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Review Article

The Intelligent Pathway: How Artificial Intelligence is Reshaping the Orthodontic Field: A Review

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Abstract

Aims: To highlight the transformative role of Artificial Intelligence in enhancing orthodontic diagnostic precision, optimizing treatment planning methodologies, and revolutionizing patient-centred care paradigms.

Materials and Methods: Narrative review of current literature on Artificial Intelligence applications in orthodontics.

Conclusions: Artificial Intelligence can improve the precision and efficiency in orthodontics, but still necessitates an orthodontist's supervision and elevates ethical and data security concerns.

Keywords: Artificial intelligence, Deep learning, Machine Learning, Prediction, Tele-orthodontics.

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INTRODUCTION

Innovative technology in the 21st century has given rise to unprecedented developments in computers and data science, which hold significant prospects for orthodontic applications. Artificial Intelligence (AI) is defined as the simulation of human mental capacities within a machine, intended to mimic human thinking processes (1).

John McCarthy was the inventor of the term AI in 1955 and was regarded as the father of this technology, as he invented the word to describe machines' capacity to execute the duties that are indexed as intelligent (2). A phase of important optimism happened in the previous seventy years, including AI improvement, interchanging with unsuccessful stages, falls in research backing deficit, and negativity (3).

The word robotics is commonly correlated with AI. The intelligence or the ability to execute the work of any required goals achieved via the usage of a technology that generates various software or a device that is responsible for these smart tasks (4). The AI term also means the research restraint that includes planning software and computing devices that are able to catch information and later alter it to perform smart activities (5).

Artificial intelligence or assistant intelligence is principally related to executing even human judgments and activities into computer-based algorithms (6). These AI algorithms accomplish three key jobs: categorizing definite data, forecasting certain values (e.g., treatment time), and creating artificial data (7).

The AI applications apply machine learning, deep learning, and data analytics to analyse dental photos, forecast treatment results, automate usual jobs, and develop patient maintenance. This integration aims to raise the efficacy and correctness of orthodontic treatments, eventually resulting in superior patient results (8). Artificial intelligence is considered the umbrella term for any software that has contact with individual smartness and includes Machine Learning (ML) in addition to Deep Learning (DL) (9).

The ML is a subdivision of AI that comprises whole methods that permit devices to learn from data devoid of previous obviously programmed activities (10).

Deep Learning is subdivided from ML that includes a mathematical framework with algorithms that replicate the construction of living neural networks in the human brain [artificial neural networks (ANNs)] (11)

'Deep' is a technological word, which means the number of layers in an ANN. These are 3-layer kinds: the input layer (gets the input data), the output layer (yields the findings of data handling), and the unseen layer (extracts the style inside the data). A deep ANN differs from the external one (single hidden layer) in having a big number of unseen layers, this makes it to execute very complicated tasks.

Convolutional Neural Networks (CNNs) are a potent kind of DL models broadly used in numerous tasks, comprising item recognition, speech recognition, computer vision, image categorization, and bioinformatics (12).

History of AI Applications in Orthodontics

It belonged to the end of the twentieth century, and noteworthy improvement was achieved in the last period. Below is a chronological overview of key milestones and developments:

1. **Early Beginnings (1980s–1990s): Rule-Based Systems**

Initial Applications: Early AI uses in orthodontics concentrated on rule-based skillful systems and decision-support tools. It assists the operators in diagnosing malocclusions and planning orthodontic treatment (13). The use of AI for the analysis of cephalometric radiographs was the first area where AI was applied for assessing dental and skeletal relationships. Early AI systems automated landmark exploration, decreasing manual work and enhancing precision (14).

2. **The rise of Machine Learning (2000s–2010s): Data-Driven Approaches**

This era is characterised by Machine Learning Algorithms with the introduction of ML, and the systems of AI have become more advanced. These algorithms can be used for recognizing patterns and forecasting treatment results via analysis of huge datasets of case registers, radiographic images, and 3D scans, and finally recognize 3D scanning and Digital Models: The coordination of 3D imaging technologies enabled AI systems to generate in detail digital models of patients' dentition and skeletal jaws. These resulting models can be employed for a virtual treatment plan and for case simulation (15).

