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ARTIFICIAL INTELLIGENCE AND ITS APPLICATIONS IN ORTHODONTICS – A REVIEW

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ABSTRACT

INTRODUCTION: Recent decades have perceived massive variations in our profession. The advent of new aesthetic options in orthodontics, the shift to a completely digital workflow, the development of temporary anchorage devices, and new imaging methods offers both patients and professionals a novel focus in orthodontic care. OBJECTIVE: This review aims to provide an overview of the existing evidence on using artificial intelligence (AI), machine learning (ML) and its translation into clinical orthodontic practice. It aims to determine the applications of Artificial Intelligence (AI) in the field of Orthodontics, evaluate its benefits, and discuss its potential implications in this specialty. MATERIAL AND METHODS: The literature for this paper was identified and selected by performing a thorough search in electronic databases like PubMed, Medline, Embase, Cochrane, Google

Scholar, Scopus, Web of Science published over the past two decades (January 2000 - December 2021). RESULTS: AI is widely implemented in a wide range of orthodontics in predicting orthodontic extractions needed for orthodontic treatments. Automated landmark detection and analyses, growth and development assessment, diagnosis and treatment planning were the most commonly studied. CONCLUSION: There has been an exponential increase in the number of studies involving various orthodontic applications of Artificial intelligence and Machine learning. AI can also advance the accuracy of orthodontic treatments, thereby helping the orthodontist work more accurately and efficiently..

KEYWORDS: Artificial intelligence; Machine learning; Orthodontics; neural networks and orthodontics; hybrid approach and orthodontics.

INTELIGENCIA ARTIFICIAL Y SUS APLICACIONES EN ORTODONCIA - UNA REVISIÓN

RESUMEN

INTRODUCCIÓN: Las últimas décadas hemos percibido variaciones masivas en nuestra profesión. La llegada de nuevas opciones estéticas en ortodoncia, el cambio hacia un flujo de trabajo completamente digital, el desarrollo de dispositivos de anclaje temporal y nuevos métodos de obtención de imágenes ofrecen tanto a los pacientes como a los profesionales

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un enfoque novedoso en el cuidado de la ortodoncia. OBJETIVO: Esta revisión tiene como objetivo proporcionar una visión general de la evidencia existente sobre el uso de inteligencia artificial (IA), aprendizaje automático (ML) y su traducción a la práctica clínica de ortodoncia. Su objetivo es determinar las aplicaciones de la Inteligencia Artificial (IA) en el campo de la Ortodoncia, evaluar sus beneficios y discutir sus potenciales implicaciones en esta especialidad. MATERIAL Y MÉTODOS: La literatura para este artículo fue identificada y seleccionada mediante una búsqueda exhaustiva en bases de datos electrónicas como PubMed, Medline, Embase, Cochrane, Google Scholar, Scopus, Web of Science publicadas durante las últimas dos décadas (enero de 2000 - diciembre de 2021). RESULTADOS: La IA se implementa ampliamente en una amplia gama de ortodoncia para predecir las extracciones de ortodoncia necesarias para los tratamientos de ortodoncia. Los análisis y la detección automatizados de puntos de referencia, la evaluación del crecimiento y el desarrollo, el diagnóstico y la planificación del tratamiento fueron los más comúnmente estudiados. CONCLUSIÓN: Ha habido un aumento exponencial en el número de estudios que involucran diversas aplicaciones de ortodoncia de inteligencia artificial y aprendizaje automático. La IA también puede mejorar la precisión de los tratamientos de ortodoncia, ayudando así al ortodoncista a trabajar de forma más precisa y eficiente.

KEYWORDS: Inteligencia artificial; Aprendizaje automático; Ortodoncia; redes neuronales y ortodoncia; abordaje híbrido y ortodoncia.

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INTRODUCTION

The human brain is one of the utmost fascinating structures to researchers and technologists for as long as history dates back. And over time, novel technologies have been established based on principles that try to mimic the functioning of human brain; however, even today, the machine that can think like a human is still a dream. Many modern computers and technologies were inspired by early attempts of Aristotle to formulate logical thinking through his syllogisms.[1] In1950, a British mathematician, Alan Turing invented the machine that decodes encrypted messages; this might be the first breakthrough in supercomputers' history. Moreover, he developed the "Turing Test," designed to determine whether a computer exhibits intelligence.[2]Today, we recognize a similar function as "artificial intelligence."

