodontists use their knowledge and experience to identify cephalometric landmarks (5).

The need to accelerate the diagnostic steps is important as it will also accelerate clinical functioning. A recent study used a computational deep CNN digital model to assess the orthodontic treatment need from intraoral clinical photographs of 700 patients, and revealed that the CNN model provided an accuracy of 99.99 % in detecting malocclusions (6). Similarly in 2022, automated lateral cephalogram landmarking advanced diagnosis, and a successful detection rate of landmarks with 98% has been reported with CephX; ORCA Dental AI (7). Lately, the applicability of a deep learning neural network was analyzed in a multi-center, multi-ethnic, and multi-device data of 309 CBCT scans from Finnish and Thai patients, and the authors advocated the inclusion of this method into clinical settings (8). Yurdakurban et al (9). evaluated the compatibility between traditional methods and machine learning in facial midline de-

termination and asymmetry assessment by marking anatomical landmarks on facial photographs of 90 patients. They argued that automatic marking has the potential to assist the clinician when used in combination with manual methods. On the other hand, some studies revealed significant deviations with AI-based landmarking compared to the human gold standard in some parameters (7,10,11).

Recent studies have shown that AI-based systems can accurately predict bone maturity by the classification of cervical vertebrae maturation stages and hand-wrist radiographs (12-14). Algorithms for upper airway segmentation have also been developed over the last decade, and numerous automated software programs have been validated for volumetric assessment (15). In 2021, Park et al. (16) assessed the accuracy of airway volume measurement using a DL model based on regression neural networks, and suggested that airway segmentation can be trained using an AI-assisted DL. Shujaat et al. (17) investigated a deep learning-based 3D convolutional neural network model to automatically segment the pharyngeal airway space. As a result, the segmented region could be distinguished by this model with the best accuracy.

A systematic review and meta-analysis by Jha et al. declared that AI algorithms developed for diagnosis of temporomandibular joint diseases (TMD) can be used as a tool to support clinicians in the decision-making process (18). More recently, a randomized trial used a predictive machine-learning algorithm on 502 patients, 170 normal and 332 with degenerative TMD, and concluded that the model might contribute to the clinical screening of such patients in clinical practice (19). Gracea et al. (5) stated in their review article that automated landmark detection by the aid of AI was the most prevalent topic, followed by determination of maturation, and diagnosis of occlusal traits according to the data from 2021- 2023. They further emphasized that cephalometric landmark detection carried out by ML or DL algorithms provided high reliability and accuracy. Again, a recent study investigated the performance of a convolutional neural network (CNN)-based online cloud platform for automated segmentation of maxillary impacted canine on CBCT images, and revealed rapid and consistent findings (20).

Despite all the aforementioned results, more evaluations are still needed by including images obtained from different devices, with different resolutions and with different acquisition parameters in future studies (21).

### **Treatment planning**

Analyzing qualitative and quantitative measures of dental and skeletal components is vital for accurate treatment planning procedures, which include tooth extraction techniques, anchorage requirements, and the necessity of surgical treatments (22). In orthodontic treatments worldwide, digitization and the pursuit of better outcomes generate a lot of data daily. Artificial intelligence can aid orthodontists in decision-making by utilizing extensive data through mathematical models and data integration. Studies based on planning and algorithms mainly focused on orthodontic treatment planning, orthognathic treatment issues and the need for extraction (5).

The assessment of the necessity for orthognathic surgery may differ among clinicians due to variations in expertise and preferences (23), with less experienced orthodontists frequently facing challenges in making such evaluations (24). Choi et al. (25) used AI models to evaluate whether orthognathic surgery is required for patients who will undergo orthodontic treatment and they suggested that these algorithms should be utilized when planning before orthognathic surgery. Kim et al. (24) utilized various convolutional neural networks as artificial intelligence algorithms, to predict the necessity of orthognathic surgery based on cephalometric radiographs, achieving accurate prediction rates ranging from 91% to 94%. Similarly, Shin et al. (26) achieved a 95% accuracy in predicting the indication for surgery using a deep learning network. A recent study evaluating the efficacy of various ML models in predicting the necessity for orthognathic surgery demonstrated that a combined ML approach model accurately predicted both Class II and III patients (27).

