IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 23, Issue 8 Ser. 4 (August. 2024), PP 38-43
www.iosrjournals.org

Artificial Intelligence In Orthodontics- A Narrative Review

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Abstract
Orthodontics has changed dramatically due to the application of artificial intelligence (AI), which has revolutionized patient care, diagnosis, and treatment planning. This review examines the development of AI in orthodontics, highlighting its significant influence on a range of clinical areas. While machine learning was first based on symbolic AI, more recent developments have placed an emphasis on flexibility and adaptation, particularly in the field of orthodontics. Deep learning and AI algorithms have greatly improved patient outcomes, treatment planning, and diagnostic accuracy. Artificial Intelligence (AI) simplifies intricate operations, enhancing accuracy and productivity, such as automating cephalometric tracing and evaluating facial proportions. AI also helps with radiograph landmark identification, treatment outcome assessment, and tooth movement prediction. The classification of machine learning methods—supervised, unsupervised, and reinforcement learning—as well as their orthodontic applications are covered in detail in this paper. It assesses the benefits of AI, such as improved workflow speed and diagnostic accuracy, while recognizing issues with dataset biases, data privacy, and financial investment. In general, AI has the potential to transform the orthodontic profession by providing chances for enhanced accuracy, efficiency, and patient care. The full potential of AI in orthodontics requires ongoing study and ethical issues.

Keywords: *Artificial intelligence, Cephalometric tracing, Facial proportions, Machine learning, Orthodontic diagnosis and treatment.*

Date of Submission: 03-08-2024 Date of Acceptance: 13-08-2024

I. Introduction

The development of AI in dentistry now stands in stark contrast to the historical background of symbolic AI, which used human-readable algorithms. If-then sentences were the foundation of symbolic AI, which was popular up until the late 1980s and mimicked human cognition.[1] But the move to machine learning emphasizes adaptability, which is a fundamental change that is particularly noticeable in orthodontics.[1,2] These revolutionary developments highlight the necessity of investigating obstacles and potential routes for integrating AI in orthodontics.[3,4,5] Symbolic AI, also referred to as "good old-fashioned AI" (GOFAI), solved problems through the application of predetermined rules, in contrast to the machine learning technique of today. Whereas symbolic AI mimicked cognitive processes of humans, contemporary AI deviates by employing models that have been trained on data to increase flexibility.[1] This change, which is more noticeable in the field of orthodontics, emphasizes how AI is developing and how important it is to carefully consider how to incorporate it into orthodontic procedures.[1,2] To properly utilize AI's promise, this kind of research is essential.[3,4,5]

II. Ai Transformations In Orthodontics

The swift advancement of artificial intelligence (AI) technology, namely in orthodontics, has ushered in a novel era in dentistry by revolutionizing methods of diagnosis and treatment. Significant progress in AI algorithms and deep learning has been demonstrated recently, with the potential to improve diagnostic accuracy and treatment planning.[2,4,6] These technology advancements not only solve long-standing problems with patient assessment and documentation, but they also open the door to automated solutions that use AI and machine learning to minimize diagnostic variations and reduce physician burden.[2,7] Artificial Intelligence (AI) in orthodontics goes beyond traditional diagnostic imaging to include face proportion analysis, cephalometrics, growth and development evaluation, and extraction decision-making.[2,4,8] More integration with electronic health data and ongoing improvements in AI algorithms should lead to increased efficiency and accuracy.