3. **Deep Learning Revolution (2010s–2020s): Neural Networks**

The revolutionary introduction of deep learning techniques (DL), especially convolutional neural networks (CNNs), modernized the orthodontic application of AI. The CNNs' jobs include automated landmark recognition, image subdivision, and classification of malocclusions. An advanced AI models were to forecast the orthodontic management outcomes, such as the possibilities of relapse or the period of treatment. These models used each individual's own data to deliver individualised recommendations (16).

4. **Modern Era (2020s–Present): Integration and Personalization:**

This era involved the following:

-*AI-Powered Software:* Marketable AI-powered orthodontic programs, such as Invisalign's ClinCheck and Dolphin Imaging, have been well developed and broadly approved. This software uses AI to mimic treatment findings, improve aligner design, and increase communication with the patient (17).

-*Remote Monitoring and Teleorthodontics:* The AI nowadays supports real-time observation by smartphone applications. AI has allowed the appearance of teleorthodontics, particularly during the time of the COVID-19 pandemic, which popularized the usage of telemedicine with distant watching in medical management, including orthodontics (18).

5. **Continuous Advancements (Present and Future):**

Orthodontics AI showed quick progression. AI knowledge is expected to be increasingly complicated. Yet, presenting precise diagnostic tool planning of treatment, a comprehensive patient observing tool, and many more applications, AI is likely to be a key function for predicting orthodontic upcoming outcome, leading to active treatments, efficient with a global approach to orthodontic patients (19).

Artificial Intelligence Applications in Orthodontics

Artificial intelligence (AI) is being increasingly integrated into orthodontics, enhancing various aspects of diagnosis, treatment planning, and patient care. With the development of AI applications, it is quickly becoming necessary for each orthodontist to be experienced in these technologies and to consider them as a main tool to aid, but not to substitute, the wide knowledge and experience of orthodontists (20).

- **Diagnosis and Imaging Analysis**

Artificial intelligence (AI) has considerably improved orthodontic diagnosis by enhancing correctness, effectiveness, and decreasing the time required for numerous diagnostic procedures. Orthodontists use image data for clinical decision-making and treatment planning. These digital dental images have innovative forms; imaging data are progressively indexed and kept in digital records, permitting rapid recovery, re-evaluation, plan modification, and monitoring (21). Contemporary orthodontics is gradually shaping the management style from a decision that depends on occlusion (occlusion-driven) to a decision that depends on face (face-driven) (22).

The abundance of digital cameras in the markets made all types of imaging, including intra- and extra-oral for both pre or post treatment, an important participant of orthodontic documentation that aids in evaluation of the treatment influence on an individual’s occlusion in relation to their facial look (23). The diagnostic imaging category has 3 major fields: operational AI, which boosts medical services provision; diagnostic AI, which helps explain patient photos; and forecasting AI, which predicts forthcoming results (24).

Different diagnostic aids like radiographs, photographs, and 3D scans can be analysed using AI algorithms to address various concerns of orthodontic diagnosis. Additionally, ML models can recognise forms and forecast treatment results, aiding orthodontists in generating a more helpful treatment plan (25). AI algorithms have the ability to recognize discrepancies in skeletal bone and dentition, aiding orthodontists to clarify the type of malocclusion as Class II or Class III. The dento-skeletal discrepancies ranked third globally in the most widespread intraoral pathologies, where approximately thirty percent of the population have excessive necessity of management such as orthodontics (26).

It has been stated that the automated diagnostic accuracy of periapical disease via analysing CBCT radiograph was 92.8% and revealed a non-significant difference in volumetric dimensions in comparison with manual measures (27). Similar research on periapical radiographs accuracy in evaluating periapical pathologies produced analogous findings (28).

