Original Article MedInform

DOI: 10.18044/MEDINFORM.2025121.2002 ISSUE 1, 2025

Capabilities and Limitations of Artificial Intelligence in Cephalometric Analysis

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Abstract

Introduction: Digital technologies are rapidly entering dentistry and artificial intelligence is incorporated into the diagnostic processes. In orthodontic practice, is has been integrated into the cephalometric analyses in order to improve the diagnostic accuracy, the treatment plan development, and outcome prediction. The automation of the cephalometry still has systematic and random errors. The aim is to establish the accuracy of a fully automatic cephalometric analysis versus automatic one in which the orthodontist controls the accuracy of the reference points.
Materials and methods: The present study utilized lateral teleradiographs of 30 patients before orthodontic treatment. The study includes measuring the difference of six parameters - ∢SNA, ∢SNB, ∢I/SN, ∢i/MP, ∢MP/SN, ∢MP/FH. The cephalometric analysis was first performed by the software. The second analysis was done on the same radiograph with orthodontist controlling the placement of the reference points after the automatic positioning. The analysis was conducted using the Planmeca Romexis Cephalometric Analysis Software and the data was processed IBM SPSS Statistics 25.0 and MedCalc Version 19.6.3.
Results: The results demonstrate variations in the measurements obtained from the two methods, ranging from 0.13º to 2.14º. The indices ∢I/SN - 0.15º and ∢I/MP - 0.13º show the smallest disparities. The most substantial disparities were identified in ∢MP/SN and ∢MP/FH, with the highest difference in the ∢MP/FH - 2.14º.
Conclusion: The obtained values are within the tolerance range for the angles most commonly used in a cephalometric analysis, making automated cephalometry fast and precise enough to enhance the efficiency of the daily orthodontic practice.

Keywords: Artificial intelligence, cephalometry, cephalometric analysis, orthodontic diagnosis

Introduction

Digital technologies are rapidly entering traditional dentistry and doctors are timidly incorporating artificial intelligence (AI) into diagnostic processes. The term 'artificial intelligence' (AI) is most often associated with robotics and the integration of robotic systems into dental practice. However, in its broader sense, AI refers to software and hardware capable of collecting data, processing it, and subsequently converting it into intelligent actions (1). The role of AI in this context is defined as the capacity of software to emulate human logic, intelligence, and insight (2,3). The integration of AI into conventional dental practices is a key factor in their modernization.

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In the field of orthodontics, the utilization of software and its management by AI has emerged as a novel mechanism that enhances the operational efficiency of medical institutions (4,5). In orthodontics, AI algorithms have been used in various applications mostly in the diagnostic and prognostic processes. The analysis of data from diverse clinical and paraclinical examinations is a physically time-consuming process, and this can be replaced by rapid AI computer processing.

In orthodontic practice, artificial intelligence (AI) has been integrated into the 3D design processes of orthodontic appliances (teeth segmentation, adapting designs from previous projects, recognizing and adapting to the tooth surface design, predicting expected material shrinkage, etc.) (6–8). A more common application in clinical practice, is in the identification of anatomical structures in radiographic images. This is used to improve the accuracy of diagnoses, aids in the development of treatment plans, and facilitate prediction of outcome.

For orthodontic diagnosis, cephalometric analysis is particularly important. Lateral cephalometry is mainly performed for sagittal assessment of skeletal and dentoalveolar relationships, analysis of facial soft tissues, changes that occurred during treatment and evaluation of growth and development patterns. The conventional cephalometric analysis is done by manual identification of reference points and landmarks, a process that is both time-consuming and potentially subject to errors and biases (9). This process is being replaced by automated analysis of cephalograms based on AI models using machine learning (ML) and deep learning (DL) algorithms. An AI-based cephalometric system typically includes two parts in its training data: original images and markers (reference points and structures). Original images include lateral teleradiographs or CBCT scans, while markers contain the desired X-Y coordinates of landmarks most commonly used by orthodontists. Landmarks pose a particular challenge. Recently, AI has demonstrated high accuracy in detecting cephalometric landmarks. Current techniques for fully automatic identification of cephalometric landmarks have undergone significant improvements in their efficiency. These tools are promising in assisting practitioners by minimizing subjective errors and saving time (10,11). The transition from manual cephalometric analysis to AI-based analysis is aimed at improving the diagnostic value of the analysis by saving time and minimizing errors.