III. Classification Of Machine Learning8

In machine learning (ML), algorithms are classified according to the kind of learning and the desired result. There are three main categories:

a) ***Supervised learning:*** "Supervised learning" is a procedure used in orthodontic decision-making, such as extraction planning, where predictions or classifications are guided by known outcomes. Discrete or continuous data feeds the system, which modifies itself dependent on input. The dependent variables in the training dataset stand in for known results. Orthodontics uses supervised learning, incorporating a variety of metrics from clinical examinations, casts, and radiographs to guide the training of neural networks.

b) ***Unsupervised learning:*** In orthodontics, unsupervised learning arranges data without labels, exposing patterns or connections. It helps with jobs that do not have set results, making analyses and classifications easier. These are important for comprehending complicated datasets used in orthodontic research and treatment.

c) ***Reinforcement learning:*** Reinforcement learning uses a feedback signal to reward the system, just like supervised learning does, but its goal is system improvement rather than augmentation. In this case, the system learns to improve its performance through repeated trial and error as it has no prior knowledge of the ambient behaviour. By using reinforcement learning to learn from mistakes and gradually modify tactics, orthodontic systems and procedures can be made more efficient.

IV. Ai Use In Orthodontics

In the discipline of orthodontics, artificial intelligence (AI) has shown itself to be a revolutionary force, transforming diagnosis, treatment planning, patient care, and more. Modern orthodontic procedures have been greatly advanced using AI technologies, which have given orthodontists strong instruments to improve accuracy and efficiency. Previous researches have revealed the various uses of AI in various aspects of Orthodontic practices as shown in Table 1.

AI use in identification of landmarks in radiographs: Orthodontic diagnosis and treatment planning have been improved by the application of artificial intelligence (AI) to recognize anatomical landmarks on radiographs. To expedite cephalometric analysis, Montúfar et al. (2018) presented a hybrid method for automatic landmark annotation in cephalometry that combines AI algorithms with dynamic shape models.[9] In a similar vein, Thurzo et al. (2021) created a clever application that tracks patients' clinical performance using telemedicine,[10] demonstrating how AI could increase landmark identification accuracy and efficiency while also improving orthodontic outcomes. Interest has been shown in the application of AI to TMJ diseases. Eye tracking was used by Wang et al. (2016) to objectively assess orthodontic treatment by laypeople.[11] Furthermore, by developing a deep learning model for automated skeletal bone age assessment, Spampinato et al. (2017) illustrated the potential of AI in skeletal structure analysis.[12] This research demonstrate how versatile AI is in the assessment of TMJ disorders, providing novel ways to diagnosis and treatment. AI is useful in assessing the impact of treatment. In order to provide useful information on treatment success metrics, Patcas et al. (2019) employed AI to evaluate the effect of orthognathic treatment on facial aesthetics and estimated age.[13] Additionally, Montúfar et al. (2018) created an AI-based automatic 3D cephalometric landmarking system to make it easier to examine the effects of therapy on craniofacial traits.[14] These studies highlight how AI, by providing objective treatment success measures, can improve orthodontic treatment planning and expedite evaluation.

In diagnosis and treatment planning: With improvements in accuracy and efficiency, the area of orthodontic diagnosis and treatment planning is changing as a result of the integration of artificial intelligence (AI).[15-,19] Through computer vision and machine learning (ML), AI automates complex patient evaluations,[2,16] giving orthodontists access to extensive cephalometric analytic tools.[2,4,15,17] By accurately detecting malocclusions and orthodontic anomalies, computer vision improves diagnostic accuracy,[2] and natural language processing (NLP) draws conclusions from research articles and clinical notes.[16,18] ML, CV, and NLP combined simplify patient diagnosis and treatment planning,[2,4,16] and they also apply to cephalometrics, face proportion analysis, and growth evaluation.[2,4,8] Continuous improvement of AI algorithms and integration of electronic health data promise improved accuracy and productivity in orthodontic clinics,[4,5] transforming patient care.[2,4,16] This modernization represents a major advancement in orthodontic procedures and could improve patient outcomes.