Remarkably, radiographic assessment in orthodontics appeared as the top widely developed field (29). In spite of reporting the automated identification of cephalometric landmarks since the middle of the 1980s, however mistake boundary of the mistake is very large when applied in the treatment field. Recently, as AI is rapidly developing, various studies using cephalometric analysis reported a significant enhancement in their efficacy, creativity, and accuracy (30-32). Many authors reported that semi-automated radiographic points detection still relies on the expertise of the operator (33).

It was reported that the accuracy of automated landmarks tracing of lateral cephalometrics using AI applications that depend on different algorithms can attain accuracy and efficiency comparable to semi-automatic ones (34). Numerous papers gave rise to satisfactory distances and angles with dimensions of less than two mm and two degrees correspondingly (35,36).

According to many studies, the accuracy of cephalometric landmarks detection via AI applications were 88% to 92%, adding to the reduction of the required time and labor compared to manual detection (37,38). Kang et al. (39) stated that the deep reinforcement learning algorithm for 3D automated landmark identification attained a mean identification error of 1.96 ± 0.78 mm for landmarks, in addition to 58.99 % and 95.70 % for identification rate falling (the two mm – Four mm range).

- **Treatment Planning**:

Precise orthodontic diagnosis is very important as it is correlated directly to the planning of orthodontic management and later the results. Nowadays, AI-driven diagnosis has been applied in treatment planning, which has captured the interest of orthodontists (40). The usage of AI to assist in orthodontic treatment planning has been in use for a long period of time. Once the orthodontists decided on the final planned position of the teeth and have sent the order, AI applications will help select the best method for altering the dental positions to solve the situations and provide a series of progressive alterations of tooth position reaching the operator's provided final position. This has proved to be very useful compared to the conventional treatment that practises only braces, necessitating skilful hand work capability where numerous operators have none due to insufficient exercise (41).

Orthodontic tooth alignment and extraoral appearance have a close association. Those estimations just applied with a skilful operator as the movement of dentition in one or more dimension influence extraoral and smile appearance (42).

Shimizu et al. (43) specially employed imaging of the face to clarify the significance of these images in planning orthodontic management. These plans, that's an AI-dependent support vector device was spontaneously ordered to address orthodontic discrepancies, depending on a catalogue that generates an obvious line to execute the required tasks. Yet, both sequencing and executing a plan job revealed minimum accuracy (65 % and 48 %) and recall (55 % and 48 %) when employed by a skillful operator.

Researchers used a DL algorithm to help plan the generation of an orthognathic surgery treatment. A study of Chaiprasittikul et al. [44] used both CNN and ANN to generate an automated system for deciding the necessity for maxillofacial surgery with an evaluation measure improvement of 96.3 %. Another study by Cheng et al. (45) employed the CNN to forecast relocation vectors in a way that will direct the surgical planning with a mean error of 1.34 mm.

Artificial intelligence applications are used to detect the age of the skeleton, along with assessment of the stage of individual growth and development, which will certainly aid the orthodontist in evaluating the cause of the disease and the subsequent required type of treatment. Anthropometric indicators, comprising individuals age, dentition age, menarche, speech sound alteration, body length attainment, and bone maturation, help in evaluating bone age. Radiograph imaging is usually used to recognize marks of bone that are fully developed (46).

In a study, spontaneous CNN-dependent age evaluation was done on dental panoramic radiographs by using the Demirjian method. The network attained an outcome in 0.3 s with an accuracy between 92 % and 96 %, which was 3 % greater than manual classification. [(47)] On the other hand, the remaining ten studies employed AI for neck vertebrae mature grading on images of lateral radiographs of cephalograms (48).

- **Predictive analytics in orthodontics**

Treatment results depend on forecasting aid in the analysis and management of dental discrepancies in a scientific manner, decreasing possible dangers with problems within and after dental Management. Recently, AI is able to assist in forecasting problems at dentition, maxillofacial region, and in the face area, in addition to human knowledge about clear aligners, thus directing the plan's steps of management (49).