The development of any intelligent system is predicated on the learning process, which is enhanced through practice and experience. The objective of ML is to facilitate the extraction of knowledge from records (in this case, from multiple teleradiographs) and the identification of solutions without the necessity for human intervention. ML is not intended to replicate human behavior, but rather to complement human intelligence by performing tasks that exceed human capabilities (1). ML is employed in orthodontics to automate landmark detection. The employment of statistical and probabilistic tools enables machines to learn from prior examples, thereby enhancing their actions when confronted with new data. Consequently, the accumulation of a substantial database of teleradiographs by the clinician contributes to the refinement of the system.

DL is a type of machine learning in which the computer recognizes features in the data and has the ability to make predictions or decisions. DL is the new name for neural network (12). An artificial neural network (ANN) is an algorithmic system that processes data in response to an external stimulus and consists of artificial neurons that are fully connected control elements. The most sophisticated forms of machine learning involve deep learning or neural network models with many levels of functions or variables that predict outcomes, which is appropriate in developing a prognosis in the development of disease or treatment. Based on this technological knowledge, the transition from manual cephalometric analysis to AI-based one, goes through the evaluation of the difference in their accuracy and objectivity. AI-based cephalometric analysis is plagued by systematic and random errors, which have thus far limited the widespread adoption of AI cephalometry. If this becomes a routine method in orthodontic diagnosis, the process will be predominantly automated, thereby enhancing the efficiency, reliability and precision of its application.

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Aim

The aim is to establish the accuracy of a fully AI-based cephalometric analysis versus AI-based one in which the orthodontist controls the accuracy of the reference points.

Material and methods

The present study utilized lateral teleradiographs of 30 patients prior to their orthodontic treatment, during the initial diagnostic phase. The digital cephalometric images were recorded in the software database and incorporated into the software's automated cephalometric analysis module.
The study encompassed various indicators, including bone points, constructed bone points, double bone points, tooth surfaces, and bone surfaces. However, airways and soft tissue indicators were excluded from the analysis.

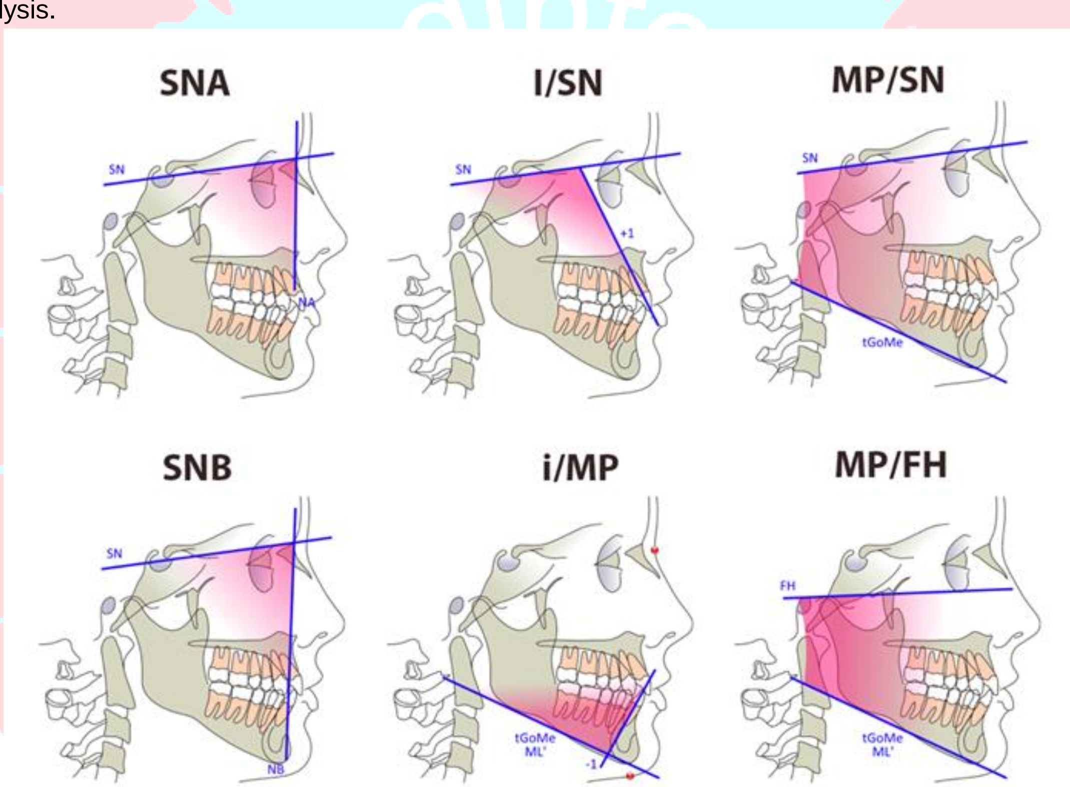

Figure 1. Visualization of the six parameters on lateral teleradiograph.

