International Journal on Advanced Science Engineering Information Technology

Vol.15 (2025) No. 2
ISSN: 2088-5334

Transforming Orthodontics: Exploring Evolution and Applications of Artificial Intelligence

HeeJeong Jasmine Lee [a], Nurul Syahira Mohamad Zamani [b], Asma Ashari [c,*], Reuben Axel Wee Ming How [d]

[a] *College of Information and Communication Engineering, Sungkyunkwan University, Suwon, Republic of Korea*
[b] *Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia*
[c] *Department of Family Oral Health, Faculty of Dentistry, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia*
[d] *Visivest Corporation, T2-6&7, 2nd Floor, Wisma SPS, 32 Jalan Imbi, Kuala Lumpur, Malaysia*
*Corresponding author: *asmaashari@ukm.edu.my*

***Abstract*—The rapid advancement of Artificial Intelligence (AI) technology, fueled by the increasing availability of extensive datasets, enhanced computing power, and the development of sophisticated algorithms, has led to its widespread integration into various aspects of daily life. AI is making significant inroads in dentistry, particularly in specialties such as orthodontics, prosthodontics, oral and maxillofacial surgery, and periodontics, where it has begun to transform traditional practices. This comprehensive review synthesizes the current literature to explore the application of AI in orthodontics. The focus is primarily on utilizing AI for image-based diagnostic tasks, including the analysis of radiographic and optical images, while addressing the potential applications, benefits, and inherent limitations of AI for non-image-based tasks within the field. AI demonstrates considerable efficacy in image-based diagnostics within orthodontics, significantly enhancing the accuracy and efficiency of the analyses. However, the application of AI to non-image-based tasks is hindered by several challenges, including the scarcity of quantitative data, the inherent complexity of oral health conditions, and the substantial computational power required to process intricate 3D data. Over the past few decades, orthodontics has undergone profound transformations driven by AI-influenced advancements, such as the development of aesthetically improved treatment alternatives, the seamless integration of digital workflows, and the emergence of cutting-edge imaging techniques. These advancements underscore the potential of AI to revolutionize orthodontic care further, offering innovative solutions that enhance both patient outcomes and clinical practices, while paving the way for future developments in the field.**

***Keywords*—Artificial intelligence; dentistry; machine learning; neural network; orthodontics.**

Manuscript received 10 Jun. 2024; revised 18 Jan. 2025; accepted 10 Mar. 2025. Date of publication 30 Apr. 2025.

I. INTRODUCTION

Artificial intelligence (AI) has been applied in many industries, including robotics, automotive, and financial analysis. Its influence has also extended to health industries, such as medicine and dentistry. In these fields, AI plays diverse roles, encompassing medical and dental imaging diagnostics, predictive analytics, drug development, smart devices, healthcare monitoring, and intelligent virtual assistants. AI applications can significantly reduce the workload of both dentists and clinicians. AI's capabilities are gaining insights from diverse information sources, known as multimodal data, to diagnose conditions rather than depending on conventional single-source information for specific diseases.

Crucial to the success of these endeavors are the concurrent evolution of computing capacity (hardware), expansive databases (input datasets), and algorithmic advancements (software). As these components progress, the prospects for AI integration into health science have become increasingly promising. Numerous ongoing studies and implemented practices have explored AI applications in dentistry, including diagnosis, treatment planning, treatment outcome prediction, and disease prognosis estimation.

This study aims to advance our knowledge of the following domains:

- To encapsulate strides used in AI research in orthodontics.
- To address the constraints inherent in the development of AI in orthodontics.

Malocclusion refers to the misalignment of teeth that occurs when the jaws of the lower and upper arches are brought together [1]. This can cause discomfort and, in some cases, even speech impediments or breathing difficulties. The main goal of dental treatment for this condition is to align the teeth according to specific empirical guidelines. These guidelines are crucial to achieving balanced occlusion and patient compliance, ultimately leading to the success of orthodontic treatment.

Diagnosis of malocclusion requires considerable effort, including clinical examination, dental impressions and models, photographic analysis, radiographic analysis, patient history, and measurement of occlusal relationships, such as cephalometric evaluation. Orthodontic treatment planning traditionally depends on the individual experience and preferences of the orthodontist. Given the uniqueness of each patient and orthodontist, treatment decisions can be subjective. Due to the complexity of diagnosis and clinicians' preferences, developing a treatment plan and predicting treatment outcomes as standards is challenging.

Therefore, AI's potential use is particularly useful for standardizing orthodontic treatment planning and predicting treatment outcomes. AI can significantly enhance communication between patients and dentists, fostering a clear understanding of the impact of orthodontic interventions. Similar to other fields, the widespread use of AI in dentistry is becoming increasingly widespread. AI applications are categorized into diagnosis, decision-making, treatment planning, and treatment outcome prediction. Utilizing AI ultimately reduces the burden on dental professionals. As a result, there has been significant growth in orthodontics that utilizes computer programs to facilitate decision-making processes. Fig. 1 shows the areas of AI in orthodontics used in this study.