Artificial intelligence is well-defined as a field of science and engineering concerned with the computational understanding of what is usually called intelligent behavior, with the creation of artifacts that exhibit such behaviour'[3,4]

The applications of these Artificial Intelligence technologies in various fields like telecommunication and aerospace have grown manifold. Technology has also revolutionized medicine and dentistry in the last decade.[5]

Orthodontic treatments are usually lengthy procedures with an average treatment duration of nearly 29 months[6,]

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which is why orthodontists must be more efficient to acclimatize to the needs of society. The application of these techniques can help to solve this issue.

To appreciate the effect of AI on orthodontics, it is first essential to discern some key elements related to AI[Figure -1]:

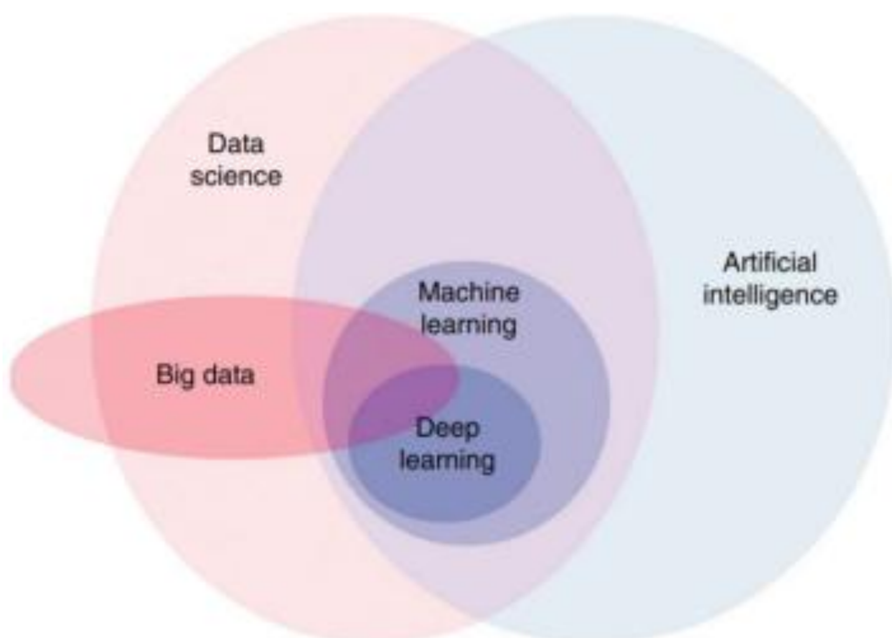

Fig -1: Key Elements of Artificial Intelligence

Artificial intelligence is a machine's ability to express its intelligence by solving problems based on data.

Machine learning uses algorithms to anticipate outcomes from a set of data. The goal is to make it easier for machines to learn from data and solve problems without human intervention.

Neural networks compute signals using artificial neurons, which operate similarly to the human brain.

Deep learning with multiple computational layers builds a neural network that automatically recognizes patterns to improve feature detection [7]

Data science is the process of analyzing data and extracting useful information from it .[8]

Big data provides users with accurate information by assessing a vast set of data that has been continually growing for years at the right time. [9]

Current orthodontic literature is abounding with studies that have documented various applications of AI and ML. However, no study has attempted to organize the existing literature to review AI and ML applications in orthodontics and provide a comprehensive mapping of studies conducted in this field. Hence, this review aims to offer an overview of the current evidence of how far the former AI and ML advancements in orthodontics have translated into clinical fruition and the limitations that have precluded their future development.

LITERATURE SEARCH:

The literature for this paper was selected by execution of a thorough search in electronic databases like PubMed, Cochrane, Google Scholar, Scopus, Medline, Embase, Web of Science

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published over the past two decades (January 2000 -December 2021). A total number of 89 articles were included in this review.

AI IN ORTHODONTICS:

To achieve successful orthodontic treatments, having detailed diagnoses, accurate treatment plans and accurate outcome predictions is crucial.

AI IN ORTHODONTIC DIAGNOSIS AND TREATMENT PLANNING:

Diagnosis forms the core of the treatment in orthodontics. AI helps in diagnosis, planning treatment and monitoring the progression of treatment by analyzing the radiographs and photographs .[10]

With the advent of intraoral scanners and cameras, making of dental impression is being replaced by digital impressions [11] and the above data is fed into the system; the set algorithms and AI software helps in predicting tooth movements and outcome of the treatment [12] to predict orthodontic treatment plans, including the determination of extraction/no extraction and anchorage patterns [13], to identify the factors that influence decision-making before orthodontic treatment and evaluating the need for tooth extraction of patients with malocclusion.[10]

Customized aligner-based orthodontics can improve case acceptance when combined with the latest technologies.

