



Artificial Intelligence in Orthodontics: A Review

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Abstract: Artificial Intelligence tools in Orthodontics advance the role and facilitate the analyses of imaging phenotypes in patients that need to orthodontic, orthopedic and/or surgical correction. That includes automated procedures for image anonymization, segmentation, landmark identification, standardized orientation, registration and quantification/classification/characterization. Their application in orthodontics has progressed slowly, despite promising results. The available literature pertaining to the orthodontic applications of AI and ML has not been adequately synthesized and reviewed. This article aims to discuss how Artificial Intelligence (AI) with its powerful pattern finding and prediction algorithms are helping orthodontics.

Keywords: Artificial intelligence, Dentistry, Orthodontics, Orthognathic surgery, Diagnosis.

Introduction

Artificial intelligence (AI) is defined as “a field of science and engineering concerned with the computational comprehension which is commonly known as intelligent behaviour and with the creation of artifacts that show such behavior.” Medical and dental imaging diagnostics, digital medicine, drug development, hospital monitoring, robotics, and virtual assistants have embraced AI.[1]

AI is the behavior of non-biological entities that perceive, learn, or react to complex environments.[2] AI is not a computational tool that necessarily mimics the workings of the human brain; rather, it is a set of tools for problem-solving, each with its own specific rules.



Research is being performed in the field of AI to achieve human-like generality. [3,4] However, most of the progress on AI has been on models that focus on a single problem, having a constrained set of rules-problems such as playing chess or identifying caries from X-ray scans. [5] For many of these problems, computers far surpass human results. While an AI model can be classified as narrow or general on the basis of its problem-solving capabilities, from an algorithmic perspective, there are two main categories of AI: Symbolic AI and machine learning. Symbolic AI is a collection of techniques that are based on structuring the algorithm in a human-readable symbolic manner. This category was the paradigm of AI research until the late 1980s and is widely known as GOF AI – good old-fashioned AI. The techniques in symbolic AI use rules, such as if-then statements, where if a certain criterion is met, then the corresponding action must be taken.[1-6]

AI has enormous potential to improve patient care, optimize treatment planning, and support clinical workflows in the dental field. Dental practitioners may use enormous volumes of patient data to generate actionable insights, customize treatment plans to meet the needs of each patient, and more accurately forecast clinical outcomes by utilizing AI algorithms and data analytics. Furthermore, AI-powered diagnostic technologies can support more accurate treatment interventions, early illness detection, and preventative oral health initiatives.[1-7]

Additionally, it provides healthcare benefits by reducing post-operative problems, which reduces the need for complex operations and enhances quality of life. This is a summary of the ways artificial intelligence (AI) is being used in dentistry and tries to help dental practitioners realize that AI could be a useful tool to help them do their daily tasks more efficiently.[2,3]

AI in dentistry has begun to take off in recent years, just like in other industries. Applications of AI in dentistry can be divided into four categories: diagnosis, treatment planning, decision-making, and result prediction.[4] The most widely used AI use in dentistry is for diagnosis. AI can diagnose patients more quickly and accurately, which will lessen the strain for dentists. On the one hand, dentists are using computer systems more and more to make choices. Conversely, dental computer programs are growing increasingly sophisticated, precise, and dependable. AI research is now being conducted in all areas of dentistry.[5]

The AI software performs the following patient management tasks:

- Scheduling and organizing appointments based on the practitioner's and patient's convenience. [6]
- Notifying patients and dentists about examinations if lifestyle or genetic data suggests heightened vulnerability to dental conditions
- Overseeing insurance and documentation tasks.



