International Journal of Computers and Informatics

Journal Homepage: https://www.ijci.zu.edu.eg

Int. j. Comp. Info. Vol. 6 (2025) 27–39

Paper Type: Original Article

Advancements in Digital Cephalometric Analysis: A Comprehensive Review

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Received: 05 Oct 2024 **Revised:** 15 Dec 2024 **Accepted:** 05 Jan 2025 **Published:** 07 Jan 2025

Abstract

Facial and jaw deformities are considered difficult problems that affect the health of society. Attempts have been made to treat and correct deformities by analyzing facial and jaw images. Specialized radiographs have emerged to diagnose these defects, such as cephalometric x-rays of the skull. Manual analysis of radiographs has been done by a group of specialized scientists such as William B. Downs, Charles H. Tweed, and others. With the introduction of artificial intelligence algorithms, it has been possible to use this technology to analyze images faster, more accurately, easier, and with high efficiency compared to the manual method.

Keywords: Artificial Intelligence; Facial; Jaw; Cephalometric x-rays.

1 | Introduction

Cephalometric analysis is a radiographic technique and a crucial diagnostic tool used in orthodontics and craniofacial surgery to evaluate the skeletal, dental, and soft tissue relationships in the craniofacial region. This process involves taking a lateral radiograph of the head and superimposing it on a standard cephalometric tracing to measure various linear and angular dimensions. These measurements are then used to assess facial growth, development, and the presence of dentofacial anomalies. By analyzing the relationships between the teeth, jaws, and facial structures, cephalometric analysis helps in diagnosing malocclusions, facial asymmetry, and temporomandibular joint disorders, as well as in planning and evaluating orthodontic and surgical treatments. Key measurements in this analysis include angles and distances that describe the positions of the teeth, the alignment of the jaws, and the balance of facial structures, which are essential for creating a harmonious facial profile. This makes cephalometric analysis an invaluable tool for orthodontists, oral and maxillofacial surgeons, and other dental professionals in their diagnostic and treatment planning processes, Among the cases that can be treated and benefit from this technique are: malocclusion, facial asymmetry, and temporomandibular joint disorders [1].

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Cephalometric analysis has its roots in the early 20th century, evolving from the need to better understand craniofacial growth and development. The technique was first developed by American orthodontist Dr. Charles H. Tweed in the 1930s, who used it to enhance the precision of orthodontic diagnosis and treatment planning. However, it was Dr. William B. Downs, another American orthodontist, who is often credited with formalizing cephalometric analysis by introducing a standardized method of taking and interpreting cephalometric radiographs in the 1940s. His work laid the foundation for modern cephalometry by establishing reference points and planes that could be used to measure the relationships between different craniofacial structures. Over the decades, cephalometric analysis has become a fundamental tool in orthodontics, craniofacial surgery, and related fields, enabling clinicians to assess skeletal and dental relationships, predict growth patterns, and evaluate treatment outcomes with greater accuracy. The development and refinement of cephalometric techniques have been pivotal in advancing our understanding of craniofacial biology, and the method continues to be an essential part of clinical practice and research in dental and orthodontic specialties [1-3].

Cephalometric analysis can be done by two methods: conventional methods by means of manual tracing and digital methods.

The manual method (conventional methods, which has been traditionally used since the inception of cephalometric analysis, involves tracing cephalometric radiographs by hand on acetate paper using a light box. The orthodontist or clinician manually identifies specific anatomical landmarks on the radiograph(X-ray), which are then connected to form various angles and measurements that help in assessing craniofacial relationships. While this method is effective, it is time-consuming and prone to human error, as the accuracy of the analysis largely depends on the precision with which the landmarks are identified and traced.

In contrast, the digital method of cephalometric analysis or computerized method has become increasingly popular with advancements in technology. Digital cephalometry involves the use of specialized software to analyze cephalometric radiographs. This method allows for automatic or semi-automatic identification of anatomical landmarks, which can significantly reduce the time required for analysis and minimize the potential for human error. Digital analysis offers additional advantages, such as the ability to store, retrieve, and compare patient records more efficiently, as well as the capacity for more sophisticated analyses, including three-dimensional assessments. Moreover, digital systems often come with integrated databases of normative values, which can be used to compare individual patient measurements with population averages. Both methods—manual and digital—are widely used in clinical practice, but the trend is increasingly shifting towards digital analysis due to its efficiency, accuracy, and the ability to integrate with other digital tools used in orthodontics and craniofacial surgery [3-8].

