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Artificial Intelligence As Applied In Orthodontics: A Review

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Abstract

This article aims to discuss the various roles played by Artificial Intelligence (AI) and computer technologies in orthodontics especially in diagnosis and treatment planning. Because of the different clinical presentation of malocclusions and enormous treatment options, it is difficult for the orthodontist to arrive at a proper decision at times. These computer programs help to make the clinical decision making much easier for the specialist and improve the efficiency in treatment planning. Various applications of AI in day to day clinical practice and its relevance with literature are highlighted in this review.

Keywords: Artificial intelligence, Diagnosis and Treatment planning, Machine learning, Neural networks.

Introduction

Orthodontics is the branch of dentistry concerned with preventing and correcting irregularities of the teeth and dentofacial structures. The objective of orthodontic treatment is to align irregularly placed teeth and basal bone so that the appearance and functional efficiency of the dentition are improved. Orthodontics speciality has come a long way as it reaches the 21st century, the researchers were focussing on to develop newer strategies for diagnosis and treatment planning for the individual patients. To achieve satisfactory orthodontic treatment outcomes, treatment planning must be carefully performed before the treatment process begins. Generally, most orthodontists make a decision with data from the clinical evaluations, photographs, plaster study models and radiographs based on their experience and knowledge. Since there is no formula for the treatment plan, the decision depends on the practitioner's experience in many cases. This often causes variability of decision making among clinicians as well as different records used for the

diagnosis can cause differences in the treatment plan. Moreover, differences in treatment planning can occur between experienced and less-experienced practitioners[1]. Over centuries, newer technologies have developed based on principles that try to mimic the functioning of the human brain, however even today the machine that can think like a human is still a dream. An enormous amount of modern computers and technologies were introduced as an early attempt to formulate the logic thinking process to aid in clinical decision making. Bioinformatics and Artificial Intelligence (AI) have opened new avenues to assist clinicians for decision-making more objectively in the medical field as well as in Orthodontics[1].

Artificial intelligence(AI) may be defined as the branch of computer science that is concerned with the automation of intelligent behaviour or it is a subfield of computer science that has the ability to interpret external data, learn from the data and eventually transform data into intelligent actions[2,3]. The term Artificial intelligence is given by John McCarthy and the concept of machine learning was first given by Alan Turing[4]. Expert system (ES) is an important branch in the field of artificial intelligence and is a computer program system that processes knowledge and information, which is composed primarily of a knowledge base and an inference machine. It simulates the decision making and working processes of experts and solves actual problems in the field of a single speciality[5].

Some of the basic terms involved with Artificial Intelligence are as follows.

Neural network: These are computing systems that mimic the structure of the biological brain[6].

Artificial neural network (ANN): ANN is a learning model based on the biological neural networks present in the brains of animals. Based on the activity of neurons, ANN are used to solve tasks that would be difficult for traditional methods of programming.

Algorithm: A formula or set of rules for performing a task. In AI, the algorithm tells the machine how to go about finding answers to a question or solutions to a problem.

Model: A mathematical representation of relationships in a data set.

Deep learning: A subset of machine learning that uses specialized algorithms to model and understand complex structures and relationships among data and datasets.

Expert system: A computer program capable of performing at the level of a human expert in a narrow problem area. These are rule based systems.

Case based reasoning: An approach to knowledge based problem solving that uses the solutions of a past, similar problem (case) to solve an existing problem.

Back propagation (BP): It is the way of training neural networks based on a known, desired output for a specific sample case.

Categories of Artificial Intelligence

(A) Symbolic AI: 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 GOFAI (Good Old Fashioned AI). Symbolic AI uses rules, such as if then statements, where if a certain criterion is met, then the corresponding action must be taken[7].

(B) Machine learning: A field of AI focused on getting machines to act without being programmed to do so. Machines ‘’learn’’ from patterns they recognize and adjust their behaviour accordingly[6]. Recent advances in digital data made machine learning possible in areas such as medical diagnosis, bioinformatics, chemical informatics, social network analysis, stock market analysis

and robotics. Machine learning techniques can be unsupervised or supervised learning based on whether the output values are required to be present in the training data. Unsupervised learning techniques require only the input feature but Supervised learning methods require the value of the input and output variable or each training sample to be known[8]. Generally, there are three stages in a machine learning application: a preparation stage, a training and test stage, and an application stage[9].