In Cephalometric tracing: Machine Learning (ML) techniques, which automate complicated operations, have enabled Artificial Intelligence (AI) to revolutionize cephalometrics in orthodontics.[18,20,21,22,23] After being trained on enormous datasets, machine learning algorithms find patterns and correlations in cephalometric photos, identifying landmarks and anatomical details that are vital for diagnosis. Reducing human error by automated landmark recognition ensures accurate measurements and speeds up tracing. AI-driven computer vision improves precision by identifying complicated anatomical structures through the

analysis of face and dental pictures. AI systems ensure their relevance and efficiency in changing orthodontic practices by continuously learning and adapting, increasing precision and efficacy over time.[2,4,5,18,21,22,23]

In facial proportions: By resolving the shortcomings of traditional methodologies, artificial intelligence (AI) is revolutionizing the assessment of facial proportions.[13.20,24,25,26] AI uses optical facial recognition for complex cognitive processes, unlike traditional evaluations that rely on profile photographs and lateral cephalometric radiographs.[4,5,13,18,21,23] By overcoming dimensionality limitations and extending evaluation beyond linear measurements, artificial intelligence (AI) makes it possible to evaluate angular measures and ratios.[2,22,27,28,29] AI provides objective insights into facial aesthetics by capturing different criteria of beauty.[13,16,23,30,31,32] This can have an impact on surgical and orthodontic operations by offering a more nuanced knowledge of attractiveness.

Estimation of growth and development: Assessing growth and development markers including menarche, skeletal maturation, height gain, and chronologic age is essential for accurate scheduling in orthodontic therapy.[33] Skeletal maturation markers were previously identified using radiography of the hands and wrists.[34] Age estimation has been transformed by recent advances in deep learning and AI, which have automated the examination of hand and wrist radiographs. Deep learning allows AI systems to evaluate skeletal maturity more accurately than experienced radiologists by using big datasets.[35] According to Kök et al. (2019), out of seven AI techniques for assessing cervical vertebral maturity, the Artificial Neural Networks (ANN) method performed best.[36] Artificial Intelligence (AI) greatly improves the accuracy and efficiency of assessing growth and skeletal maturity markers in orthodontics by modeling the human nervous system.

Use of AI in extraction procedure and its prediction: In order to determine whether extraction is necessary for malocclusion patients between the ages of 11 and 15, Xie et al. created an expert system (ES) using artificial neural networks (ANN) that achieved 80% accuracy.[25] Li et al. estimated anchorage needs with 83% accuracy,[22] while Jung et al. used ANN to forecast extraction patterns with 84% accuracy.[37] Their ANN-based approach, which considered factors like crowding and Spee's curve, achieved 94% accuracy for treatment plans, including extraction and anchoring patterns. These artificial intelligence (AI) technologies simulate human decision-making, enabling 80–90% accuracy in extraction decisions and offering insightful counsel at crucial planning stages to orthodontists, particularly those with less expertise. Artificial intelligence (AI) algorithms improve orthodontic extraction decision-making by considering soft tissue properties, patient concerns, and the linkages between the teeth and skeleton.

Management of impacted canines: Precision is necessary for effective therapeutic intervention for affected canines, which is influenced by case complexity and displacement. Based on radiographic data, the Bayesian Network (BN), a combination of statistical and artificial intelligence techniques, accurately assesses impacted maxillary canines. Unilateral impaction scenarios benefit from the differentiation of maxillary variants using the Learning-based multisource Integration framework for Segmentation (LINKS).[38] Personalized treatment interventions are advanced by this combination of statistical and AI methodologies, which improves diagnostic accuracy and customizes care for affected canines.

AI use in TMJ disorders: Artificial intelligence (AI) technology integration is beneficial for the assessment of temporomandibular joint (TMJ) diseases. In order to objectively assess orthodontic treatment from a lay perspective and provide insight into patient perceptions and preferences, Wang et al. (2016) carried out an eye-tracking study.[11] Furthermore, demonstrating the potential of AI in skeletal structure analysis, Spampinato et al. (2017) created a deep learning model for automated skeletal bone age evaluation in X-ray images.[12] These developments highlight the adaptability of AI in the evaluation of TMJ disorders, providing creative approaches to diagnosis and treatment strategy development.