1.1 | The Future: Artificial Intelligence in Cephalometry

The field is witnessing a growing interest in artificial intelligence (AI) and machine learning (ML) for dental applications. One exciting development is the use of AI to create fully automatic cephalometric analysis software. This technology has the potential to further reduce the workload for orthodontists and improve the accuracy of analysis. Finally Cephalometric analysis is a vital tool in orthodontics, offering valuable insights into facial development. While the traditional manual tracing method has served its purpose, digital software offers a faster and more accurate alternative. The emergence of AI in cephalometry holds promise for even greater efficiency and accuracy in the future.

Artificial intelligence (AI) is transforming various fields, including orthodontics, by mimicking human intelligence to make effective and ethical decisions. With advancements in technology, AI has become integral to daily life, influencing everything from social media content filtering to consumer products. A significant aspect of AI is machine learning, which uses patterns from past data to make predictions and improve over time. In orthodontics, AI is being applied to automate the recognition of cephalometric landmarks, enhancing diagnosis, treatment planning, and patient care [3-8].

2 | Literature Review

The integration of AI in orthodontics can be traced back to the late 20th century, with significant advancements made in recent years. Early applications of AI in orthodontics involved digitizing patient records, radiographs, and dental models, enabling orthodontists to access and analyze patient data more efficiently [9].

2.1 | Key Milestones in the History of AI in Orthodontics Include

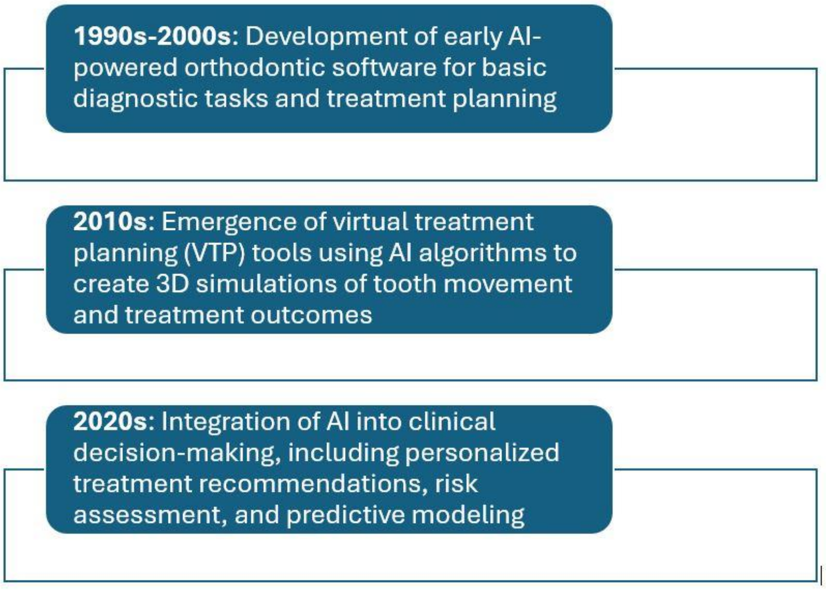

Figure 1. Key milestones in the history of AI in orthodontics include [9].

2.2 | Current Applications of AI in Orthodontics

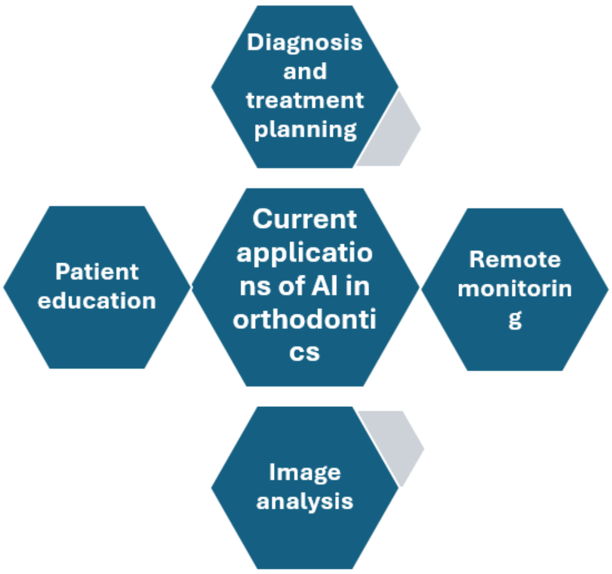

Figure 2. Current applications of AI in orthodontics [10].