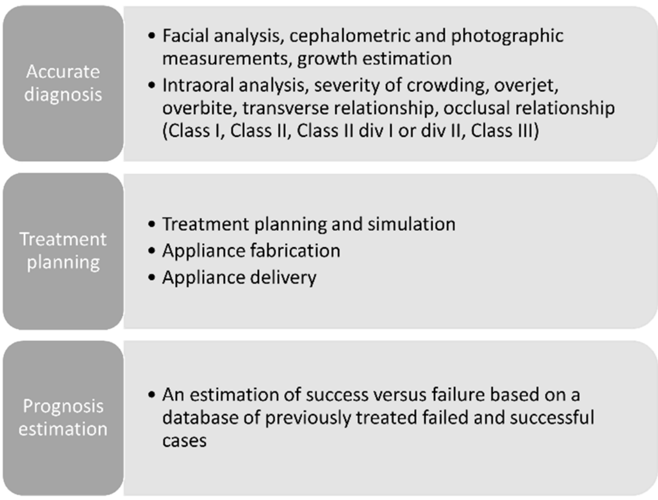

Fig. 1 AI applications in orthodontics.

II. Materials and Methods

The electronic literature search encompassed databases such as Web of Science, Scopus, IEEE Xplore, Cochrane, and MEDLINE/PubMed, spanning September 2013 to September 2023. This meticulous approach ensured the review was grounded in current data. Articles that concentrated on the AI of orthodontics were selected. Inclusion was confined to publications that incorporated Machine Learning (ML) evaluation outcomes such as accuracy, precision, recall, F1-score, etc.

III. Results and Discussion

A. *AI in Diagnosis*

Accurate orthodontic diagnosis relies on information gathered from patients. These data encompass an elaborate catalog of patient issues. Data crucial for orthodontic diagnosis can be sourced from interviews, either written or verbal, thorough clinical assessments, and a detailed review of patient records, which include dental molds, X-rays, and diagnostic images [2].

AI is an optimal diagnostic tool that showcases its utility (as outlined in Table I) in assessing the need for orthodontic diagnosis and skeletal classification. For example, the study of mandibular morphology prediction in skeletal tissue, as illustrated in Fig. 2, has been proposed as an automated learning approach. Choi et al. [3] applied two layers (one hidden layer) of ANN to diagnose orthognathic surgery with a success rate of 0.96. In addition to locating various cephalometric landmarks and facilitating classification, AI systems have been used in orthodontic treatment planning. Choi et al. [3] introduced an AI model designed to assess the necessity of surgical intervention using lateral cephalometric radiographs. A significant portion of orthodontic applications is centered on identifying landmarks and formulating treatment plans. These processes are labor-intensive for orthodontists.

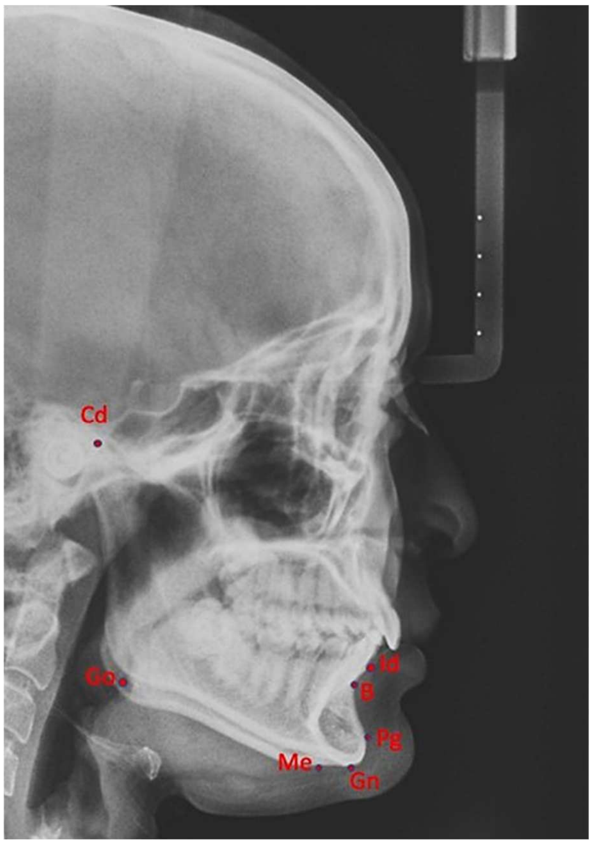

Fig. 2 An example of the mandibular variables used for the prediction of automated learning techniques