- Helping with clinical diagnosis and treatment planning; establishing recurring reminders for patients participating in tobacco or smoking cessation programs, etc. [7]
- In situations where the dental health care provider cannot be reached, emergency teleassistance is offered.[8]
- One can build a comprehensive virtual database for each patient using artificial intelligence software, which can be both incredibly thorough and easily accessible.[4]
- Compared to a human equivalent, the AI software can much more quickly and efficiently record all required data and present it to the dentist (e.g., gathering all relevant dental records, extraoral pictures, and radiographs necessary for diagnosing any dental issue). [5]
- Furthermore, the software's voice recognition and interactive features allow the dentist to complete many duties with ease. FIG.1

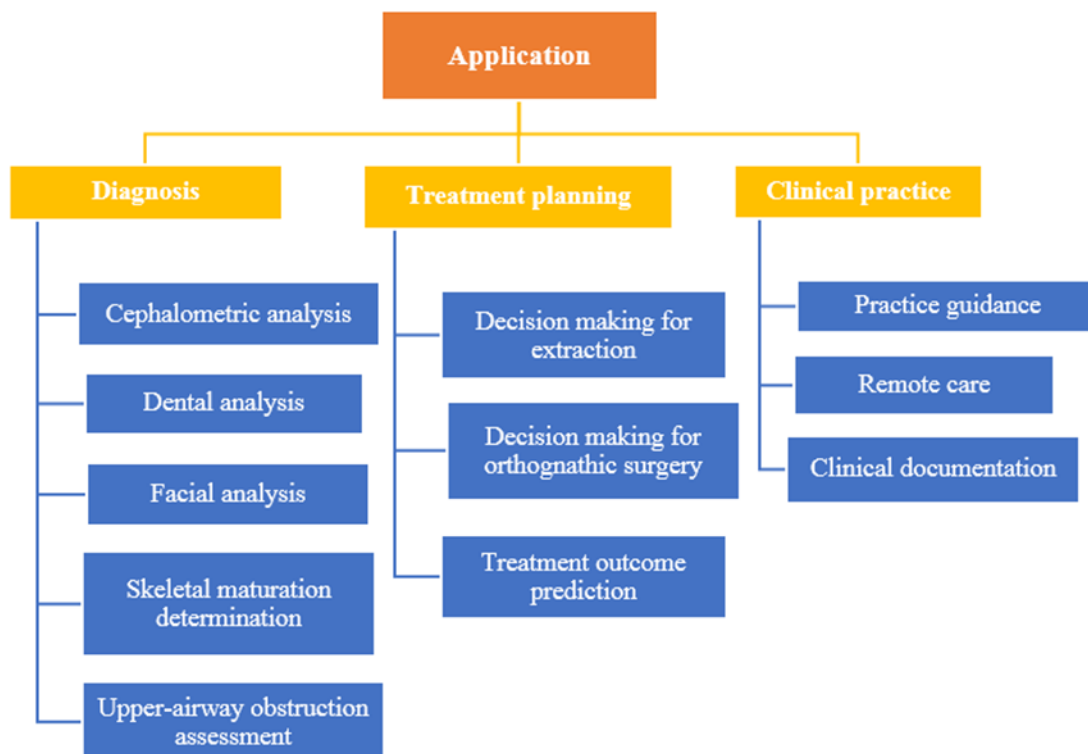


FIG.1; Application of AI in orthodontics

In dentistry, AI can improve preventive approaches, enabling early diagnosis for better treatment outcomes. Integration of software with AI facilitates quick analysis, storage, and comparison of data .[7,8] The technology aims to minimize errors in dental treatments, streamline work processes, and support clinical decision-making, ultimately enhancing the role of dental surgeons.[6-8]



This article aims to discuss how Artificial Intelligence (AI) with its powerful pattern finding and prediction algorithms are helping orthodontics.

Artificial intelligence in orthodontics

The use of AI for assisting in orthodontic treatment planning has apparently been a reality for some time. More than one aligner company claims to use AI algorithms to optimize orthodontic planning, thereby saving the time of orthodontists in this process. Because these algorithms are industry secrets, the truth is that the point where AI algorithms end and marketing strategies begin is unknown. AI is an excellent tool to help orthodontists to choose the best way to move, for instance, a tooth or group of teeth from point A to point B, once the orthodontist instructs the machine where the final position should be. This is useful because orthodontics performed in a totally traditional way – with brackets only – require high manual skill, and many professionals do not have or have not received proper training to develop it. AI assists these dentists, but there are several limitations of machine learning in contemporary aligner treatment. AI used in contemporary planning does not consider the impact of functional problems and the stability of the tooth position – or lack thereof – when tooth movements are performed. For example, problems associated with important functional etiology, such as the open bite malocclusion, can be treated using aligners.[14] However, AI today cannot determine the etiology of the problem or predict specific retention strategies.