Kesling originally projected an orthodontic tooth setup that permits the visualization of the therapeutic advancement and finishing of occlusal relationship, but hand-operated goals, such as dental segmentation and relocation, are very hard work. Due to the constant advancements of digital orthodontics and AI, the smart practical setups were broadly used, particularly in malocclusion correction using clear aligners (50).

A model of CNN type was used to forecast the cephalometric alterations of Class II cases following appliance usage as modified C-palatal plates, and attained a total accuracy of 1.79 ± 1.77 mm. (51) another study (52), attained a precision of 93.9 % if spontaneously detecting necessity for dentition removal, on other side another study(53), applied ML to identify dental extraction way were the precision of 81.63 % for maxillary and mandibular first bicuspud extraction. Volovic et al. (54), established that all verified ML design was capable to forecast the time required for orthodontic management within a clinically satisfactory range.

To predict the strategy of management, determine if dental removal is mandatory or not, determine the way of extraction, and determine anchoring, Li et al. (55) organised an artificial neural network with a multilayer perceptron. The findings shown accuracy of 94% for predictions of extraction and non-extraction, 84.2% for patterns of extraction, and 92.8% for patterns of anchoring. On the other side, problems like dental crowding and curve of Spee are the most important features for forecasting.

- **Remote orthodontic consultations (Tele-orthodontics)**

It denotes to the application of digital data and telecommunications to allow far away answer patient questions regarding treatment, comprising interconnection among operators, individuals, and any member of the community. It helps to deliver direction on care, teach both practitioners and patients, that increase community care regarding orthodontics (56). This cutting- edge method of orthodontic care delivers patients with improved suitability, enhanced approaches, and augmented efficacy in attaining an accurately corrected smile (57).

The American Dental Association has authorized the use of remote dental consultations during the spread of any disease. New research stated that despite initial doubt, remote dental treatment can provide many advantages to operators in its clinic by allowing distant therapy. On the other hand, it was important to recognize the possible danger of information leaks when sending various types of patients' data and other medical service data via tele-orthodontics (58).

Although tele-orthodontics gave rise to many advantages, it has considerable difficulties. Active connections between the individual and his orthodontist, in addition to constant online communication is important for successful accomplishment. Moreover, the orthodontist is participating in adapting to this new pattern (59).

- **Treatment Simulation**

The AI-driven software can provide virtual 3D models of patients' teeth, permitting the simulation of orthodontic treatment development and results. Additionally, AI algorithms can automatically systematize bracket positioning by evaluating tooth designs and forecasting the rightest positioning of braces, depending on the patient's dental form (60).

The AI improves the precision of the plan for surgical correction of maxillofacial structures, enhancing the strategy of surgery, accuracy, and individual agreement. The whole AI-aided processes may allow individualized planning of management with accurate surgical resemblance, in addition to permitting assessment of findings following the operation over time (61).

The optical facial appreciation was executed by AI, and it very mimic the compound mental jobs containing analyzing and fully explaining the data face. Researches at these fields displayed that AI technologies appeared to become positive creative implements to form a confirmed for human awareness of facial appeal (62). SureSmile is an example of technology that provides a digital resemblance of the development for dental alignment, permitting orthodontists to choose and utmost precise pattern of management (63).

- **Artificial Intelligence Applied to Clear Aligner Therapy**

AI algorithms show a vital part in the planning and staging of aligners. A key attention in aligner preparation is separating the wanted dental movements into logical stages. Particular AI algorithms usually handle this automatic staging by successively separating the planned movements. Another significant biomechanical attention during aligner treatment is anchorage. For example, when posteriorly moving posterior teeth followed by mesializing anterior teeth, preserving anchorage and avoiding lingual tipping of incisors are critical. This necessitates a successive movement of teeth: First molars are distalized, then premolars, canines, and finally incisors. Some aligner treatment software involves AI algorithms that automatically direct this sequential dental movement as part of aligner treatment planning (64).

