Artificial Intelligence in Orthodontics: A Review Article

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Abstract:- This review aims to determine the applications of ArtificialIntelligence (AI) that are extensively employed in the field of Orthodontics, to evaluate its benefits, and to discuss its potential implications in this speciality. Recentdecades have witnessed enormous changes in our profession. The arrival of newand more aesthetic options in orthodontic treatment, the transition to a fully digitalworkflow, the emergence of temporary anchorage devices and new imaging methods all provide both patients and professionals with a new focus in orthodontic care.A scoping review of the literature was carried out following the PRISMA-ScR guidelines. PubMed was searched until July 2022.Additionalmanual searches were performed.Forty four articles fulfilled the inclusion criteria. A total of 30 out of the 44 studies (68.18%) were published this last decade. The majority of these studies were from the USA (11), followed by South Korea (9) and China (7). The number of studies published in non-orthodontic journals (26) was more extensive than in orthodontic journals (18). Artificial Neural Networks (ANNs) were found to be the most commonly utilized AI/ML algorithm (13 studies), followed by Convolutional Neural Networks (CNNs), Support Vector Machine (SVM) (9 studies each), and regression (8 studies). The most commonly studied domains were diagnosis and treatment planning—either broad-based orspecific (33), assessment of growth and development(4), and evaluation of treatment outcomes (2). The different characteristics and distribution of these studies havebeen displayed and elucidated upon therein. This scoping review suggests that there has been an exponential increase in the number of studies involving various orthodontic applications of AI and ML. The most commonly studied domains were diagnosis and treatment planning, automated anatomic landmark detection and/or analyses, and growth and development assessment. In the growth and development research area, the Cervical Vertebral Maturation stage can be determined using an Artificial Neural Network model and obtain the same results as expert human observers. AI technology can also improve the diagnostic accuracy for orthodontic treatments.

***Keywords:-** artificial intelligence, machine learning, orthodontics, review.*

I. INTRODUCTION

Artificial intelligence (AI) is predominant in many areasof daily life. Nowadays, AI-based algorithms are includedin everyday technology and are widely used, for example,in internet search engines, mail spam filtering or onlineassistants with speech and even image recognition on socialmedia platforms[1].

To make the diagnostic process more accurate and efficient, the use of Artificial Intelligence (AI) in orthodontics has grown significantly in recent years. This knowledge is fundamental for predicting treatment prognosis. However, the addition of this AI-based knowledge does not change the fact that the health professionals, with their own knowledge gained through specialized education and years of experience, are the ones that ultimately have to diagnose and determine the best treatment plan[2]. Nevertheless, AI can be useful when making specific clinical decisions in a limited time. AI applications can guide clinicians to make better decisions and perform better, because the results obtained from AI are highly accurate and therefore, in some cases, can prevent human errors.

AI's main objective is to offer a machine the ability to have its own intelligence. Put another way, AI aims for a machine to be able to learn through data, to solve problems by itself[3]. Machine learning (ML) is the main backbone of AI. It depends on algorithms to predict outcomes based on data sets and draws influence from many research disciplines. Its purpose is to facilitate machines to learn from data so they can resolve issues without human input. The most commonly used techniques of ML include the support vector machine (SVM), logistic regression (LR), naive Bayesian classifier, decision tree (DT), random forest (RF), extreme learning machine (ELM), fuzzy k-nearest neighbour (FKNN) and convolution neural network (CNN)[2]. Neural networks are a set of algorithms that calculate signals through artificial neurons that try to imitate the functioning of human neurons. Deep learning is an integral part of ML. It uses networks with different computer layers in deep neural networks to analyse input data. Its purpose is to build a neural network that can automatically recognize patterns to improve feature detection[2,3]. Big data refers to large data sets and/or the combination of all available data points drawn from multiple sources which can be used to recognize patterns that inform a customized experience for different individuals[1].

