Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 18s (2025)
https://www.jneonatalsurg.com

Integration of Artificial Intelligence in Orthodontic Diagnosis and Treatment Planning

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Cite this paper as: Dr. Vaishnavi N S, Dr. Suma R, Dr. Rodoshi Roy, Dr. K S Sphoorthi, Dr. Salman Ali Khan, Dr. Krithi S, (2025) Integration of Artificial Intelligence in Orthodontic Diagnosis and Treatment Planning. *Journal of Neonatal Surgery*, 14 (18s), 707-712.

ABSTRACT

Technology has become a part of our daily lives, where an amalgamation of human intelligence and machine learning has influenced our lives to great heights. The machine simulates human intelligence and enhances its responses with self-adapting algorithms. Artificial Intelligence (AI) is transforming the field of orthodontics by enhanced precision in diagnosis, better treatment planning and hence improved patient care. Additionally, AI has contributed immensely to the growth of virtual treatment planning and remote orthodontic consultations, making specialized individualized care more accessible. As AI continues to expand its integration into orthodontic diagnosis and treatment planning is expected to further refine clinical outcomes and patient related care. This paper explores the evolving role of AI in orthodontics, emphasizing its current applications, benefits, drawbacks and future possibilities.

Keywords: Artificial intelligence, Machine learning, orthodontics, diagnosis, treatment planning.

1. INTRODUCTION

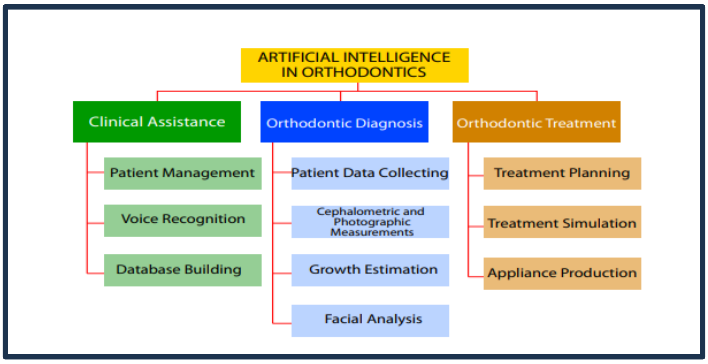
Artificial intelligence (AI) has been defined as the ability of a computer to perform tasks intelligently, equivalent to a human being, incorporating understanding and processing language with reasoning skills and problem-solving ability. AI can be further classified into sub fields like machine learning (ML), cognitive computing, deep learning, natural language processing, and expert systems.[6] In 1956, the term AI was coined by John McCarthy and adopted during a meeting at Dart mouth College.[2]

The goal of orthodontic treatment involves restoring normal occlusion as well as to improve facial aesthetics. Moreover, malocclusion is a very common issue and has a high prevalence of 56%.[5] The diagnosis of any malocclusion is made with precise measurements of distances, planes, and angles on cephalograms or CBCT images. However, because different orthodontists have different definitions of anatomic landmarks, the results of landmark coordinates and geometrical parameters vary greatly between the two methods and are mostly dependent on the image quality and the orthodontist's experience. Furthermore, diagnosing malocclusion involves time-consuming procedures.

Another essential component of orthodontic procedures is treatment planning. For example, orthodontists frequently have to decide between orthodontic therapy that involves extraction versus orthodontic treatment that does not. Additionally, patients with significant skeletal malocclusion and asymmetric jaw deformity should exercise caution when choosing orthodontic-orthognathic combined treatment due to the increased risk. In general, the long-term prognosis is significantly impacted by orthodontic decision-making. Effective techniques are therefore required to assist human specialists in enhancing their treatment planning and lowering inter-physician variability.[5]

So, this review addresses the integration of AI into various aspects diagnosis and treatment planning orthodontics.