In the field of research in orthodontics, various advancements have been made utilising AI.

AI and orthodontic treatment need:

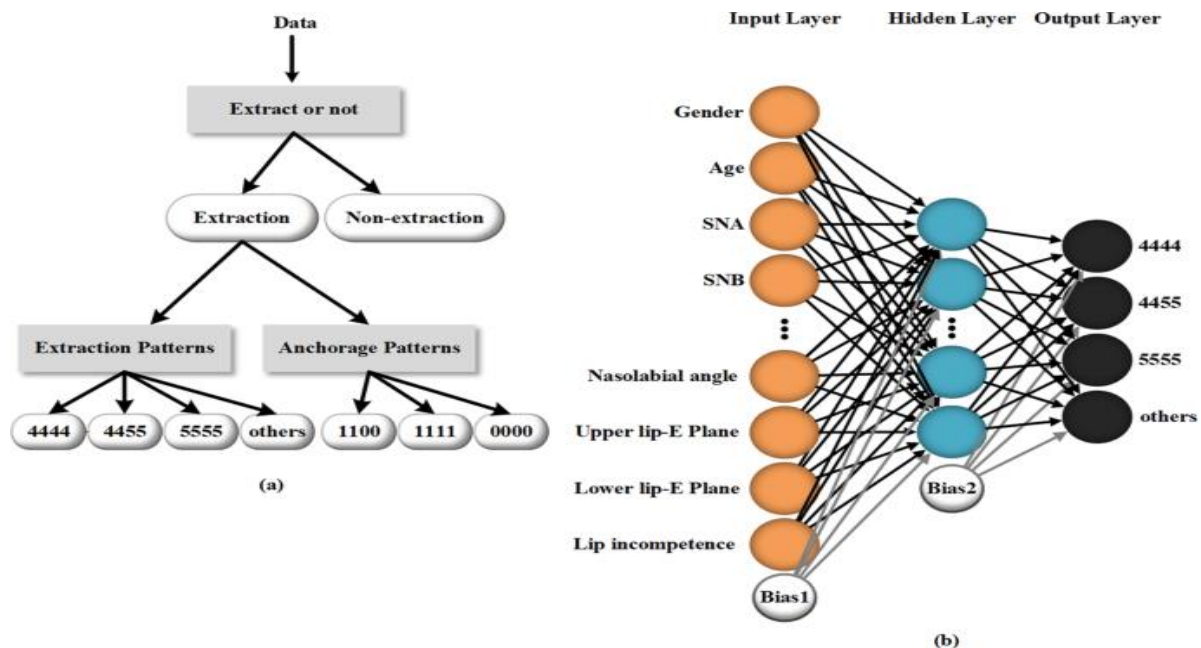


FIG. 2; Orthodontic Treatment Planning



Thanthornwong[16] utilised orthodontic impressions and facial photographs to evaluate orthodontic treatment need. The variables they used to construct the prediction model were missing teeth, overjet, overbite, anterior and posterior openbite, a diastema, anterior and posterior crossbite, anterior and posterior

displacement, supernumerary teeth, ectopic eruption, anteroposterior molar relationship, and upper and lower lip to E-line. They had a sample size of 1,000 participants, and utilised 80% of the data as training data and created a prediction model which was then tested on 20% of the data which was called the test data. A sample of 20 patients was utilised to validate the data-sets. They constructed five models, of which the one with the highest level of specificity (100%), sensitivity (95%) and accuracy (96%) was chosen. Two orthodontists with more than five years of experience predicted the treatment need. Data of 200 patients was entered into the model which was calculated for treatment need using the model. The higher scores indicated treatment need, while lower scores indicated no treatment need. A high level of agreement was found when this network was validated (kappa value -1.00 with orthodontist A, kappa value -0.894 with orthodontist B). They concluded

that the prediction model was an effective modality for the evaluation of treatment needs. FIG. 2