TABLE I
AI APPLICATIONS IN DIAGNOSIS

Study/Year	Data type and size	Algorithms	Accuracy and other performances
Diagnosis of Orthognathic Surgery/ 2019 [3]	12 measurement values of the lateral cephalogram and 6 additional indexes/ 316	ANN	Accuracy:0. 96 (diagnosis of surgery/non-surgery decision), 0. 91 (detailed diagnosis of surgery type and extraction decision)
Cephalometric analysis/ 2020 [4]	Lateral cephalograms /2075	Deep neural networks	Accuracy:0. 8843
Identification of cephalometric landmarks/ 2023 [5]	Lateral cephalometric radiograph images / 400 AP cephalometric radiograph images / 163	YOLOV3	Accuracy:0.96–0.98
Diagnosis of TMJOA/ 2023 [6]	CBCT images/ 2737	YOLO	Accuracy: > 0.95
Cephalometric analysis / 2023 [7]	Lateral cephalograms / 85	AI	Accuracy: > 0.90

A completely automated web-based system has been proposed for cephalometric analysis [4]. This system harnesses the power of deep learning to replace the traditional manual marking process, effectively identifying 23 cephalometric landmarks essential for orthodontic and craniomaxillofacial surgical cases, with a classification rate of 0.8843. The performance of this web-based tool was analyzed using 23 ground truths as illustrated in Fig. 3. This technology employs a stacked hourglass network and is meticulously crafted using a diverse dataset of lateral cephalograms obtained from various medical institutions. Training is conducted using 2D cephalometric data, and the resultant web-based application allows users to rectify predicted landmarks as needed, despite the low classification rate compared to a previous study [3].

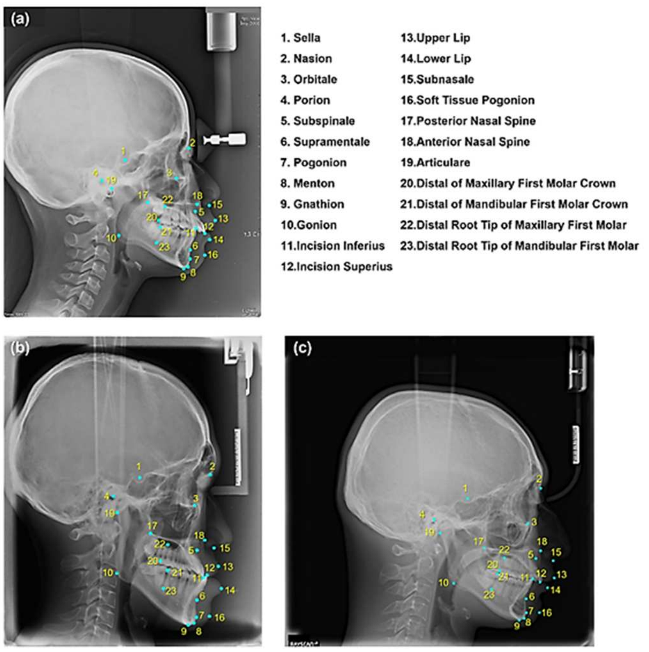

Fig. 3 The examples of 23 ground truth cephalometric landmark positions for cephalometric analysis from three devices (a), (b), and (c) [4]

In addition to its application in predicting extraction for orthodontic purposes, AI has been used to locate cephalometric landmarks. Zhao et al. demonstrated a Deep Learning (DL) algorithm that accurately identifies 19 radiograph cephalometric landmarks, as illustrated in Fig. 4 [5]. This study utilized the You-Only-Look-Once (YOLOv3) deep learning algorithm. The findings show that YOLOv3 has a performance success detection rate of up to 0.96 accuracy for anterior-posterior (AP) cephalograms and more than 0.98 for lateral cephalograms.

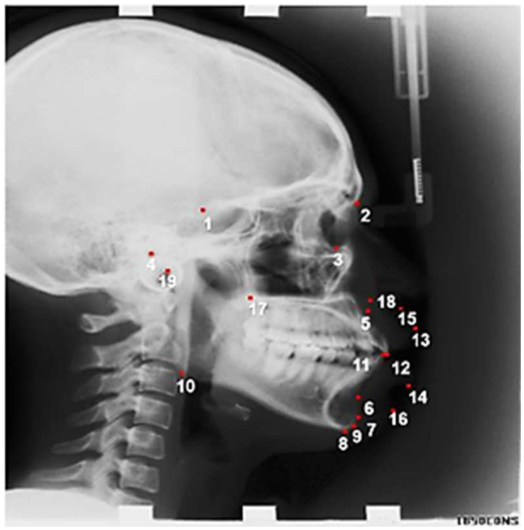
Fig. 4 The 19 lateral landmarks for detection [5]

Another study introduced an automated diagnosis of temporomandibular joint osteoarthritis (TMJOA) using a deep neural network (DNN) of YOLO [6]. YOLO is a deep learning framework used in this study for object detection. The developed system was used on 2737 cone-beam computed tomography (CBCT) images, with an average accuracy of more than 0.95. According to the author, this study has high potential for assisting clinicians in diagnosing TMJOA. Using AI approaches, Bao et al. [7] proposed an automated system for analyzing lateral cephalometric radiographs of 85 CBCT images. The diagnostic performance of the proposed system was more than 0.90 in distinguishing the classes of cephalograms.