Orthodontic Applications

Understanding the role of AI is very much required because it is going to change the future of orthodontics in the coming years. It helps to improve our efficiency in daily clinical practice by giving better organized treatment plan to our patients[10].There are various algorithms used in artificial intelligence for the purpose of diagnosis, prediction and classification of problems. They are Genetic algorithms, expert systems, fuzzy logic, logistic regression, random forest, decision tree, k-nearest neighbours algorithm (k-NN), support vector machine(SVM), Naive Bayes, and artificial neural networks[11]. Some of the recently introduced algorithms are You-Only-Look-Once version 3 (YOLOv3), Single Shot multibox detector (SSD)[12] and Learning-based multisource integration framework for segmentation (LINKS)[9]. Various applications of AI in orthodontics are as follows,

(A) Diagnosis, treatment planning and treatment prediction

Artificial intelligence, a computer encoded programme which can simulate the functions of a human brain and give more accurate information especially in complex cases like an expert does. It consists of servers, algorithms and various databases which helps in the diagnostic process and these data bases consist of various information of ongoing and previously completed orthodontic studies. Upon giving patient data such as photographs, study models, radiographs etc the servers will analyse these findings and also from the database and give a better diagnosis and treatment plan to a particular orthodontic condition[13]. Artificial neural network expert systems may be trained with clinical data and can be used as an important decision-making tool within dentistry[14].

In order to overcome the limitations of orthodontic diagnosis and treatment planning using traditional rule-based expert systems, a new case based expert system (ES) has been developed. These case based ES contain stored data of previously treated cases which helps in solving new case problems by utilizing the information already stored in the data base[15].Studies conducted to evaluate the computer-generated treatment plan with the actual treatment plan by comparing few consecutive cases with the treatment plan of already treated cases which is stored in the ES and found out that server system generated treatment plan approach matched the actual treatment plan[16]. In clinical orthodontics, an expert system of artificial intelligence is developed based on Ripple-Down rules in dentistry that comprises a knowledge base of 680 rules. This ES has the potential as an interactive advisory tool and is applicable in clinical orthodontic situations to sort out the problems[17].It is also evaluated the potential of artificial intelligence in the evaluation of facial attractiveness using a Standard Vector Regression (SVR) algorithm in combination with of geometric morphometrics[18].

Recently artificial intelligence also introduced in the CBCT evaluation of impacted maxillary canines using a novel machine learning algorithm called Learning based multisource integration framework for segmentation (LINKS) (Fig.1)[9].There is a new software that uses fuzzy logic algorithm, which upon giving case data such as facial measurements and intra oral findings by the

examiner, the server will analyse the case and propose a treatment plan (Fig.2). The data can be given in both graphic and numeric forms. This software is used to solve problems in nonsurgical cases[19].

Some authors investigated the role of artificial neural networks involved in treatment mechanics such as retraction using T springs to determine whether the artificial neural network model can be trained for simulation of the correlation between input parameters such as T-spring cross section and activation distance and the output variable such as spring force system[20].

(B) Cephalometric Evaluation

Cephalometric radiographs are an important tool in the diagnostic process. Identification of anatomical landmarks and their accurate measurements will play a crucial role in the decision making process because it is a tedious task for an analyst to identify the landmarks carefully without making any error. Recently the fully automated cephalometric landmark identification system using deep learning which is a machine learning method with artificial neural network and convolutional neural network has been developed to improve the accuracy and reproducibility in the identification of both skeletal and soft tissue landmarks for better evaluation, treatment planning and predicting treatment outcomes[12]. These systems will reduce the human tasks and make the landmark identification more accurate.

Automatic landmark identification using artificial intelligence is first introduced into cephalometrics for the identification of sella and menton points. The CLIP4 computer system is used for this study and found it very effective in identification of these landmarks[21]. Recently two types of algorithms used in deep learning methods such as You-Only-Look-Once version 3 (YOLOv3) and Single Shot multibox detector (SSD) have been introduced for the automatic identification of cephalometric landmarks. Their effectiveness was compared in terms of accuracy and timing in the identification of cephalometric landmarks and it is estimated that YOLOv3 is more accurate as a fully automated cephalometric landmark identification system for use in clinical practice in accuracy as well as in timing (Fig.3)[12]. After the introduction of the deep learning method algorithm YOLOv3, its efficiency is compared with that of a human examiner in identification of cephalometric landmarks. The cephalometric landmark identification by AI and human examiners shows that both are equally effective in identification of landmarks unless the image quality is poor due to blurring or artifacts and for repeated identification of multiple cephalometric landmarks, AI might be a viable option[22]. Few technical approaches are developed for the automatic cephalometric analysis using computer software such as Image filtering plus knowledge based landmark search, Model-based approach, Soft-computing or learning approach and hybrid approach[23].

