International Journal of Advances in Scientific Research
ISSN: 2395-3616 (Online)
Journal DOI: https://doi.org/10.7439/ijasr
Review Article

Artificial Intelligence in Orthodontics: Prediction and Planning

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Abstract

Artificial intelligence (AI) with advancement of technology has experienced remarkable growth and development in the field of dentistry. AI is an excellent tool that performs several tasks from diagnosis, treatment planning, predicting the outcome and prognosis particularly in the field of orthodontics based on individual preferences and constructed algorithm models. The present review was carried out to discuss briefly on the role and impact of AI in the field of orthodontics. It was observed that most of the AI models are based on artificial neural networks (ANNs) and convolutional neural networks (CNNs) systems widely used for Cephalometric landmarks identification, image recognition, decision making system to assist treatment planning, prediction of need for extraction and/or orthognathic surgeries, evaluating the cervical vertebrae growth pattern and maturation, predicting the facial attractiveness and post-orthognathic surgery facial profile. Further research on application of AI should be carried out focusing on formulating and establishing cloud-based platforms, integrating large data to improve learning algorithms and construct advanced automated decision making model systems with high specificity, precision, reliability to predict exact outcomes within a short span of time and improve the quality of life.

Keywords: Artificial Intelligence, Automated diagnosis, Customized treatment, Clinical Decision Support Systems, Neural Network, Virtual systems.

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***Article History:**
Received: 10/09/2021
Revised: 27/09/2021
Accepted: 27/09/2021
DOI: https://doi.org/10.7439/ijasr.v7i1.5672

QR Code

How to cite: Vinoth Kumar R, Vetriselvan A., Magdline A, Rajakumar P and Karthikeyan M. K. Artificial Intelligence in Orthodontics: Prediction and Planning. *International Journal of Advances in Scientific Research* 2020; 7(1): e5672. Doi: 10.7439/ijasr.v7i1.5672 Available from: https://ssjournals.com/index.php/ijasr/article/view/5672

1. Introduction

Artificial Intelligence (AI) is a developing and rapidly growing feature of high intelligence technology that fully counterparts with human intelligence of significant impact [1]. In 1956, the term Artificial intelligence (AI) coined by John McCarthy was introduced to create, develop and build machines that are capable of executing tasks that are normally performed by humans [2]. In simple terms, AI uses and utilizes the data based on individual preferences and performs several functions according to the needs. Today, the most predominant subfields of AI on its way of functioning includes Machine learning (ML), Deep learning (DL), Cognitive computing, Computer vision and natural language processing (NLP) [3].

Machine learning, a subfield of AI, is the study of computer algorithms that are applied to learn the inherent patterns and structures in data to find insights without being explicitly programmed on occasion that are challenging or impractical to develop conventional algorithms to perform unseen data functions as required [4]. In 1959, Arthur Samuel coined the term Machine learning that involves computers to make predictions using models built based on the available sample data [5]. ML algorithms build models like Genetic algorithm (GA), Artificial Neural Network

(ANN) that can learn and inspect the data to implement various functions. ANN constitutes the artificial neurons is the most widely accepted mathematical model system that was stimulated in-par with the human neuron model [6]. By collected networking and associating the layers of artificial neurons using several mathematical operations, a network is engineered that can solve specific tasks such as image classification in carious tooth, location of root canals during endodontic procedures, to diagnose extraction in orthodontic treatment, classification of oral malodor based on oral microflora and many other applications in the field of dentistry [7].