B. AI in Treatment

In addition to AI diagnostics, the implementation of AI has surfaced as a revolutionary influence across multiple domains, including treatment planning. This section provides an overview of AI applications in treatment planning and prognostication of treatment outcomes (as outlined in Table

2). One notable application involves simulating alterations in the visual aspect of facial photographs pre- and post-treatment. AI algorithms significantly enhance the visualization of orthodontic treatment impacts, skeletal configurations, and anatomical reference points in lateral cephalograms [8]. This technology is pivotal in improving communication between dental practitioners and their patients. AI can assist in creating personalized treatment plans for patients, including orthodontic treatment, prosthodontics, and oral and maxillofacial surgery.

TABLE II
AI APPLICATIONS IN TREATMENT

Study/Year	Data type and size	Algorithms	Accuracy and other performances
Tooth extraction determination/ 2010 [9]	23 indices / 200	ANN	Accuracy: 0.8
Assessing the needs for orthodontic treatment /2018 [13]	Data about oral conditions in the field of orthodontics / 1000	Bayesian network	Accuracy: 0.96 AUC: 0.91 Sensitivity: 0.95 Specificity: 1.00
Tooth segmentation / 2021 [14]	Dental models from intraoral scanner/ 2000	CNN	Accuracy: 0.980–0.986, F1: 0.942
Tooth and alveolar bone segmentation / 2022 [15]	Cone-beam CT (CBCT) images /4938	CNN	Accuracy: 0.915 (tooth) and 0.93 (alveolar bone)
Tooth landmark/axis detection/2022 [16]	Intra-oral scanned data and the CBCT data/ 3084	Deep neural networks	Average errors: 0.37 mm (tooth landmarks); 3.33° (axis detection)

Over a decade ago, AI technologies have shown impressive achievements in treatment planning in orthodontics, which hold immense potential to significantly improve the quality of care required for orthodontic patients while optimizing treatment outcomes. For instance, an ANN model was proposed to assess extraction requirements based on lateral cephalometric radiographs [9]. The proposed ANN model utilized 23 backpropagation neuron layers to train 180 images and 20 images to test the network. The backpropagation method aims to minimize/optimize the overall loss by propagating the error gradient of each layer from the output layer back to the input layer [10]. A perfect score for training and an overall 0.80 accuracy were recorded for testing. Therefore, an accuracy of 0.80 was decided for extraction treatment to solve malocclusion cases rather than non-extraction treatment for 11- and 15-year-old patients. It appears that the network overfits the training data, resulting in low accuracy of the testing data and ultimately leading to an underfitting problem. This constraint may stem from the insufficient amount of data being utilized. Nevertheless, an accuracy of 0.80 can be accepted in most image classification scores [11], [12].

A clinical decision support system (graphical user interface) was proposed by utilizing input data related to orthodontics on a Bayesian network for clinical/practitioner assessment [13]. The developed system was tested for 15 variables, according to the need for orthodontic treatment. The evaluated performance was in contrast with the assessment from two orthodontists, indicating a high need for orthodontic treatment for the patient. With excellent accuracy, the area under the curve (AUC), sensitivity, and specificity were 0.96, 0.91, 0.95, and a perfect score for specificity.

The considerations of orthodontic treatment in previous research, including tooth extraction/non-extraction or orthognathic surgery, appear to have subsequent effects on socio-psychological factors, particularly facial aesthetics. Understanding the adequacy of treatment planning is crucial to ensuring its suitability in predicting facial alterations. Therefore, an AI-based system was developed to predict morphological facial soft tissues, particularly after orthodontic treatment (tooth extraction) and orthognathic surgery [11]. Two deep learning algorithms were employed: System E and System S, with only two dense layers and one dropout layer. On average, this study was evaluated on system error of <1 mm 0.81 (0.98 [E] and 0.54 [S]) and system error of <2 mm (1.00 for both systems). These findings have significant potential for clinical applications in system settings.

