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REVIEW ARTICLE

ROLE OF ARTIFICIAL INTELLIGENCE (AI) IN ORTHODONTIC DIAGNOSIS AND TREATMENT PLANNING: A SYSTEMATIC REVIEW

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Abstract

Background: Orthodontic diagnosis and treatment planning are undergoing a revolution thanks to artificial intelligence (AI), which provides innovative answers to age-old problems. The quick development of AI technology offers fascinating prospects to improve orthodontic patient care.

Aim: To evaluate the current state and effectiveness of AI technology in orthodontic diagnosis, treatment planning, and clinical decision-making.

Methodology: Using PRISMA principles as a guide, a comprehensive search approach was used to find pertinent publications published between 2017 and 2023. Using pre-established search phrases, databases such as PubMed, Embase, Scopus, Web of Science, and Google Scholar were examined. The selection criteria were limited to peer-reviewed English research articles that examined the use of artificial intelligence (AI) in orthodontics, with a particular focus on diagnosis, treatment planning, and clinical decision-making. Three reviewers carried out the data extraction and quality assessment separately, guaranteeing thorough coverage and methodological rigor. The usefulness and possible drawbacks of artificial intelligence (AI) in orthodontic practice were evaluated by analyzing the synthesized data from several studies.

Results: 11 pertinent articles demonstrating the use of AI algorithms in orthodontic diagnosis and treatment planning were found during the screening process. This research showed how effective AI is at enhancing treatment outcomes, streamlining workflow procedures, and increasing diagnostic accuracy. Numerous AI applications were examined, demonstrating their revolutionary influence on orthodontic care. These included treatment result prediction, virtual treatment simulation, patient monitoring, and occlusal analysis.

Conclusion: Future research should focus on developing stringent protocols and interdisciplinary collaboration in order to ensure optimal AI integration and optimize its benefits in orthodontic treatment. Conclusively, this methodical examination provides noteworthy perspectives on the innovative function of artificial intelligence (AI) in orthodontic therapy, potentially leading to enhanced patient results and professional judgment.

Key-words: *Cephalometrics; Deep learning; Machine learning; Neural networks; Predictive modeling*

Introduction

Artificial Intelligence (AI) technology is evolving at a rapid pace, significantly changing the dental scene. The days of strict, human-readable algorithms and if-then statements that typified symbolic AI are long gone. Rather, adaptability is emphasized by the paradigm shift towards machine learning, which is a significant transformation that is especially evident in the field of orthodontics.^{1,2}

Historically, symbolic AI also lovingly called "good old-fashioned AI" or "GOFAI", used predefined rules to solve issues in a manner like how humans think. Modern AI, however, deviates from this strategy by using data-trained models to improve performance and adaptability.¹ This change, which is particularly noticeable in the field of orthodontics, highlights the dynamic character of AI and the importance of carefully navigating its integration into orthodontic procedures.^{1,2}

The application of AI to dentistry more especially, orthodontics offers an engrossing tale of promise and innovation. With previously unheard-of levels of accuracy and efficiency, artificial intelligence (AI) algorithms and deep learning approaches have the potential to completely transform the diagnosis and treatment of orthodontic disorders.^{2,3,4} These revolutionary developments not only solve long-standing issues with patient assessment and documentation, but they also open the door to automated solutions that reduce variation in diagnosis and ease the workload of doctors.^{2,5}

Diverse applications of SI in Orthodontic practice

Beyond traditional diagnostic imaging, artificial intelligence (AI) is being incorporated into orthodontic practice in a variety of cutting-edge ways that are revolutionizing the industry.

Treatment outcome prediction: The results of orthodontic interventions can be predicted by AI algorithms by analyzing patient data, such as demographics, dental records, and treatment plans. Through the consideration of multiple variables, including tooth movement patterns, length of treatment, and patient characteristics, these predictive models enable orthodontists to foresee treatment obstacles and tailor treatment plans for specific patients.⁶ Artificial neural network modeling was used by Xie et al. (2010) to enhance decision-making processes when determining whether extractions are required before orthodontic treatment.⁷ Li et al. (2019) developed a neural network to predict orthodontic treatment plans, aiding in the decision-making process.⁸

Virtual treatment simulation: Before starting therapy, orthodontists can visualize and model the expected results of orthodontic treatment using AI-driven virtual treatment simulation systems. These tools facilitate informed patient discussions and shared decision-making by creating digital models of patients' dentition and modeling orthodontic procedures. This provides useful insights into treatment feasibility, aesthetics, and functional

results.⁹ The usefulness of virtual treatment simulation in revealing information on treatment viability, aesthetics, and functional outcomes was emphasized by Sarveshwaran V et al. (2023).¹⁰ The application of AI in orthognathic surgical planning, which has a high success rate in predicting surgical outcomes, was covered by Choi et al. (2019).¹¹

Patient monitoring and compliance tracking:

AI-driven monitoring systems evaluate patient adherence to orthodontic treatment guidelines by utilizing wearable sensors, smartphone apps, and cloud-based analytics. Palanivel et al. (2021) discussed methods for orthodontists to remotely track patient compliance and discover possible obstacles to treatment success.¹² Jung SK et al. (2016) found that treatment compliance tracking significantly increased by using neural network machine learning to enhance patient monitoring.¹³ Additionally, Dipalma et al. (2023) demonstrated the utilization of AI-powered monitoring systems to evaluate patient adherence to treatment parameters to enhance patient compliance and treatment outcomes.¹⁴

Occlusal analysis and bite force measurement:

AI-based occlusal analysis technologies measure biting forces, identify malocclusions, and evaluate occlusal connections using digital imagery and machine learning algorithms. AI can assist in analyzing intraoral scans or photos to gather quantitative data on occlusal features and help to detect occlusal issues and develop appropriate treatments.¹⁵ Spampinato C et al. (2017) employed deep learning to automatically assess skeletal bone age, enhancing the precision of occlusal analysis and evaluations of treatment outcomes.¹⁶ Additionally, Asiri et al. (2020) talked about the ways in which AI could improve occlusal analysis through precise bite force measurements and evaluation of occlusal relationships.⁵

Predictive risk assessment for Orthodontic complications:

Artificial intelligence algorithms have the capability to examine patient-specific risk variables and past treatment records in order to forecast the probability of orthodontic difficulties, which may include periodontal issues, temporomandibular joint abnormalities, or root resorption. Igloukov V et al. (2017) showcased the

application of deep convolutional neural networks in evaluating complications' risk, allowing for tailored treatment plans to reduce adverse impacts.¹⁷ Larson DB et al. (2018) introduced a neural network model for assessing skeletal maturity using deep learning, emphasizing its ability to forecast issues and improve both patient safety and satisfaction.¹⁸ AI was considered to be employed to evaluate the process by which orthognathic surgery affects facial beauty and aging, supplying quantitative assessments for anticipating surgical results.¹⁹