In addition, AI algorithms do not effectively comprise several orthodontic techniques. This is due, at least in part, to the incapability of aligners to regulate certain dental movements because of mechanical issues. Thus, a major encounter in recent management is when the traditional braces means is unsuitable because of appearance and rest concerns, after that, clear aligners won't be either due to mechanical concerns. So, it still needs many efforts to generate a device design that puts in reason whole of these factors (65).

Limitations and Future Perspectives

The AI cannot be without limitations. The details of this aspect are too much to cover in this review. Briefly, AI depends heavily on total computer knowledge, with data protection, extraction value, and dependability being crucial concerns. Keeping such massive quantities of data requires substantial investment in large-scale solutions like cloud storage or data-sharing systems, as well as AI models introduce impressive potential, they still need continuous human supervision, as mistakes can happen during patient management (66).

However, even with these developments in automated dental assessment, determining the need for orthodontic treatment is still perplexing, and principally in doubtful cases. This difficulty is worsened by significant inter-examiner changeability, with kappa values ranging from 0.16 to 0.37 for remote assessments and 0.22 to 0.38 for on-site valuations. Such variability generates challenges for training models and influences the integration of AI into orthodontic evaluations. Artificial intelligence (AI) creates ethical challenges, mainly in healthcare, where concerns arise about independence and decision-making, exemplified by the use of autonomous surgical robots (67). The automation of tasks like photo analysis and individual data processing by AI can lead to productivity in work and joblessness (68).

The absence of transparency and accountability in AI systems makes it challenging to comprehend their decision-making processes, complicating efforts to clarify or hold them accountable, furthermore to a risk of over-dependence on technology, where healthcare professionals may become too dependent on AI, possibly the loss of the capability to accomplish jobs without its assistance (69).

CONCLUSIONS

Artificial Intelligence is quickly reforming the shape of the field of orthodontics by introducing advanced measures that augment diagnostic accuracy, streamline treatment planning, and advance patient care. From image analysis to treatment simulation and tele-orthodontics, AI technologies are considered necessary constituents of up-to-date orthodontic practice. Even so, AI offers promising advantages, it cannot substitute the skills and clinical decisions of orthodontists. Constant supervision, ethical concerns, and data security stay critical factors. The future of orthodontics lies in a balanced integration of AI measures with human decision-making to confirm effective, personalized, and safe patient results.

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Authors' Contribution

Hasan YMS and Aldawoody AD completed the conceptualization, data curation, formal analysis, methodology, finding acquisition, investigation, resources, software, validation, visualization, writing- original draft, and editing. Hasan YMS and Aldawoody AD completed the supervision, visualization, review & editing.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

Availability of data and materials: All data generated or analyzed during this study are included in this published article and its supplementary information files.

Declaration of Generative AI and AI-assisted technologies

During the preparation of this work, the authors did not use any of the AI tools. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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المسار الذكي: كيف يعيد الذكاء الاصطناعي تشكيل مجال تقويم الاسنان :مراجعة مقال

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الملخص

الأهداف :تهدف هذه المراجعة إلى تسليط الضوء على دور تطبيقات الذكاء الاصطناعي في تحسين تشخيص تقويم الأسنان، وتخطيط العلاج، ورعاية المرضى .

المواد وطُرق العمل: مراجعة سردية للأدبيات الحديثة المتعلقة بتطبيقات الذكاء الاصطناعي في تقويم الأسنان.

الاستنتاجات: يُحسِّن الذكاء الاصطناعي الدقة والكفاءة في تقويم الأسنان، لكنه لا يزال يتطلب إشراف أخصائي التقويم ويثير مخاوف تتعلق بالأخلاقيات وأمان البيانات.

الكلمات المفتاحية: الذكاء الاصطناعي، تقويم أسنان عن بعد، لتعلم الآلي، التعلم العميق، التنبؤ