A fundamental task in orthodontic treatment planning involves segmenting and categorizing teeth. AI has been used to achieve these objectives by analysing a range of data sources, such as radiographs and full-arch 3D digital optical scans, to detect various dental abnormalities, as shown in Fig. 5 [14].

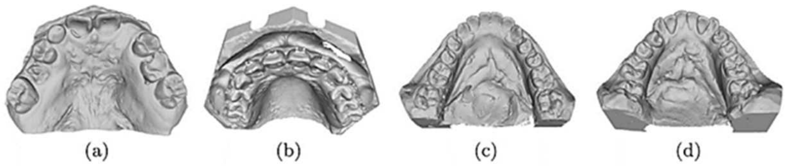

Fig. 5 The examples of the teeth abnormalities (a) missing teeth, (b) additional braces, (c) blurred boundary signals between incisors and the gum, and (d) crowding teeth [14]

Cui et al. proposed various AI approaches to automate tooth segmentation on digital models acquired through 3D intraoral scanners and CBCT images in Fig. 6 [15], [16]. Beyond tooth segmentation, their algorithms were extended to the segmentation of the alveolar bone, showing an efficiency surpassing that of radiologists (with a speed advantage of 500 times). The study also asserted the algorithm's efficacy in handling complex cases with varying dental irregularities.

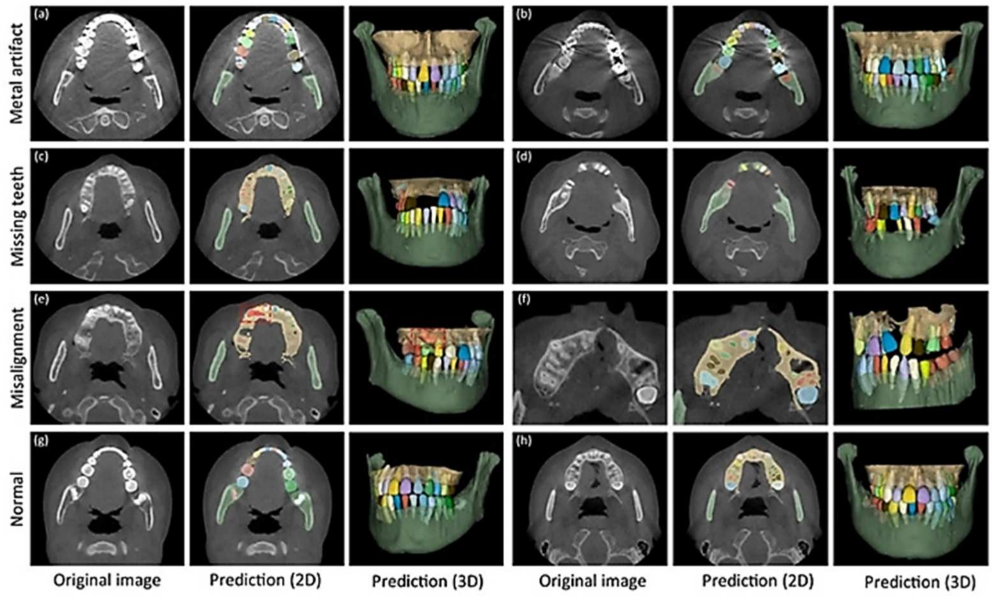

Fig. 6 Other examples of the teeth abnormalities with metal artifacts (a, b), missing teeth (c, d), misalignment (e, f), and regular teeth (g, h) [15]

Meanwhile, a novel deep learning framework was proposed to detect tooth landmarks and axes using multi-scale feature extraction with abstractions [16]. The proposed deep learning method for abstraction efficiently captures general patterns in a specific learning capability [17], [18], [19]. This work has successfully provided an efficient approach to automatically detect tooth landmarks and axes with an accuracy of 0.9955 accuracy compared with other convolutional networks within an appropriate training time.

C. AI in Prognosis Estimation

In this section, we aim to elucidate the pivotal contributions of AI in prognosis estimation within orthodontics, as listed in Table 3, to assist orthodontists in predicting and assessing the outcomes of orthodontic treatment for individual patients. For example, a prognosis prediction model was proposed to predict unexpected treatment results involving tooth extractions and accurately understand the factors influencing the model's choice to recommend extractions [20]. The developed model employing a template-matching technique was then compared with the decisions made by orthodontic experts, achieving a high accuracy rate of 0.904. This indicates that tooth extraction was advised with an accuracy of 0.904. The authors modified the model [21] and obtained an accuracy of 0.86, which is relatively low compared to the previous model. The template-matching technique involves a sliding window, as performed by CNNs, to capture patterns and features in information processing [22], [23], [24], [25].