The difference of six parameters was measured: ∢SNA, ∢SNB, ∢I/SN, ∢i/MP, ∢MP/SN, ∢MP/FH (Figure 1). The landmark identification and cephalometric measurements were first performed automatically by the software. After that the second measurements were done on the same radiograph, but the orthodontist controlled the placement of the reference points after the automatic positioning (Figure 2).

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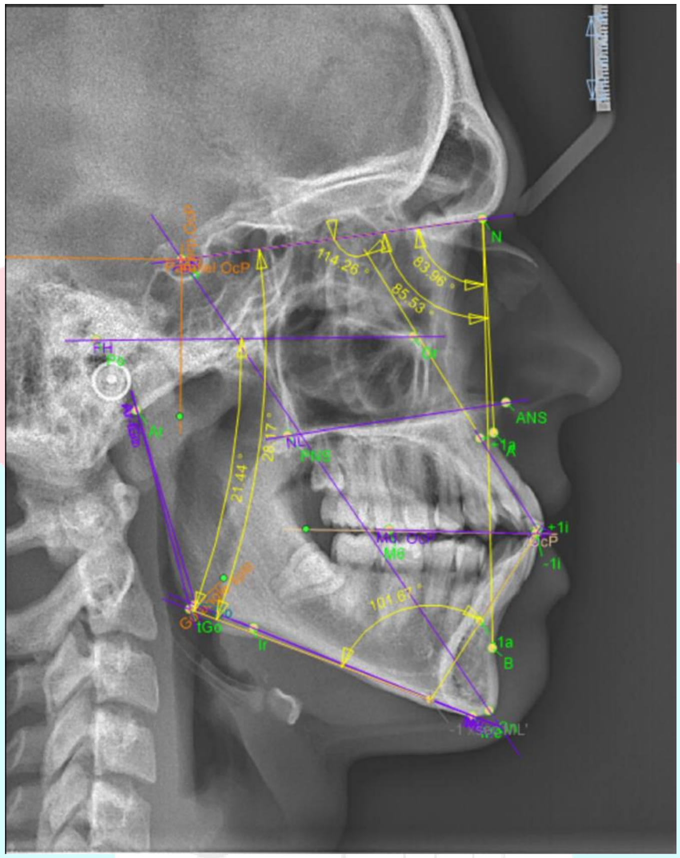

Figure 2. Cephalometric analysis and landmark positioning on Planmeca Romexis Software

The analysis was conducted using the Planmeca Romexis Cephalometric Analysis Software. The radiographic examinations were done on a Planmeca X-ray machine, which provides synchronization for enhanced automatic calibration, sizing, measurement and orientation. The Romexis AI software facilitates the automatic cephalometric analysis via detection of cephalometric landmarks, tracking and measurement. The research group's computer database contains over 800 teleradiographs. The database server stores the readout information (always following an operator-controlled position of the reference points), the location of cephalometric landmarks and cephalograms. The data was entered and processed with the statistical packages IBM SPSS Statistics 25.0 and MedCalc Version 19.6.3. A significance level rejecting the null hypothesis was taken as $p<0.05$.

Results

The results demonstrate significant variations in the measurements obtained from the two methods, ranging from 0.13º to 2.14º for the various indices. The data is presented in Table 1, with all values given in degrees. The indices defining the upper and lower incisor positions (∢I/SN - 0.15º and ∢I/MP - 0.13º) show the smallest disparities, given their well-defined outlines, precise localization, and clear borders. The next value (0.79º) was observed in SNB angle. Point B, positioned along the mandibular contour, was identified as the critical bone point for this angle. This bone point is almost always clearly visible, and thus poses no problem for clinicians and AI in determining it. The difficulty of identifying point A, inevitably leads to a higher difference value when measuring SNA angle by the two methods (difference of 1.24º). Bone and soft tissue structures

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are superimposed in the area of point A, which changes its exact position. The most substantial disparities were identified in the assessment of vertical changes, where the ratio between two planes (∢MP/SN, ∢MP/FH) was compared. The highest difference was observed in the ∢MP/FH - 2.14º. The Frankfurt horizontal (FH) is a constructed plane, where the two reference points that define it, are not specific bone points, but constructed ones relative to other bone landmarks. Therefore, it is common that AI and even orthodontists themselves to make errors in determining the points and the plane.