Significance of AI in Orthodontic diagnosis and treatment planning

For orthodontic professionals and patients alike, the application of artificial intelligence (AI) in diagnostic and treatment planning is extremely important. Artificial intelligence (AI) technologies leverage sophisticated computational algorithms and data-driven insights to provide numerous important benefits that improve the effectiveness, efficiency, and efficiency of orthodontic care. Above all, the early identification and accurate characterization of orthodontic anomalies from malocclusions and dental irregularities to skeletal discrepancies are made easier by AI-enabled diagnostic tools. Orthodontists may now diagnose issues with more sensitivity and specificity than they could with just traditional approaches thanks to artificial intelligence (AI) technologies that use automated image analysis and pattern recognition to detect minute deviations from ideal occlusal relationships. Orthodontists can create personalized treatment plans that are based on the anatomical characteristics, therapeutic goals, and treatment preferences of each patient with the use of AI-driven treatment planning tools. Artificial intelligence (AI) systems can forecast therapy trajectories, provide individualized treatment recommendations, and optimize treatment plans for maximum efficacy and efficiency by examining large databases of past treatment outcomes and clinical factors. AI technology integration improves interdisciplinary communication among dental professionals, decreases diagnostic variability, and optimizes workflow procedures in orthodontic practice. Artificial intelligence (AI) systems enable orthodontists to devote more time and resources to patient care, education, and clinical decision-making

by automating repetitive tasks like cephalometric analysis, model superimposition, and treatment outcome prediction. This increases overall practice productivity and patient satisfaction. AI-powered diagnostic and treatment planning technologies help patients and orthodontists communicate better and make joint decisions, which promotes a cooperative therapeutic relationship based on openness, mutual respect, and understanding.^{2,3,20,21} AI technologies enable patients to actively engage in their orthodontic journey, make educated treatment decisions, and see the possible advantages of suggested interventions through interactive treatment simulations, virtual outcome previews, and patient-centric treatment discussions.

Therefore, the use of AI in orthodontic diagnosis and treatment planning signifies a revolutionary advancement in the provision of individualized, patient-centered, and evidence-based orthodontic care. Orthodontists can improve treatment outcomes, shorten treatment times, and increase patient satisfaction by utilizing AI algorithms' predictive power and computational analytics' accuracy. This will raise the bar for orthodontic practice and enhance the lives of orthodontic patients everywhere. The main aim of this systematic review was to assess the current state and performance of artificial intelligence technology in orthodontic diagnosis, treatment planning, and clinical decision-making.

Methodology

Research question: This systematic review aims to assess the use of artificial intelligence (AI) technology in orthodontic diagnosis, treatment planning, and clinical decision-making, as well as its extent and effectiveness.

Timeline of the study: 2017 to 2023 (7 years)

Search strategy: To find pertinent studies, a thorough search method was created wherein 334 articles were searched in total. To maintain reproducibility and transparency, the search method for this systematic review followed the Preferred

Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria (Figure 1). To find all pertinent research, a thorough search was carried out using several computerized databases, augmented by hand searches of reference lists and amongst them only 11 relevant articles were included in the present review.

Databases searched and key words:

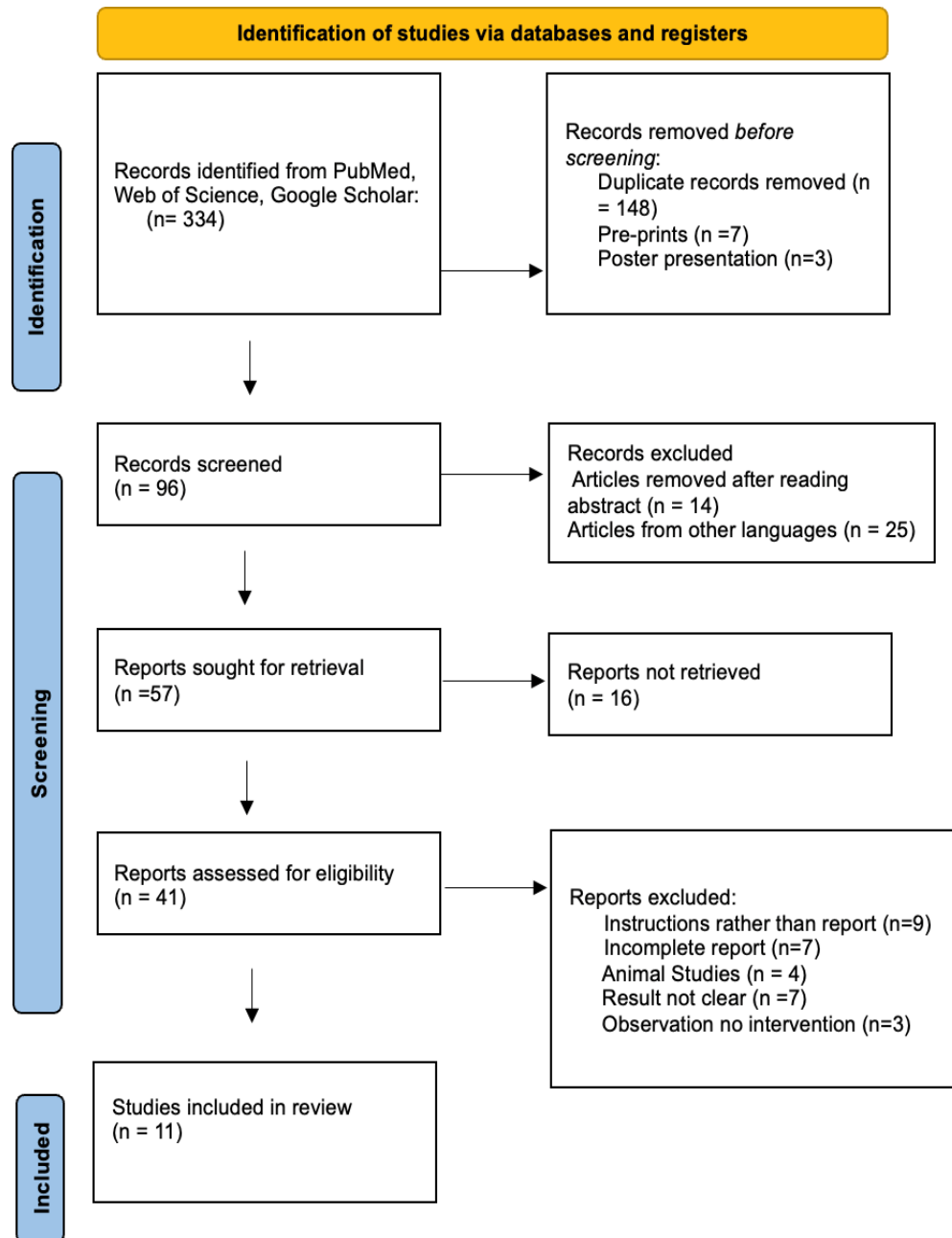
PubMed/MEDLINE, Embase, Scopus, Web of Science, and Google Scholar were among the databases that were searched. Free-text keywords and Medical Subject Headings (MeSH) terms were combined in the search strategy. The phrases "diagnosis," "treatment planning," "artificial intelligence," "orthodontia," and "clinical decision-making" were important. To optimize the retrieval of relevant research, key terms pertaining to "artificial intelligence", "orthodontics", "diagnosis", "treatment planning", and "clinical decision-making" were utilized. The search strategy's specific keywords included "dental orthopedics" OR "orthodontics" AND "artificial intelligence" OR "machine learning") AND "diagnosis" OR "diagnostic imaging" OR "computer-aided diagnosis") AND "treatment planning" OR "treatment outcome" OR "clinical decision-making" were all included (Table 1). To guarantee thorough coverage, these keywords were modified to fit the syntax and search features of each database. Boolean operators (AND, OR) and truncation were added to the search technique to help expand or contract the search area as needed. To ensure relevance and currency, the search was restricted to research published in English within a given timeframe. Throughout the search process, study characteristics including the study design, participant demographics, intervention specifics, outcome measures, and duration of follow-up were recorded. The screening, selection, and synthesis of relevant studies was made easier with the help of this information. Overall, a thorough evidence foundation for the systematic review was provided by the methodically planned and carried out search strategy, which found all pertinent literature on the use of AI in orthodontic diagnosis, treatment planning, and clinical decision-making.