In the same year, another system was proposed using a feature wrapping method with a sequential forward search (SFS) algorithm and a support vector machine (SVM) to predict Class III malocclusion [26]. SFS is a feature selection method to improve the classification accuracy [27]. This method predicted that the classification rate of 0.972 was slightly better than discriminant analysis (0.91) and higher than that reported in previous studies [20], [21]. Regardless of the lack of comprehensive current research, particularly the implementation of AI in prognosis estimation, the developed system's performance has shown an impressive classification rate.

D. Challenges of AI in Orthodontics

A rigorous overview of existing comprehensive studies of AI in various facets of healthcare has marked a transformative leap towards precision and efficiency. In orthodontics, AI is poised to revolutionize traditional paradigms, offering promising avenues for precise diagnosis, tailored treatment planning, and accurate prognosis estimation. However, this potential is met by several challenges that require careful consideration.

TABLE III
AI APPLICATIONS IN PROGNOSIS ESTIMATION

Study/Year	Data type and size	Algorithm	Accuracy and other performance
Tooth-Extraction Decisions / 2009 [20]	Data about oral conditions in the field of orthodontics/188	Template matching	Accuracy: 0.904
Tooth-Extraction Decisions / 2009 [21]	Data about oral conditions in the field of orthodontics/192	Template matching	Accuracy: 0.86
Orthodontic treatment prediction / 2009 [26]	Lateral cephalogram/38	Sequential forward search and SVM	Accuracy: 0.972

The performance of these algorithms can be affected by factors such as image quality, landmark variability, and occlusion. For example, the challenges in detecting tooth landmarks and axes in digital orthodontics include the fact that most tooth landmarks and axes do not correspond to any sharp geometry on the given tooth model and that the inconspicuous characteristics of the tooth surface make it difficult to fully detect all landmarks and axes [16]. The effective treatment of malocclusion, a prevalent concern in orthodontics, is contingent upon the accurate localization of landmarks and axes. Notably, prevailing AI algorithms have yet to integrate facial analysis fully into their algorithms, which is essential for determining the impact of orthodontic dental movements on facial aesthetics [28], [29], [30]. Additionally, AI ignores the existence of oral diseases and cannot consider the impact of functional problems on treatment. Another challenge is that discrepancies between the accounts presented at professional conferences regarding the public health impacts of such interventions and the corresponding reports featured in scientific journals may exist. Within the clinical and scientific communities, there is an underlying sense of apprehension and pressure regarding the potential legal implications of disclosing the exposure of the damage caused by these alleged corrections.

The successful implementation of AI in orthodontics requires large-scale, high-quality datasets to train algorithms effectively [31], [32], [33]. This can pose challenges, especially in rare or complex cases within the field. Moreover, the models require expert decision-making capabilities to interpret, validate, and test results, ensuring their accuracy and reliability. The lack of standardization in the variables used to construct prediction models across studies may present difficulties for healthcare providers and potentially lead to inconsistent results. Subsequently, integrating AI into orthognathic surgery requires significant investments in technology and training. In addition, ethical and legal concerns, such as patient privacy, data security, and liability, must be considered when employing AI in orthodontics [8], [32], [34], [35].

Although AI provides precise and accurate diagnoses, it cannot replace the empathic human expertise essential in inpatient care and the judgment of healthcare professionals. Therefore, its function is to complement and enhance clinicians' skills. It may also be highly beneficial for general dental practitioners interested in orthodontics to utilize AI to assist their decisions, as they are not as extensively trained as specialist orthodontists. Thus, it is imperative to meticulously assess the advantages and risks of incorporating AI into orthodontics, striking a balance between human touch in orthodontics and orthognathic surgery, to develop guidelines and standards for its use. AI models have not yet been widely adopted globally in orthodontics, underscoring the need for further research to enhance their performance and accuracy, especially in prognosis estimation applications.

IV. Conclusion

This article offers an in-depth review of AI's applications in orthodontics. The evolution of AI algorithms and enhancements in computational capabilities have contributed to increased efficiency, precision, and dependability in orthodontic treatment. The central aim of incorporating AI into orthodontics is to increase the precision and accuracy of dental practitioners' endeavors.

This study highlights the crucial role of AI in orthodontics for precise diagnosis, strategic treatment planning, and accurate prognosis. AI empowers orthodontists in decision-making to improve patient outcomes by harnessing data-driven insights and computational methods. This advanced technology enhances the quality of care, increases treatment efficiency, and reduces time consumption.

Furthermore, this article enumerates various AI applications pertinent to orthodontics, encompassing decision-making processes related to tooth extraction, facial analysis, bone segmentation, and anticipating orthognathic surgery outcomes.

Acknowledgment

This work was supported in part by the National Research Foundation of Korea (NRF) grant funded by Korean Government (MSIT) under Grant RS-2023-00250496, and in part by the National Research and Development Program through the National Research Foundation of Korea (NRF) funded by Ministry of Science and ICT under Grant RS-2020-NR047143, and Universiti Kebangsaan Malaysia (UKM DD-2023-006).