2.3 | Benefits of AI in Orthodontics

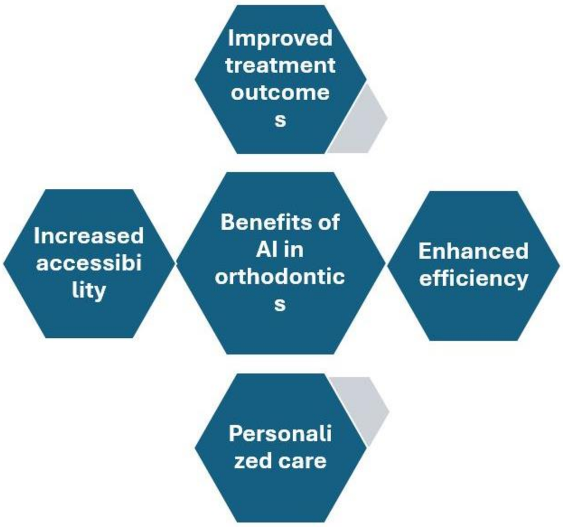

Figure 3. Benefits of AI in orthodontics [10].

3 | Future of AI in Orthodontics

The future of AI in orthodontics holds immense potential for further advancements in diagnosis, treatment, and patient care. AI-powered systems are expected to become more sophisticated, enabling real-time treatment monitoring, predictive analytics, and personalized intervention strategies. As AI continues to evolve, it will play an increasingly crucial role in shaping the future of orthodontics, leading to more effective, efficient, and personalized patient care.

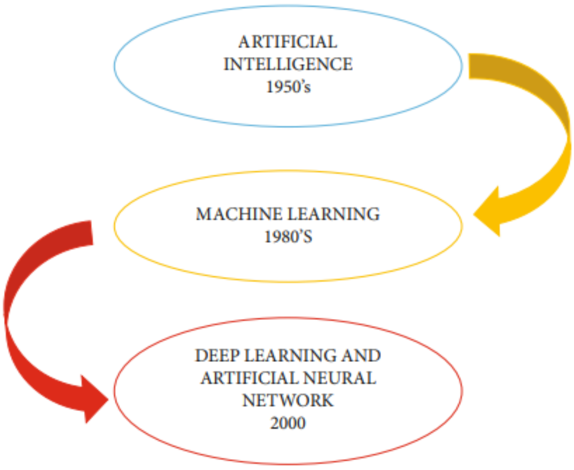

Figure 4. History of artificial intelligence [9].

4 | Various Software for Cephalometric Analysis

There are a number of commercial solutions for performing the technique. These include:

- Quick-Ceph
- Dolphin
- Nemoceph
- OrisCeph
- CephX

- WebCeph
- CephNinja
- Centro Graphic
- OnyxCeph
- Facad®
- Planmeca Romexis®
- AudaxCeph
- AutoCEPH©
- OneCeph

4.1 | Quick-Ceph

Quick-Ceph was founded in 1986 by the innovative computer coder and orthodontist,

Günther Blaseio, following his residency at Loma Linda University in California. The original Quick-Ceph software achieved remarkable success, revolutionizing treatment planning by enabling practitioners to visualize predictive profile changes in orthodontic patients. This allowed for an optimal balance between finished occlusion and profile aesthetics [11].

The software introduced Bézier curves for tracing outlines and treatment simulations in 1995 and incorporated high-resolution images in 1999. In 2005, a user-friendly version was released, featuring advanced tools such as superimpositions of variably translucent radiographs along bony structures, import and manipulation of 3-D CBCT radiographs and STL dental models, and support for unlimited sessions in a patient file. These innovations made Studio an excellent choice for orthodontic and surgical treatment planning [11].

In 2013, Quick-Ceph Office was launched after several years of development. This comprehensive software package integrates key features such as scheduling, charting, and credit card and insurance processing into a single, streamlined interface.