(C) Growth assessment, evaluation and forecasting

Diagnosis and treatment planning in orthodontics is largely dependent on the pattern of craniofacial growth. If a skeletal malocclusion like Class II or Class III can be identified early, it can be corrected easily by utilizing the growth tendency. By using artificial intelligence various growth patterns can be identified as well as the size and shape changes during growth. It is reported that the artificial neural network namely self organising neural maps is used to assess the craniofacial growth changes of orthodontically treated children between 7 and 15 years of age to determine resultant growth data. The relationships of the various growth patterns and this type of network can be used as a frame of reference for classifying and analysing previously unknown cases with respect to their growth pattern[24].

(D) Growth assessment using CVM

Growth can be assessed using various skeletal maturity indicators in order to arrive at a proper timing of treatment. Fishman's Hand-wrist radiographs and cervical vertebrae maturation indicators are commonly used nowadays for the purpose of craniofacial growth assessment. Identification of prepubertal growth spurt is very important in growth modification treatment using functional appliances. Few studies are reported in the literature about the role of artificial intelligence in these maturation indicators using various software algorithms. A study compared the various artificial intelligence algorithms for determination of growth and development by cervical vertebrae stages. AI logarithms are compared to check for highest accuracy in determining cervical vertebrae maturation stages. The algorithm used in this study were k-nearest neighbours (k-NN), Naive Bayes (NB), decision tree (Tree), artificial neural networks (ANN), support vector machine (SVM), random forest (RF)and logistic regression (Log.Regr.) and it is concluded that artificial neural networks could be the preferred method for determining cervical vertebrae stage[11].

New digitized vertebrae analysis software has been developed for quantitative assessment of cervical vertebrae maturation through computer analysis by using CVMI and Fishman's skeletal maturity indicator method, which is then evaluated with an algorithm called multinomial logistic regression model (MLRM). Recently a deep learning Convolutional Neural Network (CNN) method has been developed to determine the degree of maturation of CVM classified in six degrees with an accuracy of 95%[25]. 3-D cephalometry requires artificial intelligence especially in parametric approach of superimposition of images using pseudo biometric analysis because the use of AI helps in synthesize and compare numerical values and can manage large number of parameters[26].

(E) Extraction decision

As we already discussed about the role of artificial intelligence in diagnosis, the next important thing in treatment planning is the extraction decision of a case. Computer software will analyse the findings of a particular malocclusion given by the examiner and also using information from the database will give a decision about the extraction pattern. Some authors develop an artificial intelligence expert system for the diagnosis of extractions using neural network machine learning. They determined the need as well as the extraction positions in their study. They concluded that the artificial intelligence neural network machine learning is a newer approach in orthodontic diagnosis with high success rates. But they only studied diagnosis and treatment of nonsurgical cases and researches still needed in diagnosis of extraction patterns in surgical cases with these neural network machine learning[1].

Artificial intelligence is used in orthodontic treatment planning to determine whether extractions are required or not using an algorithm called artificial neural network (ANN) in patients between 11 and 15 years old. The model incorporated 23 indices such as cast and various hard and soft tissue measurements to know which indices are responsible for deciding an extraction pattern which is determined by the constructed ANN model. The constructed artificial neural network was able to determine that among these given indices the anterior teeth uncovered by incompetent lips and IMPA should be considered first to decide whether an orthodontic treatment needs extraction. So this constructed artificial neural network is able to correctly judge with 80% accuracy whether malocclusion patients between 11 and 15 years of age need extraction[5]. A mathematical model

has been developed with the help of a software program (MATLAB, MathWorks, Natick, MA) in order to simulate expert decisions regarding whether or not to extract teeth based on pretreatment conditions of orthodontic patients with a success rate of 90.4% at its prediction performance[27].

(F) Functional jaw orthopedics

Artificial intelligence in functional jaw orthopedics is mainly used to assess the treatment prediction when using the functional and orthopedic appliances during the prepubertal growth spurt to correct skeletal Class II and Class III malocclusion.AI is used in growth modification especially in selection of head gear appliance for orthodontic patients by using a computer-assisted inference and act as a decision making aid for inexperienced clinicians[28]. Artificial neural networks can be used to make a model for predicting the treatment outcome of various classes of malocclusion by assessing the peer assessment rating index based on initial orthodontic measurements[29]. Nowadays computer encoded devices can be incorporated with functional appliances to know the actual wear time of the appliance by the patient which also involves the use of software algorithms.