Designing software has been a great help to orthodontists to produce the best possible aesthetics for patients taking into consideration various factors like anthropological computation, measurements of face, and even patient's desire. At the same time, they are making impressions and eliminating several laboratory steps. The results are also very accurate when compared to tasks performed by humans. Mathematical algorithms and statistical analysis can determine the final treatment outcome and the desired tooth movement.[14]

EXPANDED DOMAIN OF DIAGNOSIS AND TREATMENT PLANNING:

Under the area of diagnosis and treatment planning, the applications of AI and ML were also investigated for screening of osteoporosis from panoramic radiographs [15,16]; assessment of airflow dynamics, prediction of upper airway collapsible sites, and obstructive sleep apnoea [17]; prediction of genetic risk assessment for non-syndromic orofacial cleft patients and prediction of occurrence of obstructive sleep apnoea in patients with Down's syndrome.[18]

NECESSITY OF EXTRACTIONS BEFORE ORTHODONTIC TREATMENT:

Usually, orthodontists decide whether an extraction is necessary based on their experience in practice and knowledge by analyzing data from clinical evaluation, patient photographs, radiographs, dental casts.

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One problem is that this causes intra- and inter-clinician variability in the treatment planning. By mimicking the decision making of human experts, an AI expert system might be technologically advanced based on numerous philosophies of diagnosis to assist the decision-making process based on an artificial neural network (ANN).[19]

Xie et al. (2010)[20] used an ANN system to determine whether an extraction or non-extraction treatment was best for malocclusion patients between 11and 15 years old and found the ANN worked with 80% accuracy.

These results were similar to Jung et al. (2016)[21] and Choi et al. (2019).[22] Nevertheless, the final decision will always belong to the clinicians.

Artificial neural networks (ANNs) were used to manufacture these systems. They were shown to successfully predict the extraction decision with an accuracy of 94%, 84.2% for determination of extraction pattern and 92.8% for determination of anchorage pattern. [23]

IDENTIFICATION OF CEPHALOMETRIC LANDMARKS:

Lateral cephalometry has been widely used in orthodontic practice for skeletal classification diagnosis treatment planning. The assimilation of a CNN can deliver an accurate and robust skeletal diagnostic system.[24]

Various studies demonstrated the efficacy of AI applications in recognizing cephalometric landmarks. The diagnostic

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value of the analysis rest on the accuracy and the reproducibility of landmark identification. Hwang et al. (2020) [25]concluded that AI cephalometric landmarks identification is as precise as human examiners. Similarly, Kim et al. (2020),[26] Dobratulin et al. (2020)[27] and Lee et al. (2020)[28] determined, with an accuracy between 88% and 92%, that the AI expert system could be used to identify cephalometric landmarks automatically. Guo et al. (2021)[29] also concluded that a deep learning technique without human interference can effectively overcome the limitations of manual identification methods.

Yu et al. [30] proposed a system that exhibited > 90% sensitivity, specificity, and accuracy for vertical and sagittal skeletal diagnosis and concluded that the CNN system showed potential for skeletal orthodontic diagnosis deprived of the need for intermediary steps requiring complicated diagnostic procedures.

Since then, several studies since then[31-41] have affirmed greater accuracy of landmark detection, reduced time, and human effort spent on anatomic landmark detection and analyses with AI/ML compared to traditional methods.

Various studies [42,47] that have employed AI ML techniques for automatic landmark detection analysis have shown that the results are as precise and less time-consuming as those obtained with manual analysis.

A study [48] included in this review compared frontal cephalometric landmarking ability of humans versus

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artificial neural networks. The results disclosed that ANNs could achieve accuracy comparable to humans in identifying cephalometric points and, in a few cases, surpasses the accuracy of inexperienced doctors.

3D CBCT CRANIOFACIAL IMAGES:

AI has automatically identified and classified skeletal malocclusions from 3D CBCT craniofacial images. Fast, efficient CBCT image segmentation permits large clinical data sets to be analyzed effectively.[49]

In 2020, Kim et al. presented a method that aimed to support orthodontists in deciding the best treatment path for a particular patient, be it orthodontic, surgical treatment, or a combination of both.[50]

ML can aid to determine the cephalometric predictors of the upcoming need for orthognathic surgery, as in patients with treated unilateral cleft lip and palate (UCLP).[51]

Thus, the use of AI reduces doctor assessment workload and improves diagnostic accuracy.[52]

ASSESSMENT OF GROWTH AND DEVELOPMENT:

The assessment of bone age, skeletal maturity, and its comparison to chronological age are essential for diagnosing orthodontics and orthopedic conditions.