Orthodontic treatments are usually long procedures with an average treatment duration of nearly 29 months,[4] which is why orthodontists must become more efficient to adapt to the needs of society. The application of ML techniques can help to solve this issue. Recent technological innovations in orthodontics, including cone beam computed tomography (CBCT) and 3D visualizations, intraoral scanners, facial scanners, instant teeth modelling software capabilities and new appliance developments using robotics and 3D printing, are changing the face of medical care and are quickly becoming integrated into dentistry[5].These tools enable a better understanding of the patient's anatomy and are able to create dynamic anatomical reconstructions for the specific patient, and therefore accommodate the possibility of 3D treatment planning. Convolutional neural networks (CNNs) are increasingly applied for medical image diagnostics, most frequently for the detection, segmentation or classification of anatomical structures. Deep learning has also recently been used for geometric feature learning and classification[6]. Machinelearning approaches, which are algorithms trained to identify patterns in large data sets, are ideally suited to facilitate data-driven decision-making[7]. This scoping review aims to determine the applications of AI that are extensively employed in the field of orthodontics, to evaluate the benefits of AI and to discuss its potential implications in this speciality. This article aims to provide an insight into applications of AI related to orthodontic diagnosis and treatment planning.

II. ARTIFICIAL INTELLIGENCE IN DIAGNOSIS

AI has excellent application in imaging diagnostics in the field of orthodontics due to the ease with which the machine deals with patterns[1].

Timely diagnosis of genetic syndromes tends to improve the outcomes. By the same token, craniofacial phenotypes are extremely informative for establishing the correct diagnosis of genetic congenital diseases because many syndromes have recognizable facial features. These changes in facial morphology are often of significant orthodontic interest. Several syndromes lead to dentofacial deformities and malocclusions that require orthodontic treatment. Imaging diagnoses have gradually incorporated AI to increase sensitivity (ability to adequately predict the existence of a disease or problem in a patient) and specificity (ability to exclude the disease or problem when an individual does not have it)[2,11].

In this field, AI has helped in a relevant way. One such advancement is a mobile phone application called Face2Gene (FDNA, Boston, USA). The application uses the contrast of a patient’s image against thousands of images in its databases to determine the subtle patterns that different syndromes tend to have. The diagnostic hypothesis established by the App has already proved to be useful for Caucasian and Asian populations and outperformed clinicians in diagnosing a number of syndromes[8].

AI has already been used to diagnose and classify osteoarthritis in the temporomandibular jointand it may provide future data for establishing treatments for problems that are specific to the different severities of the condition.

III. ARTIFICIAL INTELLIGENCE IN EXTRACTION OR NON EXTRACTION THERAPY IN ORTHODONTICS

Another interesting recent application of AI is the prediction of extractions in orthodontic planning.The teeth to be extracted (first and second premolars) and the variability of dentofacial alterations included in this study were limited, and this arbitrary constraint probably reflects the relatively small original database. However, this is a promising and exciting first step toward determining whether extractions are required in the treatment plan.Xie et al. constructed a decision-making expert system for orthodontic treatment of patients aged between 11 to 15 years old to decide whether tooth extraction is needed by using back propagation ANN model[7]. ANN model simulates human neural system, with neural networks which can process nonlinear relationships and exhibit learning ability. 200 subjects were chosen, 120 receiving extraction therapy and 80 receiving nonextraction therapy. 23 indices were selected as input data for each patient, and extraction or non-extraction were calculated as output data. Among 200 subjects, 180 were used as training data and 20 were used as testing data. The constructed ANN in this study showed 80% accuracy in testing set. Moreover, lip incompetence and IMPA(L1-MP) were the two indices that give the biggest contribution to the output data. Jung et al. also constructed neural network model combined with back propagation algorism[8,26].The purpose of the study was to construct an AI expert system for decision of extraction therapy and extraction pattern. There were 156 patients that included in the study. Twelve cephalometric variables and 6 indexes were selected as input data. Extraction or non-extraction and extraction pattern were set as output data. The treatment plans were determined by one orthodontic specialist. Different from Xie’s study[7], it further divided training data into training data and validation data. Iterative learning was stopped at the minimum error point of the validation set to prevent overfitting. The success rate of the models was 93% for the diagnosis of extraction or non-extraction therapy and 84% for the selection of extraction pattern.