4.2 | Dolphin

A commercially available software solution, Dolphin, was developed by Dolphin Imaging and Management Solutions (Austin, Texas) in 2001. Acquired by Allscripts in 2012, Dolphin caters to dental practices by streamlining clinic operations and enhancing patient care delivery. The latest version (20.0, released in 2022) incorporates artificial intelligence and machine learning functionalities [12].

4.2.1 | Dolphin's Core Functionalities Encompass

- Patient Management: Database management for patients, appointment scheduling, and billing tools.
- Electronic Medical Records (EMR): Comprehensive EMR system for storing patient histories and treatment details.
- Image Management: Tools for managing and organizing radiographic and digital dental images.
- Data Analytics: Features for analyzing dental data, generating reports, and performing statistical analyses.
- Hardware Integration: Compatibility with various dental equipment, including x-ray and digital imaging devices.

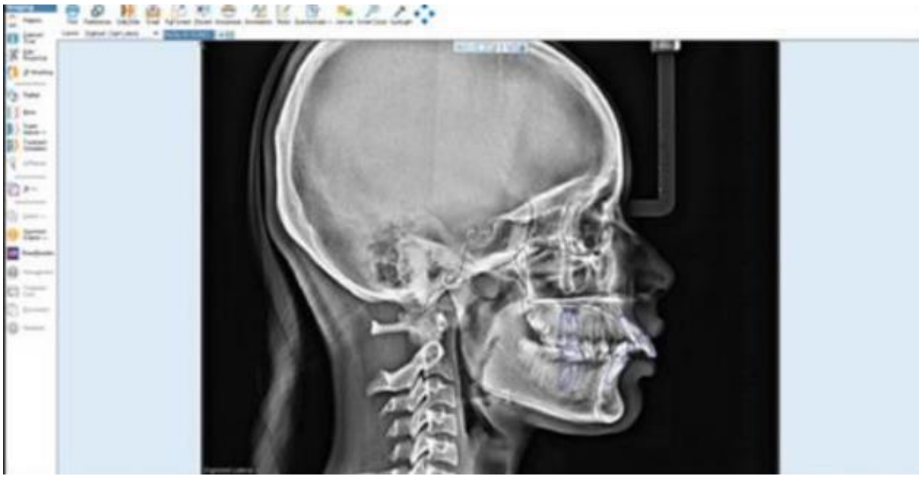

Figure 5. Cephalometric tracing done using Dolphin Imaging technology [12].

4.3 | Nemo-Ceph

Nemotec, a leading Spanish technology company founded in 1992, provides flexible and open solutions for the dental industry. Their software supports orthodontics, orthognathic surgery, implantology, and smile design. Nemo-Ceph is an advanced tool for diagnosis, treatment planning, and case presentation, offering comprehensive cephalometric analysis capabilities [12].

Figure 6. Cephalometry analysis done using NemoCeph software interface [12].

4.4 | OrisCeph

Rx Ceph OrisCeph facilitates efficient and accurate cephalometric analysis through a comprehensive suite of features. With more than 30 pre-defined procedures, cephalometric tracings can be rapidly and easily completed, while guided input ensures precise identification of anatomical landmarks and cephalometric points. Parametric values and nomograms enable real-time diagnosis, and growth simulation capabilities (VTO & Morphing) allow for dynamic profile adjustments with recalculated measurements. Sophisticated graphics tools provide refined control for resizing and drawing anatomical structures. Due to automatic profile adjustments triggered by X-ray settings, final measurements are recalculated based on the altered profiles, offering a more accurate and up-to-date analysis [12].

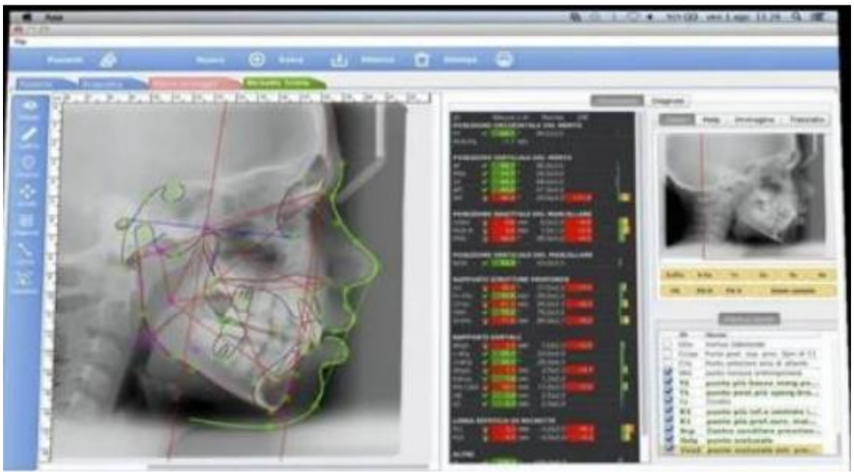

Figure 7. Cephalometric tracing done using OrisCeph Rx CE software interface.