Deep learning, a subset of ML, is the learning of complex multilayer system patterns that progressively refine the results from the available complex unstructured data based on ANN with representation learning either by supervised, semi-supervised or unsupervised [8]. Several DL models such as deep neural networks (DNN), recurrent neural networks (RNN) and convolutional neural networks (CNN) were widely used. CNN, is widely accepted main network component that extract many hierarchical features such as edges, corners, shapes, and macroscopic patterns from abstracted layers of filters capable of representing an image mainly used for processing large images like intraoral periapical radiograph, panoramic radiograph and computed tomography (CT) [9]. Apart from image recognition and image quality enhancement, DL algorithms are useful tool in localization of tooth, segmentation of alveolar bone, classification of tooth, Cephalometric landmarks, and detection of abnormal and/or cancerous lesions, dental caries, periapical disease, and prosthetic defects [9, 10]. Cognitive computing aims to simulate human processes through image and speech interpretation and responding accordingly, on the other hand computer vision recognizes content in photographic images and videos [11]. Due to these emerging and rapidly growing branches of technological advances AI, ML represented by DL can help clinicians in formulating treatment plans by computer-assisted diagnosis to arrive at accurate decisions thus reducing human errors along with affordable costs at shorter time [12]. This article focuses on the application of Artificial intelligence (AI) in dentistry with special emphasis on its role in the field of Orthodontics and Dentofacial orthopedics.

2. Methodology

A structured literature search was conducted from June to August 2021, for articles written in the English language in PubMed/MEDLINE, EBSCOhost, Google Scholar, Scopus, IEEE Xplore Digital Library and Web of Science databases was retrieved by using MeSH terms “Deep learning” OR “Neural Network” AND “Dental”, “Dentistry” AND “diagnosis” "Radiography, Dental" OR “detection” OR “classification” OR "All Metadata", “Dental, Machine learning” with alternate spellings and related terms.

Artificial intelligence in various domains of orthodontics

A. Orthodontic Diagnosis:

Accurate diagnosis and treatment planning remains the cornerstone of successful orthodontic treatment. AI incorporated diagnostic imaging methods provides fully automated diagnostic system using conventional radiographs, 3D scans and virtual models with increased sensitivity, reliability, and specificity of these diagnostic tools due to the ease with which the machine assist accurate investigation with specific learned patterns. Spampinato *et al* [13], Arik *et al* [14], Park *et al* [15], Hwang *et al* [8] have used CNNs, ANNs and Bayesian network (BN) systems to evaluate cephalometric radiographs, panoramic radiographs, lateral cephalometric radiographs and facial photographs to perform fully automated diagnosis. Knoops *et al* [16] developed clinical three-dimensional (3D) morphable model (3DMM), a machine-learning framework including supervised learning (SL) built with surface 3D scan for automated diagnosis. Weichel *et al* constructed a computer-assisted planning system (CAPS) based on Computed tomography (CT), Cone-Beam computed tomography (CBCT), cephalometry and plaster models. Nonetheless AI alone does not effectively incorporate various treatment planning strategic tools such as skeletal anchorage, essential restorative treatments, periodontal management and dental extractions which also required integrated machine learning models assisted by Neural networks to achieve excellent results [17].

B. Treatment Planning and Decision systems:

Successful outcome of orthodontic treatment depends largely on the appropriate planning and execution in a timely manner. It is evident that no specific tool exists so far to establish decision-making/treatment planning that assists orthodontists as well as patients particularly in situations where multiple treatment options are possible. In such situations, AI provides a significant contribution by using powerful pattern identification and prediction algorithms to aid in decision-making referred to as “Decision- Support system” (DSS). Suhail *et al* [18], Li P *et al* [19] investigated several clinical decision support systems (CDSS) that reduce the relative bias, difficulty of making decisions like extractions, surgical interventions. Jung and Kim demonstrated the decision of extractions and related dento-facial alterations with the help of neural network machine learning in orthodontic planning [20]. Xie *et al* used back propagation ANN model to construct decision support systems for assessing the need for tooth extraction [21]. Li P *et al* used ANN to develop extraction decision making systems that showed 94% extraction decision accuracy, 84% extraction pattern determination and 92% for anchorage pattern determination [19].

On the other hand, Choi *et al* extended the use of ANNs to determine the need for orthognathic surgery and showed 96% success rate for diagnosis of surgical and/or non-surgical decision and 91% success rate for judgment of decision towards type of extraction and specific surgical procedure decision [22]. Knoops *et al* developed a ML framework for automated analysis and computer-aided planning in reconstructive surgery [16]. These studies showed encouraging and promising step towards treatment plan by determining the need for extractions and surgical interventions in orthodontic management.