AI use in appliance selection: Treatment planning is important yet difficult, especially for new practitioners dealing with complex cases. For Class II patients, this includes choosing the appropriate headgear. The advanced fuzzy logic-based system incorporates several input variables, including as overjet, overbite, and mandibular plane angle, providing a more subtle method of making decisions. It classifies headgear into low, medium, and high pull kinds using three fuzzy logic clusters, and orthodontists report an astounding 95.6% average satisfaction rating.[39] This method makes choosing headgear easier while improving complexity and flexibility to handle a range of patient presentations. Orthodontic professionals acquire a priceless tool that simplifies decision-making and addresses a range of clinical difficulties.[35]

Assessing treatment outcomes and appliance fabrication: By expressing dependent variables as correlated independent variables, multi-regression models investigate intricate correlations between parameters and treatment outcomes in dentistry and medicine. But they fail to account for all possible outcomes and presume linear relationships.[40] Because artificial neural networks can capture complex non-linear correlations, they are an excellent tool for modeling orthodontic therapy outcomes. This makes them ideal for modeling treatment outcomes for patients with Class II and III malocclusions.[40] The development of digital clear aligner devices has made it easier to simulate orthodontic treatment, since manual methods used to make this procedure more difficult. Kesling's hypothesis of gradual tooth movement was revolutionized in 1997 with the

introduction of the Invisalign system, which used 3D technology to digitally simulate incremental alterations.[41] By using statistical analysis and input data, artificial intelligence (AI) software predicts treatment outcomes and tooth movement, which helps with the creation of different orthodontic appliances.[42] Although previous research, Faltin et al., (2003)[41] has demonstrated positive correlations between virtual and clinical outcomes with ClinCheck, the Invisalign scheduling application, more recent studies have brought attention to challenges, particularly with complex procedures and extraction therapy simulation. ClinCheck shows potential for less complex treatment regimens, despite its limits in precisely predicting occlusion in complex settings.[43] As AI in orthodontics develops further, it influences treatment planning by solving present issues and providing opportunities for the future.

AI use in Tele-health system: Artificial intelligence (AI) was included into orthodontic telemedicine systems by Thurzo, Kurilová, and Varga (2021) in order to improve clinical results and patient education. Their research presented a sophisticated remote patient monitoring program that provides tailored advice in lieu of in-person consultations. Real-time monitoring, early issue detection, and customized interventions were made possible by the AI-powered telehealth system, which increased patient happiness and compliance. It also marked a major advancement in orthodontic care by enabling medical professionals to effectively manage a greater number of patients while creating personalized treatment regimens.[10] For improving remote clinical performance and patient outcomes, AI integration into telehealth systems is essential.

V. Advantages Of Ai Use In Orthodontics

Modern orthodontics has made artificial intelligence (AI) a cornerstone as it greatly enhances diagnostic and therapeutic processes. By using AI algorithms, orthodontists may now effectively examine large datasets that include patient records, pictures, and treatment results.[5,22,44] This ability to analyze data makes it easier to create highly customized treatment regimens, which raises the bar for patient care. Artificial intelligence (AI) technologies, including machine learning and neural networks,[3,21,23] are vital in improving diagnostic accuracy because they can identify complex patterns and abnormalities in 3D imaging and cephalometric analysis. AI also improves orthodontic workflow efficiency by automating tedious activities. In addition to saving time, this automation frees up orthodontic specialists to focus on complex situations, which improves patient results overall.