The simulation of surgical outcomes is essential as it facilitates the planning of the surgical treatment and provides a visual communication tool among the orthodontist, surgeon, and the patient. The accuracy of the simulated image is crucial, because it can significantly affect the expectations of both patients and the professionals (28). DL can demonstrate simulated soft-tissue profiles through generated surgical plans. A study illustrated that the generated DL model can precisely simulate soft-tissue profiles following mandibular advancement surgery using preoperative 3D photos and CBCT images (29). Another study assessing the validity of a 3D planning software for predicting postoperative soft tissue outcomes of bimaxillary orthognathic surgery in skeletal class 3 cases, found that the predictions were clinically

satisfactory (28). On the other hand, Jeong et al. (30) evaluated facial photographs of individuals requiring orthognathic surgery with deep convolutional neural networks, and stated that soft tissue profiles alone are not sufficient to identify orthognathic surgery cases by the AI-based model. In conclusion, it has been proposed that additional investigations are necessary to further verify these results. Until that point, AI can serve as a valuable adjunct to conventional treatment planning by enhancing decision-making processes and offering a visualization tool for predicting soft tissue outcomes in orthognathic treatment (28,31).

### **Decision Making for Orthodontic Extractions**

Making the decision to extract teeth for orthodontic treatment is important and challenging because it usually depends on the practitioner's experience. A study on the consistency of orthodontic extraction decisions revealed that, orthodontists utilized varying criteria in making extraction decisions, which affects orthodontic patients. An incorrect decision regarding extraction may lead to a range of irreversible issues, including an undesirable profile, abnormal inclination of the anterior teeth, inadequate overjet and overbite, improper occlusion, and challenges in closing the extraction space (32).

Jung and Kim (33) evaluated the accuracy of an AI model on tooth extraction decision with cephalometric data of 156 patients, including their clinical examinations, overjet, molar relationship, amount of crowding, and soft tissue characteristics. As a result, they found 93% success in the decision of treatment with/without extraction and 84% for the detailed diagnosis of extraction patterns using AI. In 2021, Etemad et al. (34) evaluated the success of ML models in diagnosing the need for tooth extraction, and determined an accuracy rate of 86% in the diagnosis of extraction, and 96% in the diagnosis of non-extraction treatment. They emphasized that incompatible data made it difficult for the AI model to work, and that these models need to be developed to adequately support clinical decision making. While ML models showed high performance in extraction decisions, they were unable to exhibit the same efficacy in extraction pattern. The findings demonstrated that machine learning models significantly aid in decision-making related to orthodontic extractions, particularly for less experienced orthodontists (35).

AI models are continuously developing by learning from data sets and improving day by day. Variability due to experience between evaluators is very important in treatment planning when considering extraction (36), or orthognathic surgery (10).

### **Treatment duration prediction**

The duration of the orthodontic treatment is an essential detail that patients frequently prioritize. Offering a reliable and accurate estimate of treatment duration is important as it constitutes an essential element of the orthodontic informed consent procedure and payment structure, hence greatly impacting patient satisfaction (37,38). Experienced orthodontists possess extensive knowledge, enabling them to confidently and efficiently plan and anticipate the duration of orthodontic treatment. Nonetheless, orthodontic residents and newly certified orthodontists mostly lack this benefit. While they possess the necessary technical skills, it demands additional time and experience (39). In a study aimed at constructing and comparing machine learning models to predict the duration of orthodontic treatment and identify factors influencing this duration through a machine learning approach found that, various algorithms demonstrated similar effectiveness in predicting treatment length. The primary parameters affecting the prediction of treatment time were age, crowding, AI case difficulty score, overjet, and overbite (40). Similarly, in another study aiming to predict treatment duration using an AI model, important determinants affecting treatment duration were identified and the potential of the AI model to predict orthodontic treatment duration using pre-treatment variables were emphasized (39). As a result of all the specified information, it has been stated that, more comprehensive and multi-center data sets are necessary to generalize the proposed algorithms (41).

### **Clear Aligner Treatments**

Over the past two decades, clear aligners have emerged as an increasingly favored option to fixed appliance therapy for mild to moderate malocclusions. This treatment option is generally considered more esthetic and comfortable compared to traditional fixed appliances (42, 43). However, some patients express varying levels of discomfort and anxiety (44). Evaluating patient experiences during treatment can assist orthodontists in developing optimal patient-centered treatment plans. If significant discomfort occurs, modifications to the attachment design may be considered to enhance patient comfort and compliance. Artificial intelligence systems designed to predict patient comfort may have clinical applications that enhance patient compliance. A study used artificial neural networks to predict patient experiences,

pain, anxiety, and quality of life associated with Invisalign treatment. As a clinical consequence, they found that lingual attachments were the most significant factor impacting negative experiences (45).