Table 1. Electronic databases searched and keywords used

Database	Keywords
PubMed/MEDLINE	("dental orthopedics" OR "orthodontics") AND ("artificial intelligence" OR "AI" OR "machine learning" OR "deep learning") AND ("diagnosis" OR "diagnostic imaging" OR "computer-aided diagnosis" OR "radiographic imaging") AND ("treatment planning" OR "treatment outcome" OR "clinical decision-making" OR "neural network" OR "radiographic imaging" OR "diagnostic tool")
Embase	("orthodontia" OR "orthodontics") AND ("artificial intelligence" OR "AI" OR "machine learning" OR "neural networks" OR "predictive modeling") AND ("orthodontic diagnosis" OR "image analysis" OR "diagnostic procedures") AND ("treatment strategies" OR "treatment planning" OR "outcome prediction" OR "clinical decisions" OR "decision support systems" OR "neural network")
Scopus	("dental orthopedics" OR "orthodontics") AND ("artificial intelligence" OR "AI" OR "machine learning" OR "deep learning") AND ("diagnosis" OR "diagnostic imaging" OR "computer-aided diagnosis" OR "radiographic imaging") AND ("treatment planning" OR "treatment outcome" OR "clinical decision-making")
Web of Science	("orthodontics" OR "dental orthopedics") AND ("artificial intelligence" OR "AI" OR "machine learning" OR "deep learning" OR "neural networks") AND ("diagnosis" OR "diagnostic imaging" OR "computer-aided diagnosis" OR "radiographic imaging") AND ("treatment planning" OR "treatment outcome" OR "clinical decision-making" OR "predictive modeling")
Google Scholar	("orthodontic AI" OR "AI in orthodontics" OR "machine learning applications in orthodontics") AND ("orthodontic diagnosis" OR "diagnostic tools" OR "computer-aided diagnosis") AND ("treatment planning" OR "treatment outcomes" OR "clinical decision-making" OR "predictive risk assessment")

Selection criteria

- **Inclusion criteria:**
 - Research articles published in journals with peer review.
 - Research concentrating on the use of AI in clinical decision-making, treatment planning, or orthodontic diagnosis.
 - Research using human subjects.
 - Written research in English.
 - Research that was released within the specified timeframe.
- **Exclusion criteria:**
 - Research that was not pertinent to the inquiry at hand.
 - Studies for which the entire text was not available.
 - Research that only looks at in vitro tests or animal models.
 - Research not composed in English.



Data extraction, synthesis and quality assessment: All three reviewers, GM MC, and MMM, were instrumental in getting relevant data from the chosen

papers throughout the data extraction stage. Out of a total of 334 articles, only 11 were included in the present systematic review (Table 2).

***Table 2. Studies included in the present review to depict the use of AI in Orthodontic diagnosis and treatment planning**

Author/ year	Study design	Materials and methodology	Use of AI in Orthodontic diagnosis and treatment planning	Conclusion or inference of the study
Lee et al., 2017 ²²	Retrospective observational study	The study developed a fully automated deep learning system for orthodontic diagnosis and treatment planning, focusing on bone age assessment (BAA) using hand and wrist radiographs. The system standardized images, performed automated BAA using a fine-tuned convolutional neural network (CNN), and generated structured radiology reports.	AI was employed to automate the detection and segmentation of hand and wrist structures, standardize radiographic images, perform automated BAA with high accuracy, and generate structured reports for radiologists.	The study demonstrated the feasibility and efficacy of a fully automated AI system for orthodontic diagnosis, achieving high accuracy in BAA and streamlining workflow processes. The system's ability to reduce interobserver variability and provide standardized reports enhances diagnostic consistency and efficiency in clinical practice.
Spampinato et al., 2017 ¹⁶	Experimental	The study proposes and tests several deep learning approaches for automated skeletal bone age assessment using X-ray images of the left hand. The research is conducted by the Pattern Recognition and Computer Vision (PeRCeiVe) Lab at the University of Catania, with contributions from the Computer Science Department at the University of Torino and the Department of Orthodontics at the University of Catania	he study investigates the application of Convolutional Neural Network (CNN) approaches, including off-the-shelf CNNs and a novel network called BoNet, to automatically assess skeletal bone age. It represents the first work in this field to be tested on a public dataset covering all age ranges, races, and genders, with the source code available for further research.	The study demonstrates state-of-the-art performance in automated skeletal bone age assessment, with an average discrepancy of about 0.8 years compared to manual evaluation. It provides a comprehensive baseline for future research in the field and aims to address broader questions about deep learning in medical imaging.
Montúfar et al., 2018 ²⁰	Experimental	The study employs a method to automatically locate cephalometric landmarks on 3-dimensional cone-beam computed tomography (CBCT) volumes using an active shape model.	The researchers imported and processed 24 random CBCT scans into Matlab, creating orthogonal coronal and sagittal projections. Two trained active shape models were utilized to locate cephalometric landmarks on each projection, and 18 tridimensional landmarks were identified on CBCT volume representations by relating projections.	The proposed algorithm for automatic 3D landmarking on CBCT volumes appears to be useful for 3D cephalometric analysis. The study achieved a mean error of 3.64 mm in landmark localization, with the highest errors observed in the porion and sella regions due to low volume definition. The research suggests that a fast 2-dimensional landmark search can aid in 3D localization, potentially saving computational time compared to full-volume analysis. Additionally, using CBCT for cephalometry eliminates distortion in projections and allows for the management