Table 1: Measurements with AI and measurements with reference points placed by orthodontist. All data is measured in degrees.

Parameters	<SNA	<SNB	<I/SN	<i/MP	<MP/SN	<MP/FH
AI values	**83.25**	**79.57**	**101.74**	**95.87**	**28.39**	**21.49**
SD	4.58	4.43	9.29	6.05	6.36	5.11
Std. error	1.22	1.18	2.48	1.62	1.70	1.42
Orthodontist values	**82.01**	**78.78**	**101.59**	**96.00**	**29.43**	**19.35**
SD	4.01	4.21	10.78	7.31	7.31	4.64
Std. error	1.07	1.09	2.78	1.89	1.51	1.20
Mean difference	**1.24**	**0.79**	**0.15**	**0.13**	**1.04**	**2.14**

Discussion

The role of artificial intelligence in the modernization of conventional orthodontic practices is indisputable. Within clinical practice, its primary function is to facilitate cephalometric analysis through the identification of anatomical structures and rapid mathematical analysis of values. The assistance of artificial intelligence is instrumental in enhancing the accuracy of diagnoses, aiding in the development of treatment plans and enabling outcome prediction. Orthodontists typically verify the accuracy of reference points and rely on artificial intelligence to standardize measurements. The majority of AI algorithms used for automated cephalometric analyses demonstrate a high degree of accuracy.

The conducted study and the results obtained, revealed that the mean differences fell within the range of 0.13º to 2.14º. These values are well within the tolerance range for the angles most commonly measured in a cephalometric analysis. For instance, the normal values for <SNA are 82º±2º.

The localization of cephalometric points A and B in the horizontal plane is crucial for the determination of maxillary/mandibular relations in the sagittal plane. An inaccurate localization of these points in the range of 1.5–2 mm would result in a considerable inaccuracy of many angular and linear measurements, especially if errors are duplicated using the same landmark in several measurements (3).

Kiełczykowski et al. (3) made a literature review for the application of AI for cephalometric analysis and found that in the majority of published studies, the tolerance is found to be within 2 mm, and the mean percentage of landmarks detected within this limit is over 80%, which is clinically significant. However, from the clinical

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point of view, the localisation error up to 2 mm can be acceptable for some, but not all points traced in cephalometric analysis (3). It has also been established that mean differences between two experienced clinicians can reach up to 1.5 mm. Additionally, repeated landmark tracking on the same teleradiograph by a single orthodontist can result in an error of approximately 1 mm between two measurements (3). In contrast to manual tracking of cephalometric landmarks, the AI algorithm consistently marks the same landmark location, which may be advantageous for its use (13). Conventional manual tracking is time-consuming, experience-dependent, and affects the efficiency and accuracy of clinical diagnosis (14). Automation of cephalometric analysis helps to identify facial disharmonies, assess facial growth, and the potential for modification (15).

The majority of literature on the subject reports a continuous improvement in the reproducibility, efficiency, and accuracy of AI cephalometric analyses (16–19). However, it should be noted that errors in AI-based cephalometry can also be caused by a number of factors, including image pixelization, improper calibration, and system training levels.

Conclusion

A large number of researches have demonstrated the increasing role of artificial intelligence (AI) in orthodontics, through accelerated data analysis, diagnosis, treatment planning and clinical procedures. At this point, orthodontists have yet no complete confidence in data derived from AI activity, utilizing it as an auxilary component to enhance the quality of daily orthodontic practice (for diagnosis and automated treatment activities). Cephalometric analyses performed using AI contribute to its self-learning and augment its computational and analytical capabilities.