4.5 | CephX

CephX, also developed by Red Hat and released in 2018, is a self-managed authentication and access control system for Ceph Object Storage, utilizing SAML technology for centralized authentication [13].

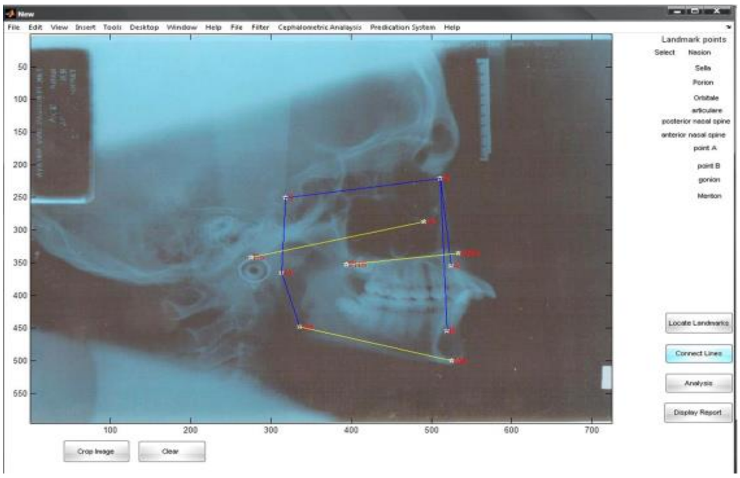

Figure 8. Automatic Cephalometric Sample using Ceph-X [13].

4.6 | WebCeph

WebCeph a web-based platform utilizing artificial intelligence for orthodontics and orthognathic, is gaining traction due to its features that streamline orthodontic treatment planning and patient record management. These features include automated cephalometric tracing and analysis, visual treatment simulation, automatic image superimposition, image archiving, and a photo gallery. WebCeph also allows for manual landmark editing with automatic measurement calculations [14].

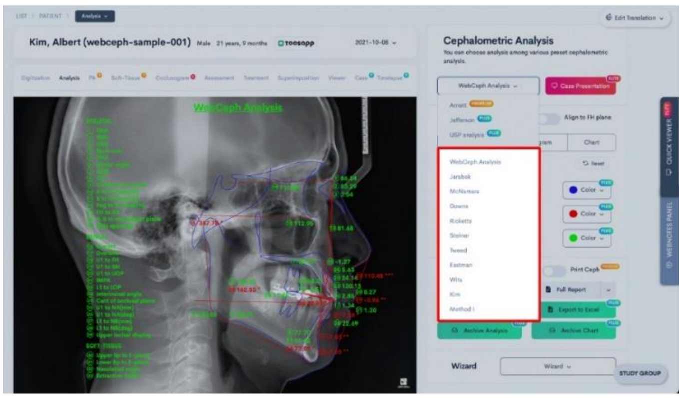

Figure 9. Automatic Cephalometric Sample using WebCeph [14].

4.7 | CephNinja

CephNinja is designed to allow orthodontists in the process of analyzing cephalometric radiograph with the advantages of (that) these applications can be conducted anytime and anywhere because the software is compatible with any Google Android® or iOS® operating system [15].

Figure 10. Automatic Cephalometric Sample using CephNinja [15].

4.8 | Centro Graphic

The Centro Graphic analysis method was evaluated for its applicability in cephalometric assessment of Egyptian adults. The study revealed that Centro Graphic offers a rapid and user-friendly approach to analyzing vertical skeletal patterns, dental relationships, and soft tissue profiles. While the centroid plane serves as a reference for vertical skeletal evaluation, incorporating a normal range of variation is essential. For dental assessments, Centro Graphic can serve as an initial tool for evaluating incisor angulations. Additionally, the analysis effectively evaluates soft tissue characteristics. Overall, Centro Graphic emerges as a valuable adjunct to conventional cephalometric analysis, particularly considering its affordability and ease of use. This addresses the need for accessible tools, complementing sophisticated software programs commonly used by orthodontists [1].