				of full structure information of a virtual patient on a personal computer.
Iglovikov et al., 2017 ¹⁷	Experimental	The study describes a fully automated deep learning approach for bone age assessment using data from the Pediatric Bone Age Challenge organized by the Radiological Society of North America. The dataset comprises radiological images of left hands labeled with bone age and patient sex.	The researchers utilize various deep neural network architectures trained end-to-end, using both whole hand images and specific hand parts for training and prediction. This approach allows for the assessment of the importance of specific hand bones in bone age analysis.	The study demonstrates superior performance of the proposed method in bone age assessment compared to other common methods. The approach achieves accurate bone age estimation, outperforming existing automated models. Moreover, the study evaluates different zones of the hand for bone age assessment, finding that assessment can be done using part of the radiogram with a slight increase in error compared to using the whole hand. The findings suggest the potential for the development of state-of-the-art bone assessment software systems, which could aid clinicians in making accurate bone age assessments in real time.
Larson et al., 2018 ¹⁸	Comparative analysis	The researchers obtained 14,036 clinical hand radiographs and corresponding reports from two children's hospitals to train and validate the model. A total of 200 examinations were used as the first test set, where the bone age estimates from the clinical report and three additional human reviewers were considered as the reference standard. Model performance was assessed by comparing the root mean square (RMS) and mean absolute difference (MAD) between the model estimates and the reference standard. A second test set, consisting of 1377 examinations from the Digital Hand Atlas, was used to compare the model's performance with that of an existing automated model.	The deep-learning convolutional neural network model was used to estimate skeletal maturity by analyzing hand radiographs. It leveraged AI techniques to provide accurate bone age estimates, similar to those of expert radiologists and existing automated models.	The study concludes that the deep-learning convolutional neural network model can estimate skeletal maturity with accuracy comparable to that of expert radiologists and existing automated models. This suggests the potential utility of AI in orthodontic diagnosis and treatment planning, particularly in bone age assessment.
Patcas et al., 2019 ¹⁹	Observational study	This observational study collected pre- and post-treatment photographs of 146 consecutive orthognathic patients (totaling 2164 images) to assess the impact of	Artificial intelligence, in the form of convolutional neural networks, was employed to objectively assess the impact of orthognathic treatment on facial attractiveness and	The study demonstrates the potential of artificial intelligence to objectively evaluate the outcomes of orthognathic treatment in terms of facial attractiveness and apparent

		<p>orthognathic treatment on facial attractiveness and age appearance. Each image was annotated with patient-related data, including age, sex, malocclusion, and type of surgery performed. Facial attractiveness (scored on a scale of 0-100) and apparent age were determined using convolutional neural networks trained on a large dataset of images (>0.5 million for age estimation and >17 million ratings for attractiveness). Statistical analyses were conducted to compare pre- and post-treatment appearances and attractiveness, both overall and in subgroups based on sex, malocclusion, and type of surgery.</p>	<p>apparent age. The AI algorithms analyzed pre- and post-treatment photographs to quantify changes in attractiveness and age appearance, providing insights into the effectiveness of orthognathic treatment.</p>	<p>age. The results indicate that most patients experienced improvements in appearance and attractiveness following treatment, particularly after profile-altering surgery. AI-based assessment offers a reproducible method for evaluating treatment outcomes, although it is essential for clinicians to consider patients' subjective perceptions and expectations. Despite its promising utility, the introduction of AI in medicine must be approached with caution, recognizing the need for further validation and consideration of patient perspectives.</p>
Li et al., 2019 ⁸	Experimental	<p>Multilayer perceptron artificial neural networks were utilized to forecast orthodontic treatment plans, encompassing the determination of extraction-nonextraction, extraction patterns, and anchorage patterns. Three neural networks were trained with 302 cases from the Department of Orthodontics, West China Hospital of Stomatology. The dataset was split into training, validation, and test sets. During training, the networks did not have access to the test set to prevent overfitting. Training set weights were updated, and validation set usage aided in avoiding overfitting. A greater percentage of data was allocated to test the models due to the smaller dataset size.</p>	<p>The neural networks were trained with 24 input features extracted from clinical records of orthodontic patients. They were trained to determine the need for tooth extraction, specific extraction patterns, and anchorage patterns. The models were assessed using receiver operating characteristic (ROC) curves and other performance metrics.</p>	<p>The study demonstrated that artificial neural networks can accurately predict orthodontic treatment plans, providing flexibility to orthodontists in decision-making. High accuracies were achieved for extraction-nonextraction prediction, extraction patterns, and anchorage patterns. Feature analysis identified important predictors for each decision part, suggesting the method's utility in assisting less-experienced orthodontists.</p>
Choi et al., 2019 ¹¹	Experimental	<p>The study aimed to develop a new artificial intelligent model for surgery/non-surgery decision and extraction determination in orthognathic surgery. The sample comprised 316 patients, with 160 planned for surgical treatment and 156 for non-surgical</p>	<p>The artificial intelligent model utilized machine learning techniques to determine surgery/non-surgery decision, surgery type, and extraction/non-extraction. The input data included lateral cephalogram measurements and clinical indexes.</p>	<p>The study demonstrated a high success rate of 96% for the diagnosis of surgery/non-surgery decision and 91% for the detailed diagnosis of surgery type and extraction decision. Extraction decision for Class II surgery cases showed a success rate</p>