(G) Clinical data storage

Clinical data storage is usually done in the form of physical data such as case history sheets, study models, photographs, radiographs, and other relevant details and demands a large storage space and also more effort of the clinician. But the introduction of newer computer technologies which incorporate software will help in collection, storage and transfer of patient data, medical information and other knowledge in the digital format. The advent of digital images, digital photography and digital study models marks the era of electronic data storage. The advantage of this digital data storage is that it can be accessed by anyone at any time and also you can share the data to your colleagues and to different software programs and be helpful in future research too. The introduction of newer technologies like CAD/CAM and 3D printing which uses artificial intelligence helps in the construction of digital models as well as various orthodontic and surgical appliances avoids the use of study models, dental stones and plasters that in turn makes the clinical data storage more confined.

Orthodontic electronic patient records can be made with two already existing informatics standards such as Health Level Seven (HL7) for textual data and digital imaging and communication in medicine (DICOM)for image data. The integration of these two standards helps in storage of data in the form of texts as well as digital images and its transfer[30].There are various clinical data management software systems are used in the medical field especially in clinical trials for the data collection and storage for further use[31].

(H) Orthognathic surgery

Artificial intelligence incorporated software changed the orthognathic surgical protocol by improving the diagnostic precision and treatment planning. The computer software helps the examiner in all steps from treatment planning to treatment follow up and has the ability to learn from every real life case it is exposed to improve the performance of the cases. The use of AI in intra oral scanner software makes its acquisition more efficient and yields higher quality images with lower doses of radiation. Machine learning techniques helps in 3D reconstruction, superimposition of various images and to automate cephalometric analysis which improves the treatment outcome and made things easier for a maxillofacial surgeon. The dynamic virtual setup such as ClinCheck, Insignia and Ortho Analyzer uses 3D digital treatment planning software which is helpful in multidisciplinary approach and acts as a tool for educating patients about

the case. AI also used in CAD/CAM and 3D printing technologies to construct surgical splints, plates etc. The computer technologies can also help a surgeon to analyse the impact of treatment on different anatomical structures and act as a tool for treatment follow up.AI also plays a role in Virtual Surgical Planning to assist the surgeon in most difficult case[32].

It is reported that artificial intelligence also helps in analysis and interpretation of a recognized face. Artificial intelligence is used to describe the impact of orthognathic treatment on facial attractiveness and age appearance by using a computational algorithm based on a Convolutional neural network and showed that it might be considered to score facial attractiveness and apparent age in orthognathic patients (Fig.4)[33]. Recently, artificial intelligence methods such as neural network and neuro-fuzzy system have been used for 3D contactless measurement in orthognathic surgery with binocular stereo vision in order to increase the accuracy of positioning of jaws during the surgery. The artificial measurements show a statistically acceptable accuracy than real time meassurements[34]. The ANN possesses the ability to improve the postsurgical video image profile predictions to a clinically applicable and treatment planning level[35]. Even though AI has got various applications in orthognathic surgery it is not beyond the level of a well trained human specialist in understanding the patient psychology and demands. So it should be used as a supplemental tool in diagnosis and treatment planning.AI has yet to demonstrate its value and capacities in the field of simulation of outcomes of orthognathic surgery.

Limitations

One of the main limitations of AI is that it does not incorporate patient's facial analysis, their proportions and aesthetics[36,37].It does not consider the impact of functional problems and the stability of the tooth position and cannot determine the etiology of the problem or predict specific retention strategies. In addition, AI algorithms do not effectively incorporate many orthodontic tools, thereby limiting treatment tools and strategies, such as skeletal anchorage, dental extractions, and integrated restorative procedures[38]. Also the role of AI in predicting treatment outcome in functional jaw orthopedics and orthognathic surgery needs to be revisited as the psychological level of the patient is not considered. The interpretation of the results formed by the machine intelligence cannot be generalised for patients from different ethnic, demographic and geographical backgrounds. There could be legal and ethical issues regarding the use of clinical imaging data for the commercial development of machine learning based systems, since the performance of the system will be highly dependent on the quality of the data. Legal liability issues are another concern due to error in interpretation by machine compared with clinician or a technician in the decision making process which should not be overlooked.