IV. ARTIFICIAL INTELLIGENCE IN GROWTH PREDICTON

The hand-wrist and lateral cephalometric radiographs (for cervical vertebrae) are commonly used to predict growth and development. Using ANN algorithms, AI technology accurately determines the growth and development rate based on hand-wrist radiographs and the cervical vertebrae.Timing is one of the key points needed to be considered during treatment planning, especially among growing patients. Several methods have been proposed for growth prediction such as chronological age, menarche, change in voice and body height, and bone age. The gold standard for assessing bone age was obtained by handwrist

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radiographs, however, Lamparski reported that by reading cervical vertebrae stages, similar accuracy could be attained and preventing additional radiation at the same time[26,27]. Spampinato used deep learning approaches to assess bone age through hand-wrist radiographs[28]. The dataset contained 1391 X-ray left-hand scans of children of age up to 18 years old with bone age values provided by two expert radiologists. The result showed an average discrepancy between manual and automatic evaluation of about 0.8 years. Kok et al. compared different AI algorisms for determination of growth by cervical vertebrae stages[29]. K-nearest neighbors, Naive Bayes, decision tree, artificial neural networks, support vector machine, random forest, and logistic regression algorithms were tested for accuracy. ANN showed most stable result and was suggested the preferred method for determining cervical vertebrae stage[14].

V. ARTIFICIAL INTELLIGENCE IN ORTHOGNATHIC SURGERY

Great investment has been made in research and development of digital orthodontics and 3D simulation of orthognathic surgery[11]. Besides, automated treatment planning and customized surgical set up planning lead to improved diagnostic precision especially among inexperienced doctors[10,11]. Knoops et al. developed a machine learning framework for automated diagnosis and computer-assisted planning in plastic and reconstructive surgery[12].They presented the large-scale clinical 3D morphable model (3DMM), a machine-learning framework including supervised learning constructed with surface 3D scan. The model was trained with 4261 faces of healthy volunteers and orthognathic surgery patients. Through automated image processing, it provides binary outcome whether someone should be referred to a specialist with 95.5% sensitivity and 95.2% specificity. Then, a specialist can automatically produce 3D simulation of post-surgical outcome with mean accuracy of 1.1±0.3 mm, without the need for conventional timeconsuming computer assisted surgical simulation. However, only surface scan was used in this study, so the underline bone movement needed to be calculated according to soft tissue movement which still remain a big task nowadays. Weichel et al. developed a computer-assisted planning system based on CT, cephalometric and plaster model[14]. The system referred to a knowledge base built in semantic web standard Resource Description Framework Schema, which transferred human knowledge into machine readable data. Gradient descent algorism was used to find local minimum of the loss function. Loss function described how good the current regression we applied. The bigger the calculated result deviate from optimal result, the bigger the loss function become. Good general agreement between the automatically generated planning proposal and planning result of a maxillofacial expert was found. But it is a preliminary study with only 5 cases was evaluated. Comparing to Knoops's study who used 3DMM to come up with diagnosis, Choi et al. applied ANN obtained from 12 measurement values of the lateral cephalogram and 6 additional indexed[11] . The machine learning model consisted of 2-layer neural network with one hidden layer. The sample included 316 patients with 160 were planned with surgical treatment and 156 were planned with nonsurgical treatment. The success rate of the model showed 96% for whether the patient need surgical treatment, and 91% for the detailed diagnosis of surgery type and extraction decision. The success rate is comparable between these two studies. Niño-Sandoval et al. tried to predict mandible bone morphology based on maxilla morphology using ANN[14]. 299 lateral cephalograms was obtained from Colombian patients with 19 landmarks on X and Y coordinates. The result showed high predictability of the selected mandibular variables which might be quite helpful for craniofacial reconstruction.