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Because this evaluation is time-consuming that may be affected by inter- and intra-rater inconsistency, the use of approaches that can automate it, like ML techniques, can be of immense value.[53]

Amasya H. et al. (2020)[54] developed an ANN to predict skeletal age. The developed ANN model performed close to, but not far better than, humans in CVM analysis. The repeatability and reproducibility of the ANN model were in the range of human observers.15 Guo et al. (2021)[55]concluded that deep learning systems, without human interference, can efficiently overcome restrictions of the manual methods in the classification of age depending on panoramic images. The CNN based program focused on low-density features round the teeth instead of using the dental morphological traits that humans use for age classification.[55]

Growth and development can be determined by staging cervical vertebrae, which can be predicted/classified using different AI algorithms.

Kök et al. (2019)[56]compared seven AI algorithms that are often used in the field of classification: Naive Bayes (NB), decision tree (Tree), K-nearest neighbours (k-NN), artificial neural networks (ANN), logistic regression (LR), random forest (RF), support vector machine (SVM), algorithms. They stated that k-NN and LR algorithms had the lowest accuracy values, whereas SVM-RF Tree NB algorithms had varied accuracy values, and ANN would be the most preferred algorithm for determining CVS.[56]

ASSESSMENT OF NEED FOR ORTHODONTIC TREATMENT:

Four studies were dedicated to assessing the need for orthodontic treatment and predicting treatment outcomes [57-60].

Thanathornwong [61] utilized the Bayesian network (BN) to assess the need for orthodontic treatment. It concluded that the results obtained by the decision support system were comparable with those suggested by expert orthodontists. Wang et al. [62] explored the function of an eye-tracking method to objectively evaluate orthodontic treatment needs and treatment outcomes from the lay perspective compared to conventional methods. They employed support vector machine methods and concluded that the eye-tracking device could accurately measure the effect of malocclusion on facial perception and the impact of orthodontic treatment on malocclusion from a lay perspective.

ASSESSMENT OF TREATMENT OUTCOME:

Predictions of treatment outcomes in class II class III patients have also been reported. Auconi et al. stated a system to predict outcomes in untreated class III patients.[63] Unsupervised learning was used to cluster patients as hyper mandibular, hyperdivergent, or balanced depending on cephalometric values. The system was applied then on a treated

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sample, where it disclosed that all of the unsuccessful cases belonged to either the hyper mandibular or the hyperdivergent cluster. He [64] also identified peculiarities of class II class III malocclusions and demonstrated that class II subjects exhibited few highly connected orthodontic features. In contrast, class III patients showed a more compact network categorized by strong co-occurrence of normal and abnormal clinical functional and radiological features. The study stated that AI network analysis could allow orthodontists to visually assess and anticipate the co-occurrence of auxological anomalies throughout individual craniofacial growth and perhaps localize reactive sites for a therapeutic approach to a malocclusion.

ALIGNERS:

Aligners can be printed using 3D technology scans to customize the orthodontic treatment. A data algorithm along with printed aligners is created which provides information regarding the tooth movement and the pressure requirement for desired tooth movement. This conjugation not only provides meticulous treatment; also, it lessens the chances of error and reduces the period required for management.[65]

DENTAL SEGMENTATION:

Dental segmentation is one of the critical steps in computer-assisted orthodontics; its accuracy is correlated to treatment outcome. This technique requires accurate positioning extraction of tooth shapes on

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the patient's digital dental cast or an intraoral scan. Through a CNN-based model for segmentation of tooth, identification achieved performance improvements compared to state-of-the-art general mesh segmentation for tooth segmentation and identification tasks.[66]

ORTHOGNATHIC SURGERY:

One of the significant areas researched includes the effect of orthognathic surgery on facial appearance and age perception [67,68]. The algorithms used in the studies stated that most patients' appearance improved with treatment (66.4%), resulting in a younger appearance of nearly one year, especially after a profile-altering surgery. In addition, comparable improvement was observed on facial attractiveness in 74.7% of patients, particularly after lower jaw surge and they concluded that AI might be considered to score facial attractive.

Choi et al. [69]expanded the use of ANNs to determine the diagnosis of orthognathic surgery in addition to extraction decision and their study results disclosed a 96% success rate for the decision of surgery/non-surgery, 91% success rate for detailed diagnosis of the type of surgery and extraction decision.