VI. Disadvantages Of Ai Use In Orthodontics

There are new issues with the use of AI in orthodontics that need to be carefully considered. The use of large datasets to train AI models raises several important questions, as it may introduce biases and limit the applicability of the algorithms to different patient populations.[1,27,29] The handling of sensitive patient data by AI systems raises privacy and security concerns, necessitating strong safeguards to maintain confidentiality and adherence to data protection laws. Smaller orthodontic clinics may find it difficult to adopt AI technology due to the initial large financial outlay that is necessary.[8,15,32] As AI develops further, it will be necessary to provide orthodontic experts with ongoing training so they can use new technologies efficiently. In the ever-changing field of orthodontics, ethical issues pertaining to patient care, informed consent, and data privacy demand constant attention.[4,18]

VII. Conclusion

The science of orthodontics is about to undergo a paradigm shift with the introduction of Artificial Intelligence (AI), which has great promise for improving treatment planning and diagnostic accuracy. The large body of literature demonstrates how AI tools like machine learning and neural networks, which analyze enormous datasets and identify complex patterns in patient records and imaging, significantly improve personalized orthodontic care. The persistent pattern shows an increasing dependence on artificial intelligence (AI)-driven solutions, which streamline orthodontic workflows and free up practitioners to work on complex patients. The pattern shows a progressively favorable influence, despite obstacles including initial financial investments and privacy concerns. Artificial intelligence (AI) seems to have a significant role in the future of orthodontics, with the promise to provide more accurate, patient-centered, and efficient treatment plans. For orthodontic professionals to fully utilize AI, ongoing education is essential. The future of orthodontics and artificial intelligence (AI) together has enormous potential to improve treatment outcomes and change the orthodontic care environment.

Table 1: Previous studies and research works depicting the use of AI in various Orthodontic practices

Author/Year	USE OF AI IN ORTHODONTICS
Hägg U, Taranger J. 1980[34]	Evaluation of Voice Change and Menarche as Markers of the Pubertal Growth Spurt in Orthodontics
Xie X et al. 2010[25]	Artificial Neural Network-Based Decision Support System to Determine Whether Extractions Are Required for Orthodontic

	Treatment
Yagi M et al. 2010[18]	Orthodontic Treatment Planning Decision-Making System Based on the Direct Application of Expertise Knowledge
Murata S et al. 2017[19]	Creation of a Completely Automated Diagnostic System for Dental Orthodontic Therapy
Patcas R, et al. 2019[13]	Using AI to Evaluate the Effect of Orthognathic Therapy on Estimated Age and Facial Attractiveness
Li P et al. 2019[22]	Scheduling Orthodontic Treatment Using Artificial Neural Networks
Subramanian AK, et al. 2022[20]	Artificial Intelligence for Orthodontic Cephalometric Analysis
Nanda SB, et al. 2015[17]	Artificial Intelligence Modeling and Analysis to Forecast Changes in Lip Curvature After Orthodontic Therapy
Jung SK et al. 2016[37]	Novel Method for the Neural Network Machine Learning-Based Extractions Diagnosis
Wang X et al. 2016[11]	An Eye-Tracking Study as an Objective Approach to Assessing Orthodontic Treatment from the Lay Perspective
Spampinato et al. 2017[12]	Automated Skeletal Bone Age Determination in X-ray Images via Deep Learning
Montúfar J et al. 2018[9]	In related projections, automatic three-dimensional cephalometric landmarking using active shape models
Kök H et al. 2019[36]	Application and Evaluation of AI Algorithms for Orthodontic Growth and Development Assessment by Cervical Vertebral Stages
Kunz F et al. 2020[2]	Fully Convolutional Neural Network-Based Automated Cephalometric Analysis
Iglovikov VI et al. 2018[45]	Bone Age Determination in Pediatrics Through Deep Convolutional Neural Networks
Larson DB et al. 2018[46]	Applicability of a Deep-Learning Neural Network Model for Pediatric Hand Radiographs in Evaluating Skeletal Maturity
Nino-Sandoval TC et al. 2016[47]	Utilizing Craniomaxillary Variables in an Automatic Method for Classifying Skeletal Patterns in a Colombian Population; Automated Learning Techniques for Predicting Mandibular Morphology in Skeletal Classes I, II, and III
Lee H et al. 2017[48]	Fully Autonomous Deep Learning System for Determining Bone Age

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