Application of AI in various aspects of diagnosis and treatment planning in orthodontics



Areas of use of AI in Orthodontics[1]

CNN and ANN have been utilised for extraction prediction, orthodontic treatment need, cephalometric analysis, and age and gender discrimination. Neural networks have a role to play in diagnostic interpretations utilising computed tomography (CT), cone-beam computed tomography (CBCT), lateral cephalograms, bitewing, facial photographs and orthopantomograms.[6]

2. ARTIFICIAL INTELLIGENCE AND ORTHODONTIC DIAGNOSIS

Having thorough diagnoses, precise treatment plans, and accurate outcome forecasts are essential for successful orthodontic treatments. A proper orthodontic diagnosis requires a comprehensive evaluation of the patient, which involves looking at the patient's facial profile, skeletal and dental relationship, skeletal maturation stages, and upper airway patency. These analyses include upper-airway blockage, skeletal maturation determination, face analysis, dental analysis, and cephalometric analysis. Additionally, skeletal malocclusions from 3D CBCT craniofacial scans have been automatically identified and classified using AI.[3]

Therefore, the application of AI unquestionably lessens the labour for doctors doing assessments and enhances the relationship between diagnostic accuracy, skeletal maturation phases, and upper-airway patency.

1. Dental Analysis

Orthodontic study models and intraoral photos are essential for dental analysis in orthodontic clinical practice. The YOLO algorithm was used by Talaat et al. to identify malocclusion in intraoral photos, specifically crowding or spacing of teeth, abnormal overjet or overbite, and crossbite. The results demonstrated a remarkable 99.99% accuracy rate. When Ryu et al. evaluated tooth crowding using four CNN algorithms, they found that VGG19 had the lowest mean errors in the mandible (1.06 mm) and maxilla (0.84 mm).[13]

2. Facial Analysis

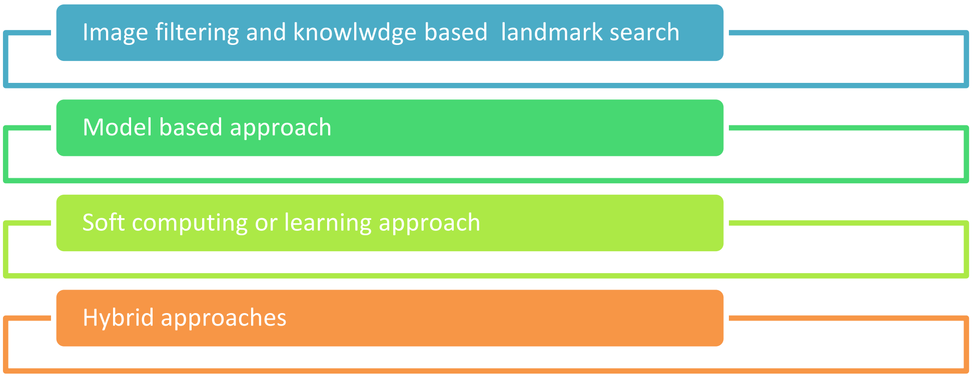
Facial photographs play a pivotal role in evaluating facial asymmetry and proportions. Rousseau et al. employed a CNN to analyse the vertical dimension of patients. The results showed higher precision and efficiency than manual measurements, with the 95%.[13]

3. Automated cephalometric tracing

The precision and reproducibility of landmark recognition determine the analysis's diagnostic value. Identifying landmarks is the main difficulty faced by manual cephalometry. Despite being a crucial procedure in orthodontics, manual cephalometric analysis is prone to human error. Convolutional neural networks and other machine learning AI methods have been created for graphic picture analysis in order to address this. Additionally, AI algorithms can improve contrast, eliminate noise, and fine-tune images to provide dentists sharper radiographs.

Research has demonstrated the potential of convolutional neural networks (CNNs) in facilitating skeletal orthodontic diagnoses while eliminating the need for intricate intermediary procedures. A study by Yu et al. introduced a system that achieved over 95% sensitivity, specificity, and accuracy in diagnosing vertical and sagittal skeletal patterns.[2]

Additionally, another study assessed the capability of artificial neural networks (ANNs) in identifying frontal cephalometric landmarks compared to human evaluators. The results suggested that ANNs could accurately pinpoint cephalometric landmarks, often matching human precision and, in some cases, outperforming less experienced clinicians.[2] Guo et al. (2021)16 also came to the conclusion that the drawbacks of manual identification methods can be effectively overcome by a deep learning technique free from human intervention. [3]



Approaches to identify landmarks [9]