		<p>treatment. Input values for the artificial neural network were obtained from 12 measurement values of the lateral cephalogram and 6 additional indexes. The machine learning model consisted of a 2-layer neural network with one hidden layer, trained in 3 stages, and the 4 best-performing models were selected.</p>	<p>Decision-making success rates for various aspects of orthognathic surgery were calculated using the trained models.</p>	<p>of 97%, whereas for Class III surgery patients, it was 88%. The study suggests that the developed artificial intelligent model could be effectively applied in diagnosing orthognathic surgery cases. Despite the potential drawbacks in minimizing job demand for experienced surgeons, AI systems can serve as auxiliary tools, aiding in treatment planning progress. Further research is recommended to address limitations such as excluding skeletal asymmetry cases and incorporating patient's subjective needs into diagnosis. Deep learning methods like convolutional neural networks hold promise for analyzing diagnostic image data in future studies.</p>
<p>Kök et al., 2019²³</p>	<p>Experimental</p>	<p>The study aimed to determine cervical vertebrae stages (CVS) for growth and development periods using cephalometric radiographs from 300 individuals aged 8 to 17 years. Nineteen reference points were defined on the second, third, and fourth cervical vertebrae, and 20 different linear measurements were taken. Seven commonly used artificial intelligence classifiers were selected for comparison, including k-nearest neighbors (k-NN), Naive Bayes (NB), decision tree (Tree), artificial neural networks (ANN), support vector machine (SVM), random forest (RF), and logistic regression (Log.Regr.).</p>	<p>Artificial intelligence algorithms were utilized to classify cervical vertebrae stages based on cephalometric radiographs. Various classifiers were compared for their accuracy in determining different CVS. These classifiers included k-NN, NB, Tree, ANN, SVM, RF, and Log.Regr. The study assessed the performance of each algorithm in predicting CVS, providing insights into their effectiveness in orthodontic diagnosis and treatment planning.</p>	<p>The study findings suggest that certain artificial intelligence algorithms, such as decision tree, support vector machine, and k-nearest neighbors, demonstrated higher accuracy in determining cervical vertebrae stages compared to others. ANN was identified as a stable and effective method for CVS prediction across different stages. However, algorithms like kNN and Log.Regr. showed lower accuracy values in this context. Overall, ANN could be considered a preferred method for determining CVS, indicating its potential utility in orthodontic diagnosis. Further research and validation may be necessary to confirm these findings and explore additional applications of AI in orthodontics.</p>
<p>Makaremi et al., 2020²⁴</p>	<p>Experimental</p>	<p>The study aimed to develop a Deep Learning (DL) method for directly determining the degree of maturation of Cervical Vertebra Maturation</p>	<p>Machine Learning (ML) and Artificial Intelligent (AI) tools were employed to classify lateral X-ray radiographs and determine the CVM degree. The DL</p>	<p>The study successfully developed a DL classification method for determining CVM degree directly from lateral radiographs, a crucial</p>

		(CVM) from lateral X-ray radiographs, classified into six degrees. Three hundred images were used for training, 200 for evaluation, and 100 for testing.	method was specifically designed for this task and achieved a 90% accuracy rate. Orthodontists can utilize the implemented software for efficient CVM determination.	parameter in orthodontics. While high accuracies exceeding 95% were achieved during training and validation, the accuracy for testing images did not exceed 85%. The authors suggest that increasing the number of training and validation images, to about 1000 each, could improve accuracy in future implementations.
Bao et al., 2023 ²⁵	Observational	Reconstructed lateral cephalograms (RLCs) from cone-beam computed tomography (CBCT) in 85 patients were selected for the study. Computer-assisted manual analysis (Dolphin Imaging 11.9) and AI automatic analysis (Planmeca Romexis 6.2) were utilized to locate 19 landmarks and obtain 23 measurements.	The AI automatic analysis software was employed to perform cephalometric landmark localization and measurements, while computer-assisted manual analysis was used as a comparison.	The study found that the AI automatic analysis software demonstrated a mean radial error (MRE) of 2.07 ± 1.35 mm for 19 cephalometric landmarks, with soft tissue landmarks showing the most consistency. Dental landmarks exhibited the most variation. Despite this, 15 out of 23 measurements were within the clinically acceptable level of accuracy (2 mm or 2°). The rates of consistency within the 95% limits of agreement were all above 90% for all measurement parameters. The findings suggest that while automatic analysis software can effectively collect cephalometric measurements for clinical use, it cannot fully replace manual tracing. However, additional manual supervision and adjustment for automatic programs can enhance accuracy and efficiency.

Data on study design, sample size, AI algorithms used, outcome measures, and important findings from the listed studies were painstakingly collected by MC. In a similar vein, GM concentrated on gathering information about the methodological facets of the studies to guarantee accuracy and comprehensiveness when evaluating the caliber of the study. MMM, meantime, focused on gathering information related to the conclusions and findings documented in the research. Because each reviewer contributed their area of expertise to ensure a comprehensive dataset, the division of labor allowed for a rigorous and

comprehensive extraction procedure.

Using well-known instruments like the Newcastle-Ottawa Scale and the Cochrane Risk of Bias Tool, GM, MMM, and MC independently assessed the methodological rigor and risk of bias in the included studies during the ensuing quality assessment phase. While MC concentrated on assessing the possibility of bias and potential sources of confounding, GM thoroughly evaluated the studies to evaluate the caliber of their design and execution. MMM simultaneously investigated how reliable the results and findings; the strengths and limitations of the

studies that were reported. Consensus discussions among the reviewers resolved any disparities in the quality rating, guaranteeing uniformity and

dependability in the evaluation procedure (Tables 2 & 3).

***Table 3: Strengths and limitations of the included studies**

Author/ year	Strengths of the studies	Limitations of the studies
Lee et al., 2017 ²²	created a deep learning system that is completely automated for treatment planning and orthodontic diagnostics. used CNN to measure bone age with good accuracy. standardized radiological reports and streamlined workflow.	design of a retrospective observational study. restricted to radiographs of the hands and wrists; may not translate to other orthodontic imaging requirements.
Spampinato et al., 2017 ¹⁶	explored several deep learning methods for automated determination of skeletal bone age. utilized a public dataset and a novel CNN network (BoNet). set the stage for upcoming medical imaging research.	There could be a lack of clinical validation in real-world experiments. Greater use in orthodontic diagnosis is limited by the emphasis on skeletal bone age assessment.
Montúfar et al., 2018 ²⁰	a technique for automatically localizing landmarks on CBCT volumes was developed. used in the investigation of 3D cephalometrics. less time spent on computing when compared to full-volume analysis.	Average localization error for landmarks, especially in specific areas. restricted to CBCT scans rather of the conventional 2D radiographs that are often utilized in orthodontic practice.
Iglovikov et al., 2017 ¹⁷	A fully automated deep learning method for determining bone age. better performance in comparison to current models. assessed the significance of hand bones for evaluation.	Generalizability may be restricted if a dataset from a particular challenge is relied upon. Possible overfitting because of the features in the dataset.
Larson et al., 2018 ¹⁸	skeleton maturity was highly accurately estimated using a CNN model trained via deep learning. like highly skilled radiologists. large-scale training and validation dataset.	restricted to hand radiography for comparison. The primary benchmark for model evaluation is current automated models; radiologists are not directly compared.
Patcas et al., 2019 ¹⁹	AI-based objective evaluation of orthognathic therapy results. quantitative evaluation of age appearance and face attractiveness. Reproducible technique for assessing results.	observational research design with possible patient selection bias. AI-based evaluations could miss patient perception and subjective pleasure.
Li et al., 2019 ⁸	Orthodontic treatment regimens are accurately predicted by MLP neural networks. helpful in making decisions about anchorage and extraction strategies. high precision while making predictions.	Study constrained by scope and amount of dataset. Model training and feature selection have a significant impact on performance.
Choi et al., 2019 ¹¹	AI model for extraction decision-making and surgery/non-surgery decision-making developed. high rates of achievement on diagnostic tasks. Possibility for orthognathic surgery clinical decision support.	Research limits its generalizability by excluding patients with skeletal asymmetry. Absence of patient outcomes in the decision-making process.