AI algorithms are also used to reduce the prolonged preparation process of an orthodontist by optimizing orthodontic planning. It assists planning of tooth movement from the current position to the preferred final position based on the instructions provided to the system thus minimizing the need for highly skilled practitioners or specialized orthodontic dental professionals. However AI algorithms do not often consider the impact of oral diseases, functional problems, facial analysis and smile esthetics in contemporary planning. In order to overcome this limitation Chen *et al* developed a machine learning algorithm utilizing Learning-based multi-source Integration framework for segmentation (LINKS) used with CBCT images to measure volumetric skeletal maxilla discrepancies and recommended palatal expansion in patients with canine impaction (Unilateral) [23]. Thus it is essential that an orthodontist should carry out complete clinical examination, followed by preliminary investigations to arrive at a suitable diagnosis before executing the treatment assisted by AI tools.

C. Automated Landmarks Detection/Analysis:

AI/ML application on lateral cephalograms, Cone-Beam computed tomography (CBCT) have demonstrated greater accuracy of anatomical landmark detection at faster rate, reduced time, and human effort expended on traditional landmark detection and/or analyses methods. Yu *et al* [24], Muraev *et al* [25] demonstrated better sensitivity, specificity, and accuracy on frontal cephalometric land marking, vertical and sagittal skeletal diagnosis using CNN-incorporated system compared to manual tracing and elicited enhanced skeletal orthodontic diagnosis without the necessity for intermediary steps requiring complex diagnostic processes. Arik *et al* [14] applied CNNs, Park [15] and Hwang used Deep learning [8], Kunz used open source CNN deep learning algorithm for automated lateral cephalometric landmark identification [26]. Nino-Sandoval *et al* attempted to predict morphology of mandibular bone based on maxillary bone using ANN and observed significant output in craniofacial reconstruction [27]. Wang *et al* applied a learning-based framework method for automated segmentation of maxilla and mandible simultaneously through CBCT [28]. All these studies suggest that AI based automated systems can be used as an effective supplementary tool in orthodontic decision making to reduce time and in specific situations necessitating frequent or recurrent identification.

D. Growth Analysis and Treatment outcome prediction:

Wang *et al* demonstrated the eye-tracking method as an effective support vector machine technique to evaluate the role of malocclusion and its correction outcome on facial profile [29]. Auconi *et al*. developed a prediction system in untreated class II, III patients and concluded neural network analysis could possibly assist orthodontists in skeletal classification systems, decision making on extraction of tooth, to anticipate the prevalence of associated anomalies during craniofacial growth clinically, and to evaluate therapeutic approach to the predicted malocclusion [30]. Alkhal *et al* [31], Makaremi *et al* [32], Kok *et al* [33], Cericato GO [34] reported AI based automated systems using ANNs to assess the bone age by determining the growth and development stages of cervical vertebrae. Eichenberger *et al* [35], Patcas R *et al* [36] used CNNs to predict the facial appearances following Orthognathic surgeries and estimate facial attractiveness scores to ensure restoration of functional and esthetic appearance. Lu *et al* used ANN based model for predicting post-orthognathic surgery facial profile along with related structures [37]. Than athornwong [38], Nieri *et al* [39] showed Bayesian network (BN) as an effective and reliable prediction system in determination of orthodontic traction duration and forecast post-treatment periodontal consequences.

3. Future perspective:

Artificial Intelligence is used in several stages of orthodontics from diagnostic procedures to treatment planning and follow-up monitoring. With advanced neural network systems, algorithms assisting 3D scans and virtual models, accurate diagnosis and customized treatment modalities are made possible at present. Further research on application of AI should be carried focusing on formulating and establishing cloud-based platforms, integrating large data to improve learning algorithms, training several volumetric and angular measurements, virtual model analysis system, construct advance automated decision making model systems with high specificity, precision, reliability to predict exact outcomes within a short span of time and improve the quality of life.

Acknowledgment: Nil

Financial Support and Sponsorship: Nil

Conflicts of Interest: Nil

Reporting guidelines: Adhered to STROBE guidelines

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