4. Estimation of growth / Determination of skeletal age

The adoption of tools that may automate this evaluation, such as machine learning, can be very beneficial because it is a time-consuming process that may be impacted by inter- and intra-rater variability. For figuring out Cervical Vertebrae Maturation, ANN would be the recommended technique.[3] An ANN model was created by Amasya H. et al. (2020)[15] to ascertain skeletal age. The ANN model's repeatability and reproducibility fell within human observational bounds. In order to classify the resulting growth data and track the relationships between the different development patterns, 3ux et al. created an artificial neural network known as self organizing neural maps.[4] Seo et al. were able to show that their forecasts for various AI systems had an accuracy of over 90%.[12]

5. Size prediction of unerupted teeth

In order to plan the treatment, Moghimi et al. (2012) forecasted the size of unerupted teeth. He predicted the canine and premolar sizes using genetic algorithms and a neural network hybrid system.[5]

6. Palatal shape analysis

The form of the palate is influenced by a variety of factors, including breathing patterns and occlusion, as well as facial patterns. A deep learning model for palatal shape analysis was presented by Croquet B et al. This automated model showed good accuracy and outstanding repeatability.[10]

7. Upper airway obstruction

Airway obstruction and skeletal deformities have a reciprocal effect. Breathing changes brought on by upper airway congestion may impact the normal development of craniofacial features and result in abnormalities. Lateral cephalograms have demonstrated a high degree of accuracy and dependability in detecting adenoid enlargement. The hierarchical masks self-attention U net (HMSAU-Net) and 3D-ResNet are two deep learning algorithms that Dong et al. suggested to autonomously split upper airways and diagnose adenoid hypertrophy from CBCT, respectively. Notably, the adenoid hypertrophy diagnosis model attained a high accuracy of 0.912.[13]

Moreover, AI can help not only to diagnose orthodontic findings but also to detect contraindications for orthodontic treatment, like the presence of active carious lesions, apical lesions, or periodontal bone loss.

Artificial intelligence in treatment planning –

CNN and ANN have been utilised for extraction prediction, orthodontic treatment need, cephalometric analysis, and age and gender discrimination. Neural networks have a role to play in diagnostic interpretations utilising computed tomography (CT), cone-beam computed tomography (CBCT), lateral cephalograms, bitewing, facial photographs and orthopantomograms

a) Extraction decision –

The two major reasons for extraction of teeth are

- Space to align the teeth in the presence of severe crowding

- To allow the teeth to be moved (usually to retract incisors) so that the protrusion can be reduced, or the skeletal Class II or Class III problems can be camouflaged.
  With the multitude of clinical, radiographic, and even sociocultural factors that must be considered when deciding on the indication for orthodontic extraction therapy.

Orthodontic extraction therapy requires careful consideration of multiple factors, including clinical assessments, radiographic findings, and even sociocultural influences. To assist in this decision-making process, Xie et al. (2010) developed an artificial neural network (ANN) system to evaluate whether patients with malocclusions, aged 11 to 15 years, would benefit more from extraction or non-extraction treatment. Their findings demonstrated an 80% accuracy rate, aligning with similar studies conducted by Jung et al. (2016) and Choi et al. (2019).
Further advancements in AI-driven orthodontic analysis were made by Kong et al., who employed a multilayer perceptron-based artificial neural network to predict treatment plans. Their system determined whether extractions were necessary, identified the extraction pattern, and assessed anchorage requirements. The study reported an accuracy rate of 94% for extraction decisions, 84.2% for extraction patterns, and 92.8% for anchorage assessments.[4]
Additionally, research conducted by Alberto et al. explored the effectiveness of three different predictive models for assessing the need for orthodontic extractions. Using an automated machine learning (AutoML) approach, these models achieved up to 93.9% accuracy in predicting tooth extraction requirements, demonstrating performance comparable to more intricate analytical methods.[8]

b) **Head gear** - Akgam et al. developed a computer assisted inference model for selecting the right type of headgear appliance that acted as a decision-making aid for less experienced orthodontists. [4]

c) **Soft tissue** - Nanda SB et al. proved that ANN could predict the changes in the lip curvature following orthodontic treatment with or without extractions. The predicted change and actual change was 29.6 % and 7 % for upper and lower lip respectively. [4]