VI. ARTIFICIAL INTELLIGENCE FOR TMD CLASSIFICATION

Shoukri et al. applied neural network to stage condylar morphology in temporomandibular joint osteoarthritis (TMJOA).The neural network was trained on 259 condyles to detect and classify the stage of TMJOA and compare to clinical expert's classification. Condylar morphology was classified into 6 groups by CBCT image. Predictive analytics of the AI's staging of TMJOA compared to the repeated clinicians' consensus showed 73.5 and 91.2% accuracy. The results suggest that TMJOA condylar morphology can be comprehensively classified by AI. AI have been applied to robotic surgeries in neurological, gynecological, cardiothoracic and numerous general surgical procedures. It is quite promising in the near future that AI robotic technologies could be applied to orthognathic surgery as well. It can reduce infection rate because only robotics have contact with the patient[22]. Higher precision of jaw movement can be expected at the same time. Last but not least, thanks to the power of technology, diagnostic and therapeutic philosophy are going through a paradigm shift from the traditional 'signs and symptoms' approach to 'precision medicine' approach. Starting with patients deep phenotyping, which gathered not only clinical data but genetic and biomarkers information, even lifestyle and environmental condition as well. Then data cleaning, exploratory data analysis, and feature engineering will be conducted by data scientists. Applying AI technology, we can build a diagnostic/prognostic model based on the 'big data' and predicting treatment results. It is not only a oneway process, taking the goodness of the predictive result as a feedback, we can further fine-tune the previous model and feature engineering process to get a positive feedback loop. In orthodontic field, the concept of precision medicine means a more complex diagnostic process, a more personalized treatment planning and a more sophisticated treatment process and those might lead to a more efficient treatment with less side effects and treatment duration. Hopefully, the medical quality could be raised while decreasing the medical costs through the application and development of AI technology[22].

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VII. ARTIFICIAL INTELLIGENCE AND ITS LIMITATIONS

AI today completely ignores the existence of oral diseases and possible previous health treatments that may affect the prescription of orthodontic corrections, either with aligners or fixed appliances.Patients with periodontitis seem to be more interested in correcting the alignment of their teeth,[as pathological tooth migration is a common consequence of periodontitis. However, performing orthodontic movement with active disease is contraindicated. Thus, it is essential that an orthodontist prepares a proper anamnesis, examines the patient, makes a diagnosis, and only then prescribes the appropriate treatment before performing it. More often than not, orthodontics is performed after essential endodontic, periodontal, restorative, etc., treatments.

This fact makes it particularly risky to use AI technology for the so-called “do-it-yourself orthodontics.” Companies in several countries have been selling aligners to patients without proper dental supervision. This has led to numerous reports of tooth mutilation and bone loss in the general population. However, a mismatch exists between the professional reports in conferences of these damages to the health of the population and the reports of these problems in scientific journals. In addition, there is some subliminal pressure and fear in the clinical and scientific community regarding the possibility of legally responding to the exposure of the damage caused by these alleged corrections. Companies’ financial resources for a legal fight go beyond that of clinicians and – in some cases – even that of the largest orthodontic associations[31].

Another limitation of AI algorithms being implemented today is that they do not incorporate patients’ facial analysis, their proportions, and esthetics. There is a direct interaction between orthodontic dental movements and facial esthetics. Only a qualified orthodontist can perform these analyses because tooth movement in any direction of the space is commonly connected with facial and smile esthetics.In addition, facial analysis is the first step toward determining whether dentofacial deformities are presentand thereby the possibility of surgical orthodontic corrections[28].

In addition, AI algorithms do not effectively incorporate many orthodontic tools, thereby limiting treatment tool and strategies, such as skeletal anchorage, dental extractions, and integrated restorative procedures. This is at least partially associated with the mechanical limitations of aligners to control certain tooth movements. When the fixed orthodontic appliance was developed, nearly 100 years ago, we had doctor- centered treatments and not patient-centered ones. In other words, more consideration was given to how easy and efficient the treatment would be mechanically for the doctor, rather than how comfortable and effective the treatment would be for patients. Moreover, brackets, wires, and other attachments were developed from the doctor’s point of view[18].

VIII. CONCLUSION

This scoping review showcases that there has been an exponential increase in the number of orthodontic studies involving various applications of AI and ML over the past three decades.AI technologies have been increasingly applied to the field of orthodontic treatment. It is proved to be a reliable and time saving tool in many aspects. Future effort could be made on creating cloud-based platforms for data integration and sharing. Given that data is the foundation of well-constructed models, with high quality and quantity of data, higher accuracy of predictive result and image interpretation could be achieved through machine learning process. In terms of orthodontic research, a well-trained AI model can help not only landmark identification, but all kinds of linear and angular measurements and volumetric measurements as well. It can save tremendous time by fully automated AI measurements so researchers will have more energy finding new insights within clinical examinations.

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