Kök et al., 2019 ²³	Cervical vertebrae phases are reliably classified using AI algorithms. comparing the accuracy of different classifiers. Possibility of enhancing treatment planning and orthodontic diagnosis.	restricted to cervical vertebral stages and age ranges (8–17 years). There might not be as much generalizability throughout different patient demographics.
Makaremi et al., 2020 ²⁴	created a DL technique to directly determine CVM from lateral radiographs obtained from X-rays. good initial classification accuracy. Possibility for clinical implementation in CVM evaluation.	reduced accuracy when comparing training and validation datasets to testing photos. Greater training dataset sizes are required to increase robustness and generalizability.
Bao et al., 2023 ²⁵	AI software for measuring and localizing cephalometric landmarks. Good for clinical application and consistently able to identify landmarks. increases cephalometric analysis efficiency.	A mean radial error was found while localizing landmarks, especially dental landmarks. more manual tweaking is necessary to achieve the best precision.

MC, GM, and MC worked together to synthesize the retrieved data and analyze the results of the included studies after data extraction and quality assessment. Leading the process of qualitative synthesis, GM found recurring themes and patterns in the data. MC participated in the quantitative meta-analysis by combining data from several studies and, when necessary, calculating summary effect sizes.

MMM helped assess the combined data and come to relevant conclusions in the interim. A unified approach to data synthesis was made possible by the reviewers' regular contact and cooperation, which improved the validity and resilience of the findings of the systematic review. The reviewers also analyzed the specific articles that did not meet the criteria to be included in the review (Table 4).

***Table 4: List of studies excluded from the review with reasons**

S. No	Author and Year	Title of the study	Reason for exclusion
1.	Dipalma et al., 2023 ¹⁴	Artificial Intelligence and Its Clinical Applications in Orthodontics: A Systematic Review.	Systematic review
2	Siddiqui et al., 2022 ⁴	Artificial intelligence in dentistry, Orthodontics, and orthognathic surgery: a literature review.	Literature Review
3	Banumathi et al., 2011 ²⁶	Diagnosis of dental deformities in cephalometry images using support vector machine	Article published before the study inclusion period
4	Xie et al., 2010 ⁷	Artificial neural network modeling for deciding if extractions are necessary prior to orthodontic treatment.	Article published before the study inclusion period
5.	Sarveshwaran V et al. 2023 ¹⁰	Machine Learning based Intelligent Diagnosis of Orthodontics: a comprehensive review	Review article
6.	Jung SK et al., 2016 ¹³	New approach for the diagnosis of extractions with neural network machine learning.	Article published before the study inclusion period

Risk of Bias assessment: Either the ROBINS-I tools for non-randomized studies or the Cochrane Risk of Bias Tool for randomized controlled trials were used to evaluate the risk of bias in individual studies based on their specific study design. Validity and dependability of the combined evidence were enhanced by this evaluation.

* **Table 2:** Studies included in the present review to depict the use of AI in Orthodontic diagnosis and treatment planning

* **Table 3:** Strengths and limitations of the included studies

* **Table 4:** List of studies excluded from the review with reasons

Results

Several researches demonstrating the application of artificial intelligence (AI) to orthodontic diagnosis and treatment planning are included in the Table 2. Lee et al., 2017 created a deep learning method for bone age evaluation.²² Spampinato et al., 2017 explored deep learning techniques for skeletal bone age assessment to establish a baseline for subsequent study.¹⁶ Montúfar et al., 2018 suggested an approach for automatic landmarking on cone-beam computed tomography (CBCT) volumes to facilitate 3D cephalometric analysis.²⁰ Iglovikov et al., 2017 outperformed previous methods in demonstrating a deep learning strategy for bone age assessment.¹⁷ A convolutional neural network model for skeletal maturity estimate was presented by Larson et al., 2018. Its accuracy is comparable to that of professional radiologists.¹⁸ Patcas et al., 2019 used AI to provide objective assessments of the alterations in the face after orthognathic surgery.¹⁹ Neural networks were used by Li et al., 2019 to forecast orthodontic treatment plans, which aided in the decision-making process.⁸ With a high diagnosis success rate, Choi et al., 2019 created an AI model for orthognathic surgical

decision-making.¹¹ In their 2019 study, Kök et al., investigated AI classifiers for determining the cervical vertebrae stage, emphasizing ANN as the recommended approach.²³ A DL approach for determining Cervical Vertebra Maturation (CVM), which is crucial in orthodontics, was introduced by Makaremi et al., 2020.²⁴ The accuracy of AI in cephalometric landmark localization was lastly assessed by Bao et al., 2023, highlighting the possibility of automatic analysis in clinical practice.²⁵ Together, these studies highlight the importance of artificial intelligence (AI) in orthodontics by providing standardized, effective, and efficient approaches for diagnostic and treatment planning, which eventually improve patient results.

Table 3 presents the advantages and disadvantages of different research works incorporating artificial intelligence (AI) in orthodontics. Every research shows progress like automated treatment planning, precise bone age assessment, and improved diagnostic skills using deep learning models. Nevertheless, constraints involve dependence on past designs, biases specific to datasets, and difficulties in extending results across various patient populations and clinical settings. Despite these limitations, AI has the potential to improve orthodontic diagnosis and treatment planning, but continued validation and fine-tuning are essential to ensure practical application in clinical settings and patient-focused results.

In a systematic review or meta-analysis, Figures 2 and 3 presented a visual summary of the risk of bias evaluation for each study. Bias in various aspects, such as patient selection, index test, reference standard, and flow and timing, was assessed in every study. Figure 2 demonstrated a generally low risk of bias in all parameters, with only a slight high risk observed for the index test parameter.