Figures

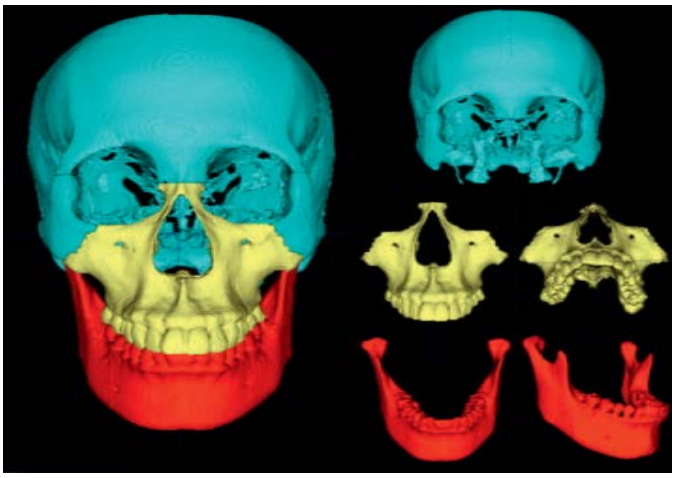

Fig.1: 3D Auto segmentation

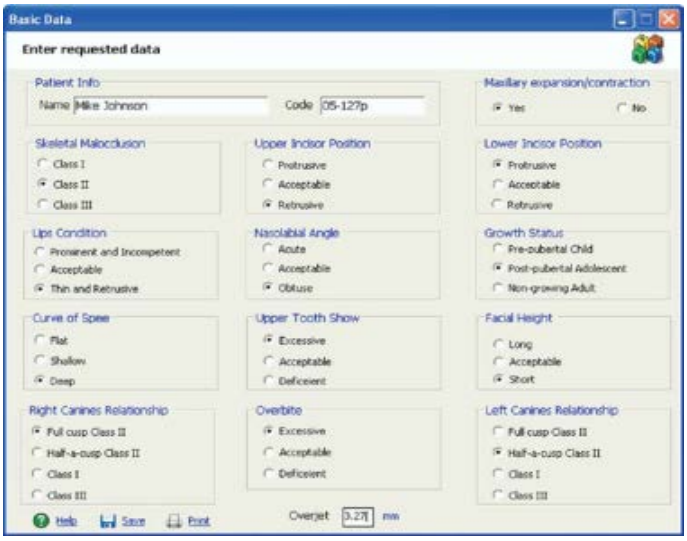

Fig. 2: Orthodontic treatment planning software

Fig. 3: Automatic landmark identification

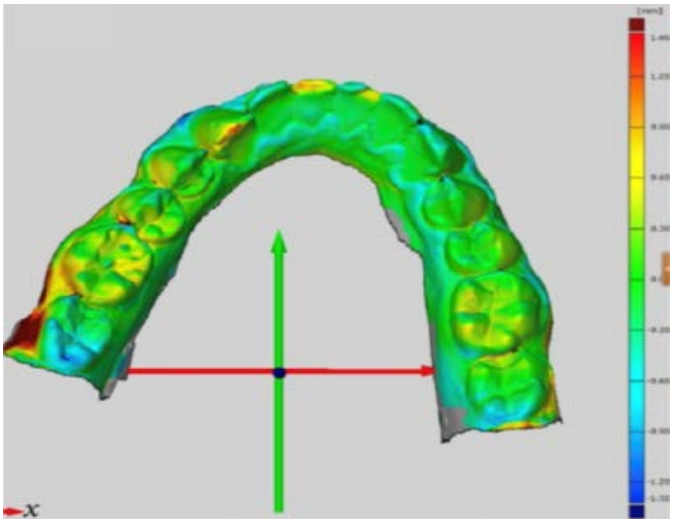

Fig. 4: AI in 3D superimposition of models

Conclusion

Going through these literature reviews, the role of artificial intelligence in Orthodontics is inevitable in the future. Because of the various types of malocclusions, facial patterns and enormous treatment modalities, it is always a challenge in the decision making process. In such cases AI plays a crucial role in diagnosis, treatment planning and treatment optimization. Even though AI is a good tool in assisting clinicians in diagnosis and treatment planning, in an era of evidence based treatment planning where treatment predictability is determined based on higher level scientific evidence, it is not a substitute for clinical decision making. It should be utilized in a careful manner to make the most out of its use. However AI has got several applications, its feasibility in daily clinical practice needs to be precise or made available easily to an examiner. Artificial intelligence in orthodontics still needs various researches in areas such as functional jaw orthopedics, quantification of orthodontic forces, prediction of treatment outcomes in orthodontic and orthognathic surgery and in robotic wire bending.

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