References

1. Asiri SN, Tadlock LP, Schneiderman E, Buschang PH, Asiri SN, Tadlock LP, et al. Applications of artificial intelligence and machine learning in orthodontics. APOS Trends in Orthodontics. 2020 Mar 30;10(1):17–24.
2. Ribas-Sabartés J, Sánchez-Molins M, d'Oliveira NG. The Accuracy of Algorithms Used by Artificial Intelligence in Cephalometric Points Detection: A Systematic Review. Bioengineering (Basel). 2024 Dec 1;11(12).
3. Kiełczykowski M, Kamiński K, Perkowski K, Zadurska M, Czochrowska E. Application of Artificial Intelligence (AI) in a Cephalometric Analysis: A Narrative Review. Diagnostics (Basel). 2023 Aug 1;13(16).
4. Kostov I., Georgieva M. Innovations and New Technologies in Daily Orthodontic Practice. Orthod Rev. 2024;26(2).
5. Iliyan Kostov, Mirela Georgieva. The Use of Artificial Intelligence in Dental Practice and Patients' Attitudes Towards it. Vol. 61, KNOWLEDGE-International Journal. 2023.
6. Jindal P, Juneja M, Siena FL, Bajaj D, Breedon P. Mechanical and geometric properties of thermoformed and 3D printed clear dental aligners. Am J Orthod Dentofacial Orthop. 2019 Nov 1;156(5):694–701.
7. Khan MI, SM L, Gopal T, Neela PK, Khan MI, SM L, et al. Artificial intelligence and 3D printing technology in orthodontics: future and scope. AIMS Biophysics 2022 3:182. 2022;9(3):182–97.
8. Vodanović M, Subašić M, Milošević D, Pavičin IS. Artificial Intelligence in Medicine and Dentistry. Acta Stomatol Croat. 2023 Mar 1;57(1):70–84.

DOI: 10.18044/MEDINFORM.2025121.2002 ISSUE 1, 2025

9. Sitaras S, Tsolakis IA, Gelsini M, Tsolakis AI, Schwendicke F, Wolf TG, et al. Applications of Artificial Intelligence in Dental Medicine: A Critical Review. Int Dent J. 2025;
10. Subramanian AK, Chen Y, Almalki A, Sivamurthy G, Kafle D. Cephalometric Analysis in Orthodontics Using Artificial Intelligence-A Comprehensive Review. Biomed Res Int. 2022;2022.
11. Hong M, Kim I, Cho JH, Kang KH, Kim M, Kim SJ, et al. Accuracy of artificial intelligence-assisted landmark identification in serial lateral cephalograms of Class III patients who underwent orthodontic treatment and two-jaw orthognathic surgery. Korean J Orthod. 2022 Jul 1;52(4):287–97.
12. Bichu YM, Hansa I, Bichu AY, Premjani P, Flores-Mir C, Vaid NR. Applications of artificial intelligence and machine learning in orthodontics: a scoping review. Prog Orthod. 2021 Dec 1;22(1).
13. Graf S, Tarraf NE, Kravitz ND. Three-dimensional metal printed orthodontic laboratory appliances. Semin Orthod. 2021 Sep 1;27(3):189–93.
14. Liu J;, Zhang C;, Shan Z, Liu J, Zhang C, Shan Z. Application of Artificial Intelligence in Orthodontics: Current State and Future Perspectives. Healthcare 2023, Vol 11, Page 2760. 2023 Oct 18;11(20):2760.
15. Thakur SM, Shenoy U, Hazare A, Karia H, Khorgade P, Nandeshwar N, et al. Transforming orthodontics with artificial intelligence: A comprehensive review. Journal of Advances in Dental Practice and Research. 2024 Dec 14;0(0):1–9.
16. Kim J, Kim I, Kim YJ, Kim M, Cho JH, Hong M, et al. Accuracy of automated identification of lateral cephalometric landmarks using cascade convolutional neural networks on lateral cephalograms from nationwide multi-centres. Orthod Craniofac Res. 2021 Dec 1;24 Suppl 2(S2):59–67.
17. Park JH, Hwang HW, Moon JH, Yu Y, Kim H, Her SB, et al. Automated identification of cephalometric landmarks: Part 1-Comparisons between the latest deep-learning methods YOLOV3 and SSD. Angle Orthod. 2019;89(6):903–9.
18. Mahto RK, Kafle D, Giri A, Luintel S, Karki A. Evaluation of fully automated cephalometric measurements obtained from web-based artificial intelligence driven platform. BMC Oral Health. 2022 Dec 1;22(1):1–8.
19. Blum FMS, Möhlhenrich SC, Raith S, Pankert T, Peters F, Wolf M, et al. Evaluation of an artificial intelligence-based algorithm for automated localization of craniofacial landmarks. Clin Oral Investig. 2023 May 1;27(5):2255–65.

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Emiliyanov E, Kostov I, Capabilities and Limitations of Artificial Intelligence in Cephalometric Analysis, Medinform 2025; 12(1):2002-2008.