Figure 3 illustrated how bias risk assessments were distributed among the studies in the review, indicating the percentage of studies with low, unclear, or high bias risk for each parameter evaluated.

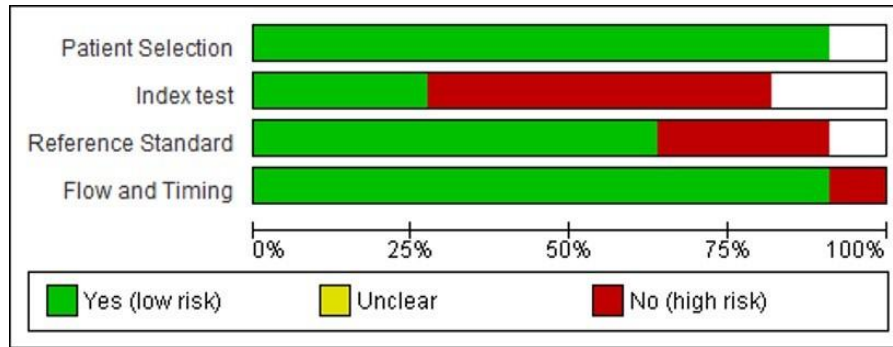


Figure 2. Risk of BIAS summary

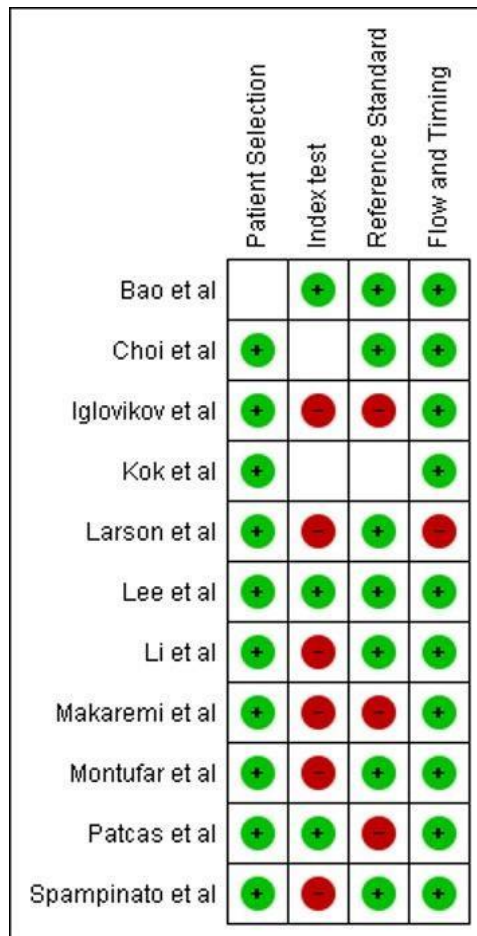


Figure 3. Risk of Bias Graph

It pointed out mostly low risk of bias, with a small amount of high risk linked to the index test parameter. Iglovikov et al.,¹⁷ Larson et al.¹⁸ and Makaremi et al's²⁴ studies were discovered to exhibit a greater potential for bias than other studies, whereas Lee et al's²² study was recognized for its superior methodological quality and minimal bias risk.

*Figure 2: Risk of BIAS summary

*Figure 3: Risk of BIAS Graph

Discussion

Driven by the incorporation of artificial intelligence (AI) into routine practice, orthodontics is at the vanguard of a technological revolution. The delivery of orthodontic care has been completely changed by this paradigm shift from conventional, rule-based algorithms to dynamic machine learning techniques. AI has created new opportunities for individualized treatment planning and better patient

outcomes due to its extraordinary accuracy and efficiency when analyzing large volumes of data. Orthodontists are now able to navigate difficult diagnostic challenges more accurately by utilizing AI algorithms, which can detect subtle deviations and anomalies that may have gone undetected in the past.^{13,14,27,28} In addition, virtual treatment simulations made possible by AI-powered tools let patients see and comprehend the anticipated results of their orthodontic interventions.^{3,29,30,31} Orthodontists can remotely oversee patient progress and intervene proactively to maximize treatment effectiveness through continuous monitoring and compliance tracking made possible by wearable sensors and smartphone apps.^{4,12,21} Furthermore, quantitative data from bite force measurement and AI-driven occlusal analysis technologies help to better inform treatment choices and evaluate results.^{5,10,16,18} Recent studies have shown how artificial intelligence (AI) has revolutionized orthodontics by greatly improving diagnostic skills.¹

Applications of AI in Orthodontics

The area of orthodontics has undergone a tremendous change with the advent of artificial intelligence (AI) technology, offering creative solutions to persistent issues. There are studies that have emphasized the ways in which artificial intelligence (AI) is advancing orthodontics and providing novel opportunities for patient care, diagnostics, and treatment planning and one such area of focus has been Orthodontics in terms of treatment outcome and prediction.^{1,2,19,22} These studies demonstrate how artificial intelligence (AI) systems can assess patient data to accurately forecast treatment results, enabling orthodontists to tailor treatment plans for the best results.^{19,22} The topic of AI-driven virtual therapy simulation by Thurzo et al. is another example of AI usage in orthodontics.³⁰ With its realistic visualizations of treatment outcomes, promotes better patient understanding and participation and increases the effectiveness of treatment planning.⁹ AI has also fundamentally altered patient monitoring and compliance tracking, enabling remote assessment of therapy progress and prompt intervention when necessary. Dipalma et al., 2023 demonstrates the application of AI-driven monitoring systems to evaluate patient adherence to treatment parameters and optimize patient compliance and treatment

outcomes.¹⁴ AI is crucial to diagnostic processes, particularly occlusal analysis. AI has had an impact on intricate situations that involve both implant prosthetic rehabilitation and orthognathic treatment, as shown by Hakobyan GV et al. (2022). This demonstration highlights how AI can improve collaboration across disciplines by aiding in precise treatment coordination and predicting outcomes.³² Moreover, AI plays a role in radiology and orthodontic planning according to Abdulelah Sameer Sindi et al. (2023), with AI algorithms improving the precision of dental radiography for more accurate diagnosis and treatment planning. These developments highlight the transformative power of AI in orthodontics, aiming for personalized treatment plans and better results for patients.³³