d) **Decision for surgery** – Knoops et al. utilized an SVM model to diagnose whether patients needed orthognathic surgery using facial scanning images. Although the system achieved an accuracy of 95.4%, sample selection bias was used because of the fact that normal dentofacial individuals were chosen as non-surgery patients. The CNN model could extract the profile feature from the front and side facial photographs, and subsequently divided the cases into surgery and non-surgery. [5]
Stehrer R et al. reported on an AI model for predicting perioperative blood loss following orthognathic surgery. The model demonstrated an excellent result and efficiently predicted the perioperative blood loss prior to surgery. [10]
Tanikawa C et al. reported on an AI model designed for predicting facial morphology post orthognathic surgery. The model demonstrated an excellent success rate in predicting facial morphology. Kim YH et al. reported on an AI based deep learning model designed to diagnose orthognathic surgery. The model demonstrated excellent performance in predicting the diagnosis of orthognathic surgery [10]

e) **Management of impacted canines-**Impacted canine needs a complex therapeutic management requiring interdisciplinary approach for the final orthodontic and periodontal outcome.
The random forest algorithm proved to have highest accuracy and precisely anticipated the eruption status of canine (83 %).[5] Wang et al. introduced a machine learning method called Learning-based multi-source IntegratioN frameworK for Segmentation (LINKS), which was used with CBCT to quantify the variation in maxilla in cases of unilateral canine impaction

8. Patient compliance and communication

Artificial intelligence (AI) has the potential to transform patient follow-up procedures by utilizing remotely gathered data from wearable devices and imaging technologies. Research by Prasad et al. (2023) highlights this advancement. The integration of AI into telemonitoring software has been well-received by both patients and dental professionals, as noted in a study by Dalessandri et al. (2021). [16]
However, the use of AI-driven applications to provide medical guidance without the involvement of healthcare professionals raises ethical and legal concerns. Schneeberger et al. (2020) have emphasized the risks associated with relying solely on AI for medical decision-making, highlighting the need for professional oversight in patient care.

9. Orthodontic treatment outcome

Peer Assessment Rating (PAR) was introduced by Richmond et al. (1992) to assess the results of orthodontic treatment. It summarizes the information on misalignment and variation from the optimal occlusion. By comparing the PAR scores before and after treatment, the success is evaluated.
Zarei et al. (2006) developed ANN to predict the treatment outcomes in Class II and Class III patients. Kim et al. (2009) developed a system called feature wrapping to precisely predict the prognosis of Class III treatment.[4]

3. LIMITATIONS TO USING AI-POWERED SYSTEMS IN ORTHODONTICS:

1. **Accuracy**: AI-powered systems can help with diagnosis and treatment planning, but they are not as accurate as a trained orthodontist in identifying and treating complex cases, although some reports have shown that the level of accuracy is nearing the human level.
2. **Expertise**: AI systems do not have the same level of clinical expertise as a trained orthodontist. They may not be able to fully understand the patient's needs and cannot provide the same level of individualized care.
3. **Ethical concerns**: There are also ethical concerns about the use of AI in healthcare, including the possibility of biased algorithms and the potential to replace human labor with automation
4. **Cost**: AI systems can be expensive to implement and maintain and may not be accessible to all patients or clinicians.
5. **Regulation**: the use of AI in healthcare also comes with regulatory challenges. These include the need for oversight to ensure the accuracy and safety of AI-powered systems

4. CONCLUSION

The integration of artificial intelligence (AI) in orthodontic diagnosis and treatment planning is revolutionizing the field by enhancing diagnostic precision, streamlining workflows, and improving patient outcomes. AI-driven technologies, including machine learning models and deep neural networks, assist in analysing complex orthodontic data, predicting treatment needs, and optimizing clinical decisions. While AI offers remarkable advancements, ethical considerations and the necessity of human expertise remain crucial in ensuring safe and effective patient care. As AI continues to evolve, its synergy with orthodontics promises a future of more efficient, accurate, and personalized treatment approaches, ultimately enhancing both practitioner efficiency and patient satisfaction.

With deep learning techniques it is possible to eliminate the subjectivity associated with human decision-making; traditional manual methods are likely to incorporate a relatively higher degree of intra- and inter observer errors due to that subjectivity, which can lead to an increase in the prediction error.

AI could become a valuable tool to use in those procedures that require high precision and are more time consuming, such as indirect bonding, precise Analysis or wire bending, in order to increase the quality of the treatments we offer to our patients.

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