AI can assist patients in visualizing potential outcomes prior to beginning actual treatment. Invisalign SmileView (SV) is an interactive application that employs a ML algorithm to accurately demonstrate prospective patients regarding the potential enhancement of their smile after undergoing treatment with aligners. A recent study found that SV simulates broader smiles, which are mostly achievable with aligner treatments, and shows high predictability for vertical incisor movements. It modified the upper incisors' mesiodistal size in simulations and identified and corrected dental midline deviations from the face midline (46).

Recently, AI methods have also been utilized in digital setup software to automate teeth segmentation and alignment processes. Orthodontic tooth setup simulates orthodontic treatment by separating individual teeth and aligning them in the desired position (47). It can be utilized to fabricate orthodontic appliances, including indirect bonding systems and clear aligners (48). Im et al. (49) conducted a comparison of automatic segmentation techniques, specifically the landmark-based method (Ortho analyzer), tooth designation method (Autoalign), and deep learning. They reported the highest success rate of 97.26% with the deep learning approach. A recent study assessed the accuracy and efficiency of automated digital setup software, indicating a significant enhancement in time efficiency. While the setup results have improved, additional manual adjustments may still be required for clinical applications, including indirect bonding and clear aligner therapy (48).

### **Teleorthodontics**

Nowadays, Dental Monitoring (Dental Mind, Paris, France) (DM) applications another area that utilizes deep learning AI to facilitate orthodontists in tracking aligner treatment progress and allowing shorter treatment time because of improved patient compliance and early interception of problems. Using a smartphone, DM lets patients scan and record their teeth and lets the orthodontist check their development from far away. This technology detects gaps between aligners and teeth (unseats), indicating deviations from planned movements. The application also directs the patient to either change to the next aligner (GO) or continue with the current aligner for a specified duration prior to re-scanning (NO-GO), according to the provider's established preferences (50,51). The evaluation of clear aligner treatment with and

without dental monitoring presented that the monitoring improved aligner tracking. Additionally, study confirmed that patients utilizing AI-driven remote monitoring with Invisalign needed nearly 25% fewer visits than those treated conventionally (51). A case report indicated that the DM system is a promising method for enhancing doctor-patient interaction. Treatment outcomes also showed DM is generally acceptable and beneficial to patients, even in critical clinical situations, provided there is optimal compliance and proper usage of the tool (50). Conversely, a recent study indicated that the technology is presently unsuitable for independent use and requires ongoing orthodontist supervision during treatment (52).

AI applications can be used to inform patients to ensure proper oral hygiene, motivate them to use appliance/intermaxillary elastics or to remind clinical appointments (53). Li et al. (54) utilized the WeChat application to remind patients about their appointments and provided informative messages regarding oral hygiene. Consequently, they achieved less bracket detachment, and reduced treatment duration. Nevertheless, the innovative AI technologies enable real-time feedback, ultimately boosting motivation for both patients and orthodontists (55).

### **Ethical dilemmas of using artificial intelligence**

Data confidentiality in orthodontic diagnostic materials may create ethical challenges, especially clinical photographs may pose a security problem in terms of identifying patients. Ethical dilemmas revolve around issues related to informed consent, respect for privacy, protection of personal data and reliability of data information. A debate is being held regarding AI systems in the field of health due to moral subjectivity, lack of empathy and insufficient level of critical thinking. The ethical issues raised by AI in healthcare in the future must fundamentally address nonmaleficence and beneficence (56).

### **Conclusion**

Rapidly evolving AI models have the potential to improve orthodontic diagnosis, treatment planning, prediction processes and patient follow-up by automating tasks, increasing accuracy, and minimizing variability. With the development of AI technologies, prediction of treatment options becomes easier even for difficult patients, and patient motivation and satisfaction increases. However, different AI methods used in the studies create a limitation in terms of comparability, and most algorithms are trained on unicentric data. Despite the advances in AI algorithms, generalizing the results may still be inaccurate when clinical cases

with individual differences and ethical issues are taken into account. In conclusion, orthodontists still have to rely on their experience and knowledge for decision-making and further studies are needed to ensure the safety of AI-based models in clinical performance.

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