4.9 | OnyxCeph

It is created for patient education, treatment planning, diagnosis, and archiving. This software processes data in two dimensions (2D) and three dimensions (3D). Image import, image adjustment (classify and crop image), mirror image, model base (modify models and attach base), segmentation, and cephalometric analysis and measures (separation and completion) With the use of these 2D and 3D image data, Ricketts Visual Treatment Objective, superimposition, image editing, data export, copy/save/send/display/print image, treatment simulation, slide show, and online/offline reports are available [12].

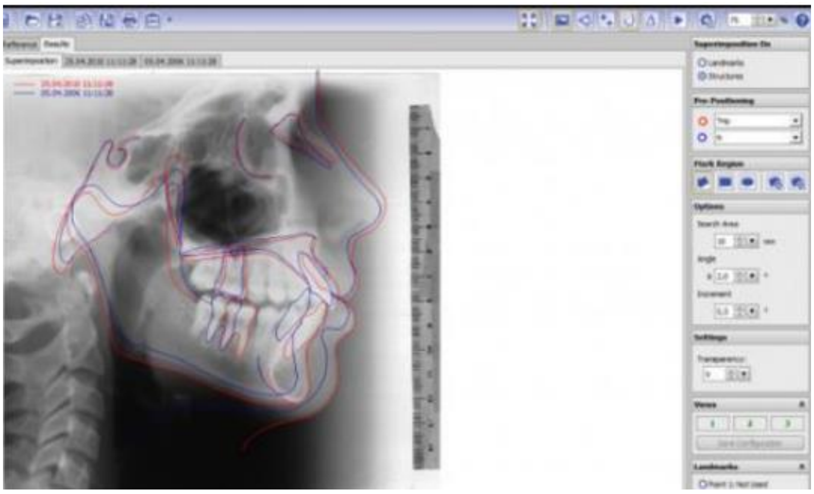

Figure 11. Superimposition tracing using the OnyxCeph interface [12].

4.10 | Facad

Facad is a software program used for orthodontic tracing, cephalometric analysis, and visual diagnostic imaging, as well as for treatment planning with soft tissue profile prediction for both orthodontics and maxillofacial surgery. This program is meant to be used by dentists, orthodontists, and orofacial surgeons [12].

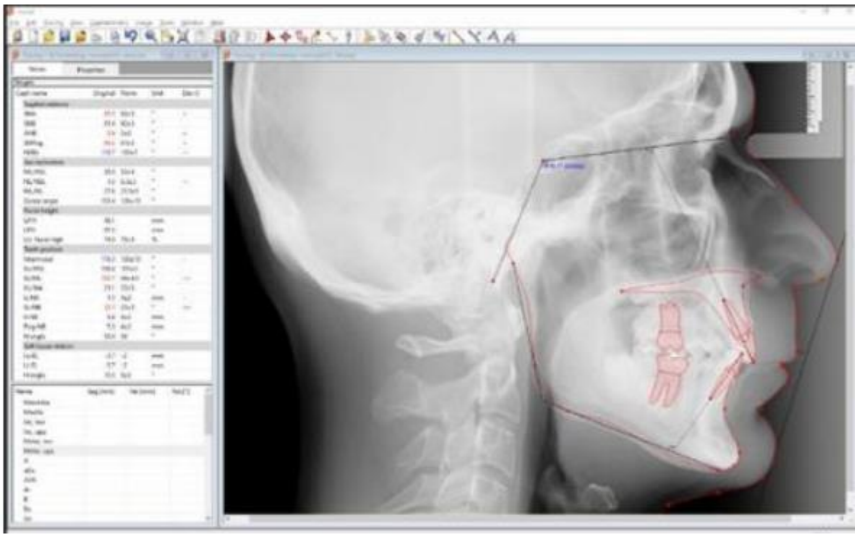

Figure 12. Cephalometric analysis using Facad using a software interface [12].