References

[1] N. S. M. Zamani et al., "Distributed force measurement and mapping using pressure-sensitive film and image processing for active and passive aligners on orthodontic attachments," IEEE Access, vol. 10, pp. 52853–52865, 2022, doi: 10.1109/access.2022.3175210.

[2] B. S. Akdeniz and M. E. Tosun, "A review of the use of artificial intelligence in orthodontics," Journal of Experimental and Clinical Medicine (Turkey), vol. 38, no. 3s, pp. 157–162, 2021, doi:10.52142/omujecm.38.si.dent.13.

[3] H. Il Choi et al., "Artificial intelligent model with neural network machine learning for the diagnosis of orthognathic surgery," Journal of Craniofacial Surgery, vol. 30, no. 7, pp. 1986–1989, 2019, doi:10.1097/scs.0000000000005650.

[4] H. Kim, E. Shim, J. Park, Y. J. Kim, U. Lee, and Y. Kim, "Web-based fully automated cephalometric analysis by deep learning," Comput Methods Programs Biomed, vol. 194, p. 105513, 2020, doi:10.1016/j.cmpb.2020.105513.

[5] C. Zhao et al., "Automatic recognition of cephalometric landmarks via multi-scale sampling strategy," Heliyon, vol. 9, no. 6, Jun. 2023, doi:10.1016/j.heliyon.2023.e17459.

[6] W. M. Talaat et al., "An artificial intelligence model for the radiographic diagnosis of osteoarthritis of the temporomandibular joint," Sci Rep, vol. 13, no. 1, Dec. 2023, doi: 10.1038/s41598-023-43277-6.

[7] H. Bao et al., "Evaluating the accuracy of automated cephalometric analysis based on artificial intelligence," BMC Oral Health, vol. 23, no. 1, Dec. 2023, doi: 10.1186/s12903-023-02881-8.

[8] H. Ding, J. Wu, W. Zhao, J. P. Matinlinna, M. F. Burrow, and J. K. H. Tsoi, "Artificial intelligence in dentistry—A review," Frontiers in Dental Medicine, vol. 4, pp. 1–13, 2023, doi:10.3389/fdmed.2023.1085251.

[9] X. Xie, L. Wang, and A. Wang, "Artificial neural network modeling for deciding if extractions are necessary prior to orthodontic treatment," Angle Orthodontist, vol. 80, no. 2, pp. 262–266, 2010, doi:10.2319/111608-588.1.

[10] M. Li, "Comprehensive review of backpropagation neural networks," Academic Journal of Science and Technology , vol. 9, no. 1, pp. 1–5, 2024, doi: 10.54097/51y16r47.

[11] C. Tanikawa and T. Yamashiro, "Development of novel artificial intelligence systems to predict facial morphology after orthognathic surgery and orthodontic treatment in Japanese patients," Sci Rep, vol. 11, no. 1, p. 15853, 2021, doi: 10.1038/s41598-021-95002-w.

[12] N. S. M. Zamani, E. Yoon Choong Hoe, A. B. Huddin, W. M. D. Wan Zaki, and Z. Abd Hamid, "Deep learning for an automated image-based stem cell classification," Jurnal Kejuruteraan, vol. 35, no. 5, pp. 1181–1189, Sep. 2023, doi: 10.17576/jkukm-2023-35(5)-18.

[13] B. Thanathornwong, "Bayesian-based decision support system for assessing the needs for orthodontic treatment," Healthc Inform Res, vol. 24, no. 1, pp. 22–28, 2018, doi: 10.4258/hir.2018.24.1.22.

[14] Z. Cui et al., "TSegNet: An efficient and accurate tooth segmentation network on 3D dental model," Med Image Anal, vol. 69, p. 101949, 2021, doi: 10.1016/j.media.2020.101949.

[15] Z. Cui et al., "A fully automatic AI system for tooth and alveolar bone segmentation from cone-beam CT images," Nat Commun, vol. 13, no. 1, pp. 1–11, 2022, doi: 10.1038/s41467-022-29637-2.

[16] G. Wei et al., "Dense representative tooth landmark/axis detection network on 3D model," Comput Aided Geom Des, vol. 94, p. 102077, 2022, doi: 10.1016/j.cagd.2022.102077.