CLASSIFICATION OF SKELETAL PATTERNS:

One of the opening methods of using ANN in assessing growth occurred in 1998 when 43 children [untreated] were classified based on changes in size and

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shape.[70] Nino-Sandoval et al. utilized a support vector machine to classify skeletal patterns through Cranio maxillary variables yet attained only 74.51 % accuracy in the precise distinction of class II skeletal pattern from class III pattern and vice-versa .[71,72]

AI IN MAXILLARY EXPANSION:

Three studies focused on assessing maxillary constriction and maxillary canine impactions[73-75]. Chen et al. [75] developed a machine learning algorithm utilizing a Learning-based multi-source Integration framework for segmentation (LINKS) used with CBCT images to measure volumetric skeletal maxilla discrepancies, suggested palatal expansion might be advantageous for those with unilateral canine impaction, as underdevelopment of maxilla often accompanies canine impaction in early teen years.

AI IN CANINE IMPACTION:

A study [76] concluded that amongst learning machine systems tested to categorize data, the best performance was obtained by random forest system, with a total accuracy of 88.3% in predicting canine eruption. They performed measurements on 2D routinely executed radiographic images, found them independently correlated to canine impaction and exhibited reliable accuracy in predicting maxillary canine eruption. Bayesian network analysis [77]showed bilateral impaction was related to palatal impactions longer treatments; pre-treatment alpha-angle was an element for the duration of the orthodontic traction.

SELECTION OF ORTHOPAEDIC APPLIANCES:

One of the major challenges encountered by less experienced orthodontists is the selection of the apt treatment modality, appliance. Therefore, a system was developed to help orthodontists select the proper headgears [78]. Compared to the choices made by eight expert orthodontists, the system correctly identified the appropriate headgears 95.6% of the time.

AI - DENTAL EDUCATION:

Since its commencement in the 1980s, the arena of intelligent tutoring systems has come a long way. Both the systems, augmented reality and virtual reality, are used widely in the field of dental education to create conditions that simulate clinical work on patients and eliminate all the risks associated while training on a live patient.[79]With the recent integration of artificial intelligence in intelligent tutoring systems like in Unified Medical Language System (UMLS); there is a massive improvement in the quality of feedback that the pre-clinical virtual patient provides the students.[80,81] The interactive interphase allows the students to evaluate their work and compare it to the ideal, thus creating high-quality training environments. Many

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studies on the efficacy of these systems have indicated that students accomplish a competency-based skill level sooner than with traditional simulator units. [82-84]

MISCELLANEOUS APPLICATIONS:

Detection of activation pattern of tongue musculature and evaluation of effects of a different curing unit and light-tips on temperature increase during orthodontic bonding [85]

CURRENT RECOMMENDATIONS AND FUTURE PROSPECTIVES:

AI has transformed dentistry in the recent years. Studies show that these AI-powered automated systems performed exceptionally well in various scenarios. AI systems work in distinct extents of orthodontics. Orthodontists can use AI as an auxiliary tool to improve the accuracy of diagnosis and treatment planning, predict treatment results. In addition, automated systems can save time and improve the efficiency of clinicians.

Moreover, with deep learning techniques, it is possible to eliminate the bias related to human decision-making; conventional manual methods are likely to incorporate a relatively higher degree of intra- and interobserver errors due to this subjectivity, which can lead to a rise in the prediction error. AI could be a valuable tool to use in those procedures which need high precision and are more time-consuming, such as indirect bonding, precise Bolton Analysis, or wire bending, to increase the quality of our

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patients' treatments. There are orthodontic studies involving various applications of AI and ML over the past three decades.

Although the improvement of AI is an excellent help for orthodontic professionals, the final decisions on health matters will at all times be the clinicians' responsibility.

CHALLENGES OF AI:

Systems must be improved to protect patient confidentiality and privacy from integrating AI into clinical operations. Thus, personal data will have to be anonymized before considering broader distribution.[86]

AI systems are also linked with safety issues. The transparency of AI algorithms data is an important issue. The quality of predictions performed by AI systems relies quickly on the precision of annotations and labeling of the dataset employed in training. Poorly labeled data can lead to poor results.[87]Clinic-labelled datasets may be of inconsistent quality, thus limiting the efficacy of the resultant AI systems. Furthermore, health care professionals should possess a complete understanding of the decisions and predictions made by an AI system and the capability to defend them.[88] Interpretability of AI technology is a known problem. Significant advances are required before specific algorithms, such as neural networks, can make clinical diagnoses or treatment recommendations with complete transparency. These issues will remain to represent a considerable

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challenge to our legal system for the foreseeable future.[89]

CONCLUSION:

AI has immense potential to aid in the clinical decision-making process. It is crucial to plan treatments carefully to achieve predictable outcomes for patients in orthodontic treatments. Furthermore, ensuring that the best clinical decision is made before initiating irreversible procedures. Therefore, it is vital to ensure that AI is integrated safely and skilfully to assure that humans hold the ability to direct treatment and make informed decisions.

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