Wang et al.[17] evaluated the effects of treatment need through aesthetics using eye-tracking devices. Eye tracking devices use anthropometric landmarks to determine the responses for areas of interest, which were the eyes, mouth and nose. The study sample consisted of 88 subjects who were shown pictures of normal individuals along with pre- and post-treatment ones in smiling and repose views. The results of the eye tracking device were compared with mixed-effect linear regression and support vector machine (SVM). SVM was further compared using Index of Orthodontic Treatment Need-Aesthetic Component (IOTN-AC) for the evaluation of accuracy of treatment need and outcome. The mouth was highlighted as the area of interest in smiling photographs for normal, pre- and post-orthodontic treatment. SVM was found to be highly accurate in identifying treatment needs between normal and pretreatment photographs (97.2%) and for treatment outcomes between pre- and post-treatment (93.4%).

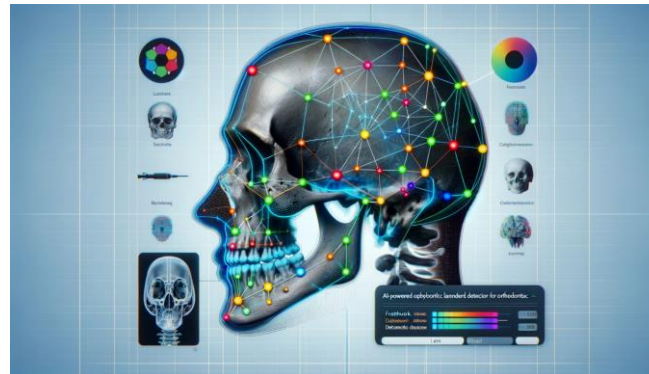


FIG.3; AI-Powered Cephalometric Landmark Detection for Orthodontic Diagnosis

Cephalometric analysis:

Numerous studies have been conducted in the past few years which have focussed on assessments of lateral cephalograms. The main focus has been on the accuracy of "automated landmark location" before conducting the actual analysis. Kim et al.[18,19] using CNN on lateral cephalograms and CBCT for posterioranterior cephalometric landmark tracing, found a high level of accuracy (88.43%, 80.4%). An error of 2mm,however, was reported for landmark identification for Postero-anterior (PA) cephalograms, but overall results were satisfactory.

A higher level of landmark identification was obtained when CNN was modified using an algorithm for "biomedical image segmentation" called U-Net. [20]The level of accuracy achieved was 92%. Dobratulin et al.[20] concluded that the results obtained were similar to landmark identification by a group of orthodontists. Lee et al.,[21] using the Bayesian Convolutional Neural Networks (BCNN)BN, found a 90.11% level of accuracy. **FIG.3**