[17] M. Mitchell, "Abstraction and analogy-making in artificial intelligence," Ann N Y Acad Sci, vol. 1505, no. 1, pp. 79–101, 2021, doi: 10.1111/nyas.14619.
[18] S. Kumar, I. Dasgupta, R. Marjieh, N. D. Daw, J. D. Cohen, and T. L. Griffiths, "Disentangling abstraction from statistical pattern matching in human and machine learning," PLoS Comput Biol, vol. 19, no. 8, pp. 1–21, 2023, doi: 10.1371/journal.pcbi.1011316.
[19] S. F. Ahmed et al., "Deep learning modelling techniques: current progress, applications, advantages, and challenges," Artif Intell Rev, vol. 56, no. 11, pp. 13521–13617, Nov. 2023, doi: 10.1007/s10462-023-10466-8.
[20] K. Takada, M. Yagi, and H. Eriko, "Computational formulation of orthodontic tooth-extraction decisions: Part I: To extract or not to extract," Angle Orthodontist, vol. 79, no. 5, pp. 885–891, 2009, doi:10.2319/081908-436.1.
[21] M. Yagi, H. Ohno, and K. Takada, "Computational formulation of orthodontic tooth-extraction decisions: Part II: Which tooth should be extracted?," Angle Orthodontist, vol. 79, no. 5, pp. 892–898, 2009, doi:10.2319/081908-439.1.
[22] S. Wang et al., "Automatic laser profile recognition and fast tracking for structured light measurement using deep learning and template matching," Measurement (Lond), vol. 169, Feb. 2021, doi:10.1016/j.measurement.2020.108362.
[23] D. Luo, W. Zeng, J. Chen, and W. Tang, "Deep learning for automatic image segmentation in stomatology and its clinical application," Front Med Technol, vol. 3, 2021, doi: 10.3389/fmedt.2021.767836.
[24] M. M. Taye, "Theoretical understanding of convolutional neural network: Concepts, architectures, applications, future directions," Computation, vol. 11, no. 3, pp. 1–23, 2023, doi:10.3390/computation11030052.
[25] A. A. Tulbure, A. A. Tulbure, and E. H. Dulf, "A review on modern defect detection models using DCNNs – Deep convolutional neural networks," J Adv Res, vol. 35, pp. 33–48, 2022, doi:10.1016/j.jare.2021.03.015.
[26] B. M. Kim, B. Y. Kang, H. G. Kim, and S. H. Baek, "Prognosis prediction for class III malocclusion treatment by feature wrapping method," Angle Orthodontist, vol. 79, no. 4, pp. 683–691, 2009, doi:10.2319/071508-371.1.
[27] L. Gong, S. Xie, Y. Zhang, M. Wang, and X. Wang, "Hybrid feature selection method based on feature subset and factor analysis," IEEE Access, vol. 10, pp. 120792–120803, 2022, doi:10.1109/access.2022.3222812.
[28] B. Shan, M. Werger, W. Huang, and D. B. Giddon, "Quantitating the art and science of esthetic clinical success," Jun. 01, 2021, Elsevier Inc. doi: 10.1016/j.ejwf.2021.03.004.
[29] G. Dipalma et al., "Artificial intelligence and its clinical applications in orthodontics: A systematic review," Diagnostics, vol. 13, no. 24, Dec. 2023, doi: 10.3390/diagnostics13243677.
[30] R. T. Kondody, A. Patil, G. Devika, A. Jose, A. Kumar, and S. Nair, "Introduction to artificial intelligence and machine learning into orthodontics: A review," APOS Trends in Orthodontics, vol. 12, no. 3, pp. 214–220, Jul. 2022, doi: 10.25259/APOS_60_2021.
[31] T. A. Siddiqui, R. H. Sukhia, and D. Ghandhi, "Artificial intelligence in dentistry, orthodontics and orthognathic surgery: A literature review," J Pak Med Assoc, vol. 72, no. 1, pp. 91–96, 2022, doi:10.47391/jpma.aku-18.
[32] Y. M. Bichu, I. Hansa, A. Y. Bichu, P. Premjani, C. Flores-Mir, and N. R. Vaid, "Applications of artificial intelligence and machine learning in orthodontics: a scoping review," Prog Orthod, vol. 22, no. 18, pp. 1–11, 2021, doi: 10.1186/s40510-021-00361-9.
[33] V. Allareddy et al., "Call for algorithmic fairness to mitigate amplification of racial biases in artificial intelligence models used in orthodontics and craniofacial health," Dec. 01, 2023, John Wiley and Sons Inc. doi: 10.1111/ocr.12721.
[34] C. M. Mörch et al., "Artificial intelligence and ethics in dentistry: A scoping review," J Dent Res, vol. 100, no. 13, pp. 1452–1460, 2021, doi: 10.1177/00220345211013808.
[35] M. I. Khan, S. M. Laxmikanth, T. Gopal, and P. K. Neela, "Artificial intelligence and 3D printing technology in orthodontics: future and scope," AIMS Biophys, vol. 9, no. 3, pp. 182–197, 2022, doi:10.3934/biophy.2022016.