4.11 | AudaxCeph

Automating tasks with Artificial Intelligence. It's quick, efficient, and an essential tool for your orthodontic practice. Obtain measurements for treatment forecasts, simulations, projections of skull growth, and treatment plans. Save valuable time by allowing artificial intelligence to quickly and accurately position cephalometric markers. Arrange all the paperwork associated with your course of treatment into separate containers so you may access them at any time. At all times, be prepared to show and explain to your patients how their orthodontic treatment is progressing. There are two versions of our cephalometric software, each with a distinct set of capabilities. However, the same cephalometric engine is included in both editions, allowing for quick and accurate readings.

The AudaxCeph SuperEasy's simplicity is empowered with Artificial Intelligence which instead of you places cephalometric points of soft and hard tissue landmarks in seconds. Cephalometric visual treatment objective VTO, STO, planning, simulation, and prediction can be done interactively. Superimposition is done automatically, manually or structural superimposition with extensive reporting capabilities [12].

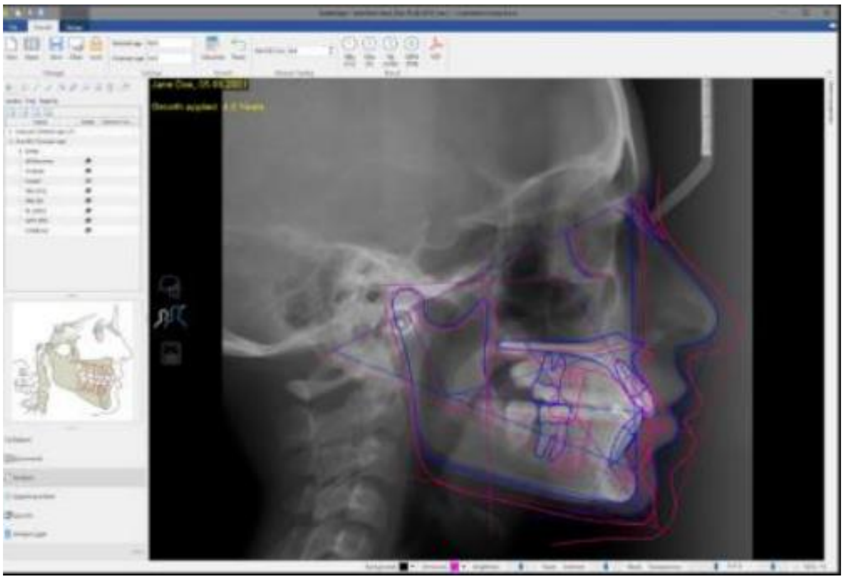

Figure 13. AudaxCeph software interface cephalometric tracing is applied [12].

4.12 | Planmeca Romexis

Romexis Cephalometric Analysis provides simple-to-use tools for rapid and effective picture analysis. In a matter of seconds, the software's automatic tracing tool positions the points and soft tissue silhouettes on a cephalometric image, giving you more time to analyze the study's findings. The software automatically superimposes profile pictures, tracings, and X-ray images from various treatment stages [12].

Figure 14. Romexis® Cephalometric Analysis module using software 6.3 [12].

4.13 | AutoCEPH

A 2-D cephalometric analysis program called AutoCEPH© helps maxillofacial and orthodontic surgeons analyze patients. The Centre for Dental Education and Research (CDER), AIIMS, New Delhi, India, and CSIR-Central Scientific Instruments Organisation, Chandigarh, India, worked together to develop it. After mapping landmarks, a curve can be automatically traced, and the resulting curves can be readjusted. It includes seventeen distinct analyses, each with a graphic representing a different parameter. Three Posterior Anterior Analysis, or 3 PA Analysis, has sophisticated visuals [12].

Autoceph provides six different kinds of superimpositions to its customers, it supports several image formats, including uncompressed DICOM,.jpg,.png,.tiff, and .bmp., Management of patient repositories [12].