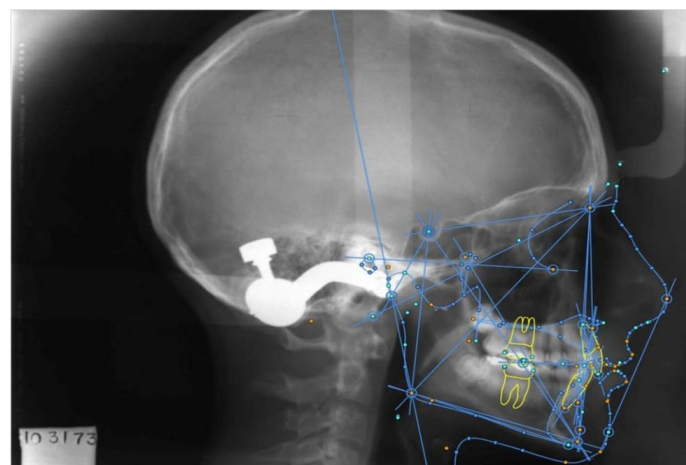


FIG.4;Artificial Intelligence Automatically Calculates Orthodontic Measurements



We believe that accurate landmark location and identification are imperative in conducting an accurate cephalometric analysis. This was determined by Shin et al.[22] who conducted a study on 840 lateral and frontal cephalograms to predict the need for orthognathic surgery on skeletal malocclusion using a recurrent neural network (RNN) algorithm. The algorithm uses sequential data input which is stored in its internal memory. Sequential data input requires that all information be introduced in a sequence of steps. These steps are then followed for the assessment of new data incorporated into the system. A high level of accuracy (95.4%) was obtained with this system for the assessment of patients requiring orthognathic surgeries.

Recently, AI has been used specifically for cephalometric analyses. Silva et al.[23]used CEFBOT (RadioMemory Ltd., Belo Horizonte, Brazil), an AI-based cephalometry software, to measure 30 lateral cephalograms using Arnett's analysis. CEFBOT successfully performed measurements in 9/10 variables. The measured variables were re-evaluated after 15 days and correlated with human findings. Repeated measures of CEFBOT gave a high-reliability level (Intra-class correlation [ICC] >0.94)

and they were not statistically different from the human findings.

AI in orthodontic diagnosis:

AI has been extensively explored for effective and efficient diagnosis as well as patient care. Bichu et al.,[24] in their scoping review of 62 shortlisted articles, found that 33 articles emphasized the use of AI for diagnosis and treatment planning.

CNN and ANN have been utilised for extraction prediction, orthodontic treatment need, cephalometric analysis, and age and gender discrimination. Neural networks have a role to play in diagnostic interpretations utilising computed tomography (C cone-beam computed tomography (CBCT), lateral cephalograms, bitewing, facial photographs and orthopantomograms. FIG.4

Kok et al.[25] used different algorithms to determine their accuracy in the assessment of cervical vertebrae maturation through the Lamparski method. The data was obtained from 300 cephalograms. They found an accuracy rate in the range of 78.7-93% for cervical vertebral maturational stage 1(CVS 1) with the highest being for ANN (93%), {k-nearest neighbours [k-NN] (78.7%), Naove Bayes [NB] (92.1%), SVM (84.8%), random forest [RF] (91.8%)}. Decision tree (DT) gave the highest

accuracy for the determination of vertebral body shape at 97.1%. Amasya et al. [26] measured data on 498 cephalograms for cervical vertebral maturation (CVM) staging using ANN (kappa score - 0.926), SVM (kappa score - 0.874), RF (kappa score - 0.908) and DT (kappa score - 0.921).



AI in orthodontic treatment planning:

The interest in AI for orthodontic treatment plans and outcomes has gained gradual interest with time. Earlier works consisted of the construction of mathematical models which could correctly identify patients in need of extractions.

Takada et al. [27] and Yagi et al. [28] conducted a two-part research where they configured a mathematical model which could tell the need for and the desired pattern of extractions for a case. It was developed with the purpose of projecting an unexpected treatment outcome with extractions and to correctly identify the traits which led to the model's decision-making for choosing extractions.

The input data consisted of patients' standardized photographs, radiographs and orthodontic casts. The model would identify features of presenting malocclusion and place it next to the nearest template already in the system. Multiple decisions were taken depending on the traits of the case. An overall computation of the outcomes was done before the final result was given. The accuracy of the model was tested

against the decisions of the clinicians and an accuracy

rate of 90.4% was obtained. The traits leading to extraction decisions were overjet and upper and lower arch length discrepancy. The model created was modified and tested to determine extraction patterns versus clinicians. An accuracy of 86% was obtained with correction of incisor inclination and overjet and overbite as the causes for extractions. The model was further evolved by Xie et al. [29] using ANN. The model was tested for its ability to differentiate between extraction and non-extraction cases along with possible causes for extractions. The model had 80% accuracy in identifying extraction patients aged 11-15 years. The factors responsible for extraction were incompetent lips and proclined lower incisors.