Significance of AI in Orthodontic diagnosis and treatment planning

Artificial Intelligence (AI) has become a disruptive force in orthodontic diagnosis and treatment planning, providing innovative answers to traditional problems. Using radiographs of the hand and wrist, investigations by Lee et al., 2017²² and Spampinato et al., 2017¹⁶ demonstrate the effectiveness of AI in determining bone age. To streamline workflow procedures, a completely automated deep learning system for orthodontic diagnosis was created that standardizes photos and produces structured reports.²² Similarly, this achieved state-of-the-art performance when compared to manual evaluation by proposing many deep learning algorithms for automated skeletal bone age assessment.¹⁶ Furthermore, a technique for automatic landmark annotation on cone-beam computed tomography (CBCT) volumes was presented by Montúfar et al., 2018, which made 3D cephalometric analysis easier.²⁰

This innovative approach provides information on occlusal characteristics that are critical for treatment planning while increasing diagnosis efficacy and precision. Iglovikov et al., 2017 presented a fully automated deep learning approach for estimating bone age that demonstrated potential for prompt clinical deployment and outperformed earlier methods.¹⁷ Additionally, Larson et al., 2018 employed a deep learning-capable convolutional neural network model to accurately and almost equal the judgments of skilled radiologists about the skeletal maturity of hand radiographs.¹⁸ Their findings demonstrate the

usefulness of AI in establishing bone age, a crucial aspect of orthodontic diagnosis. Patcas et al., 2019 used convolutional neural networks to assess how orthognathic treatment affected the appearance of age and facial attractiveness. This AI-based approach enhances treatment result analysis and complements subjective assessments by offering objective evaluation measures.¹⁹ Li et al., 2019 used artificial neural networks to forecast orthodontic treatment plans, providing orthodontists with greater decision-making flexibility. Their study highlights the potential benefits of artificial intelligence (AI) in clinical decision-making and treatment results.⁸ Additionally, an artificial intelligence model was developed by authors for extraction determination and surgery/non-surgery decision-making in orthognathic surgery that has a high success rate in diagnosis accuracy.¹¹ Additionally, Kök et al., 2019 showed the efficacy of decision tree and support vector machine methods in properly predicting stages by classifying cervical vertebrae stages based on cephalometric radiographs using artificial intelligence algorithms.²³ This work advances orthodontic diagnosis, especially in determining growth and developmental stages. Furthermore, demonstrating AI's potential for accurate diagnostic applications in orthodontics, Makaremi et al., 2020 created a deep learning technique for evaluating cervical vertebra maturation degree directly from lateral X-ray radiographs.²⁴

AI has demonstrated potential in assessing the initial caries lesions linked to fixed orthodontic therapy. This analysis provides accurate early-stage caries diagnosis, which is essential for prompt interventions and improved treatment outcomes.³⁴ Furthermore, AI-assisted instruments are increasing the accuracy of aesthetic assessments, especially when evaluating the harmony and proportions of anterior teeth, which are essential for attaining the best possible smile aesthetics.³⁵ Moreover, AI is being used to improve implant success rates and lower problems in patients with systemic disorders by providing more precise and customized treatment plans.³⁶

All things considered, the application of AI to orthodontic diagnosis and treatment planning has great potential to transform clinical practice by improving patient outcomes, speed, and accuracy.

Limitations of the use of AI in Orthodontics

The introduction of Artificial Intelligence (AI) into

orthodontic work brings about important progressions, but it also presents several built-in constraints. AI technologies heavily depend on past data and particular algorithms, potentially causing biases in patient selection and data interpretation. The issue of generalizing findings to different patient groups and clinical environments is still a significant challenge because of differences in anatomy and treatment complexities.^{13,14} AI-based tools like virtual therapy simulations and automated diagnostics offer improvements in treatment planning and patient communication, but they also have the potential to oversimplify important clinical judgments needed for orthodontic decision-making.^{30,31} These technologies might not accurately represent the complex differences and patient-specific elements that impact treatment results.^{4,21} Additionally, validating AI for monitoring patient adherence and assessing treatment efficacy in actual clinical environments is necessary to guarantee precision, dependability, and ethical concerns regarding patient confidentiality and self-governance.^{5,12} It is crucial to overcome these obstacles to fully utilize AI in orthodontics and uphold patient-focused care and high clinical standards.^{3,29}

Future perspective and challenges

Even while AI has a lot of potential for application in orthodontic diagnosis and treatment planning, there are still several major barriers to overcome. Numerous important points of view and difficulties have been noted, emphasizing the necessity for future developments to concentrate on enhancing and changing AI algorithms to satisfy the changing needs of orthodontic practice. To maintain their effectiveness and consistency in a range of clinical contexts, AI systems need to be regularly updated and modified in response to new imaging modalities and technical developments. Combining AI with other cutting-edge technologies like virtual reality (VR) and augmented reality (AR) offers exciting new possibilities for improving patient communication and treatment planning. AR and VR can help orthodontists make decisions more intuitively and enable more accurate treatment simulations by giving them access to immersive visualization tools. However, the effective integration of these technologies requires interdisciplinary collaboration between engineers, computer scientists, and healthcare professionals.

benefits. Sharing and using patient data for AI model training is still hampered by concerns about data security and privacy. In addition, the ethical, legal, and regulatory issues surrounding the use of AI in healthcare necessitate strict control and oversight to guarantee patient safety and autonomy. It will take coordinated efforts from researchers, clinicians, legislators, and industry partners to address these issues. The establishment of defined protocols, data sharing frameworks, and regulatory norms through collaborative initiatives can contribute to the development of trust and confidence surrounding AI-driven orthodontic treatments. The application of AI in orthodontics has the potential to transform patient care, improve clinical outcomes, and move the field closer to more individualized and effective treatment plans if certain obstacles are overcome.

Conclusion

The systematic review highlights how AI can revolutionize orthodontic diagnosis and treatment planning. The amalgamation of data from various research works emphasizes the effectiveness of artificial intelligence algorithms in simplifying workflow procedures, improving diagnosis precision, and maximizing therapeutic results. The review has certain limitations, though, which should be acknowledged. These include the possibility of bias in the selection and interpretation of the studies, as well as the dynamic nature of AI technology, which could make some of the findings out of date over time. It is advised that to overcome these constraints, future research should adopt a strict methodology, welcome interdisciplinary collaboration, and keep up with technological developments. To encourage the responsible and moral integration of AI into orthodontic practice, additional efforts should be focused on developing standardized protocols, guaranteeing data privacy and security, and encouraging regulatory compliance. Overall, despite the ongoing difficulties, the review's collective findings provide insightful information and helpful advice for maximizing artificial intelligence's potential to transform orthodontic treatment and enhance patient outcomes.

Declarations

Conflicts of interest and financial disclosures

The author declares that he has no conflict percent and there was no external source of funding for the research in question.

Ethical approval

The study was approved by the University ethics committee and was conducted in accordance with the Declaration of the World Medical Association.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Source of funding

The work was not funded.

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