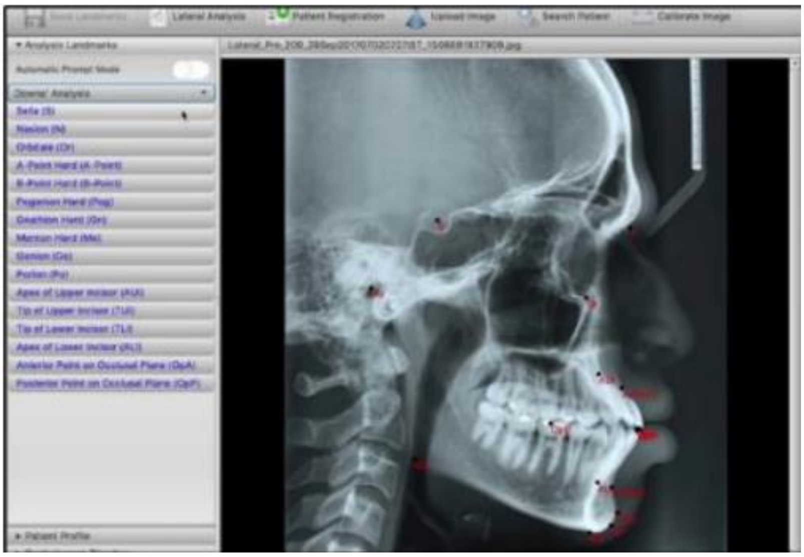

Figure 15. AutoCEPH© cephalometric analysis software interface [12].

4.14 | OneCeph

OneCeph is one of the few easily available software which can be downloaded from the Google Play store app in any of the current smartphones which run on the Android operating systems. The reliability and reproducibility of this newly launched software have not been compared with the conventional manual tracing. Hence in our study, we compared the accuracy of cephalometric analysis done using both OneCeph software and manual tracing to verify the accuracy of the software. Steiner's analysis was chosen for this study because it is one of the most widely used cephalometric analyses which has both angular and linear measurements as well as skeletal and dental parameters [15] It is observed that when the hard copies of the radiographs are converted into soft copies the accuracy of scanning plays a vital role as it can lead to distortion [16].Therefore in our study the previous records which were mostly hard copies of cephalograms were not included in the study to avoid any errors in scanning [4].

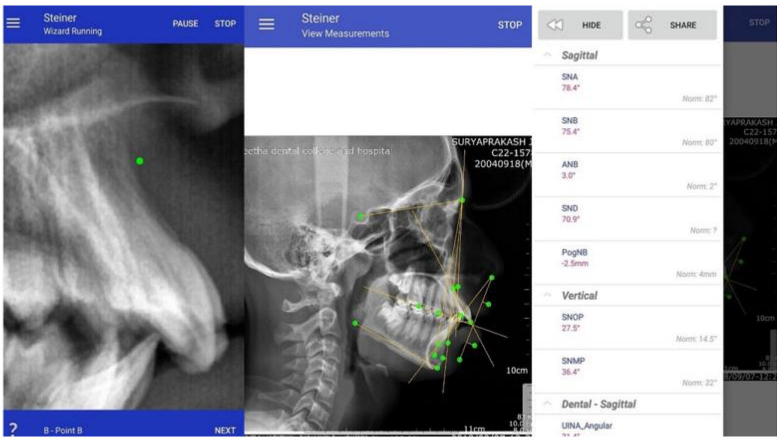

Figure 16. Digital tracing of cephalometric points and analysis done using the OneCeph software [4].

There are several commercial alternatives to perform the technique; among them, we can mention Quick Ceph, Dolphin, Nemoceph, OrisCeph, CephX, WebCeph, CephNinja , Centro Graphic, OnyxCeph, Facad®, Planmeca Romexis®, AutoCEPH© and OneCeph.

Using the software is very helpful for orthodontic practitioners in performing cephalometric analysis and determining diagnostic and treatment plans. However, the cost of purchasing this software is quite expensive [2].

5 | Conclusions

The application of artificial intelligence in orthodontic treatment is on the rise. It has demonstrated significant potential in saving time and serving as a dependable resource. AI shows promise in enhancing cephalometric tracing within standard clinical settings and in the analysis of extensive databases for research endeavors. This review examines the historical context, applications, and diverse methodologies of AI utilized for cephalometric evaluation. The primary aim of this narrative review is to aid clinicians and researchers in understanding the various aspects of this field of study.

Acknowledgments

The authors are grateful to the editorial and reviewers, as well as the correspondent author, who offered assistance in the form of advice, assessment, and checking during the study period.

Author Contribution

All authors contributed equally to this work.

Funding

This research has no funding source.

Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors

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