Different programmes have been tested to determine their accuracy for extraction/non-extraction decisionmaking.

Jung and Kim. [30] used the language R programme for the machine model to create a programme which could correctly identify extractions patients. The model was further tested for its ability to detect identical and differential extraction patterns based on 5 treatment plan groups which had been built into the system. The model was compared with the clinical plans of an experienced orthodontist. The model achieved an accuracy of 93% in identifying patients needing extractions with overall 84% accuracy in the extraction plan.

The advancement in AI has led to the emergence of different programmes. Li et al. [31] compared ANN with k-NN. Their neural network showed 94% accuracy of prediction of extraction versus non-extraction treatment. They also reported the accuracy of anchorage patterns to be around 92.8%. They found curve of Spee, angle ANB (angle formed between



point A [point of deepest convexity on the labial cortical plate of the maxilla above the maxillary central incisor], nasion and point B [point of deepest convexity on the labial cortical plate of the mandible below the mandibular central incisor]) and crowding in the upper arch to be the most important features for prediction of their neural networks.

Over the years, orthodontic record-keeping has become more technologically advanced as dynamic records of patients are more preferred than the traditional static forms. Tanikawa and Yamashiro [32] explored the possibility of an AI system that could be used by stereophotogrammetry to differentiate between extraction and orthognathic surgery cases. The model was constructed using landmark-based geometric morphometric methods (GMMs), and ML and two AI systems were developed. Data of a presenting case would be collected using anthropometric landmarks of the face and compared with the data of the previous patients already in the system. The systems showed a success rate of 54% for surgical and 98% for extraction cases at a system error of <1mm. However, when the system error was at <2mm, a success rate of 100% was achieved.

Artificial intelligence in orthognathic surgery:

With the continuing advancements in technology, AI has been extensively explored in the field of surgery, ranging from ophthalmology [33] and spinal surgery[34] to knee arthroplasty. Benefits include complex movements over shorter periods with high levels of precision.[35]

The preparation of patients requiring orthognathic surgeries can become a long and tedious procedure combining clinical and laboratory work. The traditional methods require the fabrication of acrylic splints which are used by surgeons as intraoperative guides. This is prone to errors as materials used undergo dimensional changes due to inherent properties or may fracture due to pressure. To overcome these limitations, Woo et al.[36] devised a surgical set of robotic arms which transferred

information from the virtual screen to the operating room. The robotic arm was primarily designed to facilitate the surgeons during the procedure. The robotic arm could undergo movements at 6 degrees. On-screen movements centred on specific points were called tool centre points. These were located on a virtual simulation of the maxillomandibular complex around which axis movements were done. Overall, highly accurate and predictable movements of the jawbones were produced. Despite the advantages, Grischke et al.[34]found these procedures high in cost.

Mandibular surgeries are often associated with shifting of the condylar heads during repositioning of the segments. They can lead to the development of condylar sags post-surgically. To overcome these limitations, Lee et al.[36]devised an electromagnetic tracker



device that could record movements of the condylar heads real-time. Other benefits included 3D coronal and sagittal views to ascertain the position of the condylar heads in the fossa.

AI has also been explored for the creation of surgical splints. Elnagar et al.[37] in their research developed a 3D diagnostic model for diagnosis and a virtual orthodontic orthognathic treatment plan. The model was fabricated using scanning and CBCT images which were combined to form a single model. The outcome led to the fabrication of a 3D splint using 3D printing as an intraoperative guide for the surgeons.[38,39]

Conclusion

AI can assist orthodontists to choose the best way to move a tooth or group of teeth, but AI today completely ignores the existence of oral diseases, does not fully integrate facial analysis in its algorithms, and is unable to consider the impact of functional problems in treatments. At the same time, imaging diagnosis has been incorporating AI to increase sensitivity and specificity in numerous conditions, from syndrome diagnosis to caries detection.

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Conflicts of interest

There are no conflicts of interest

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