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Accuracy of Eyes of AI™ Artificial Intelligence-Driven Platform for Lateral Cephalometric Analysis

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Aim: The objective of this prospective study was to evaluate the accuracy of cephalometric analyses acquired through manual tracing and the Eyes of AI™ AI-driven web-based program.

Materials and Methods: This prospective study employed randomization conducted via computer software, with a determined sample size of 150 cases. Inclusion criteria encompassed good quality lateral cephalograms available in both digital and print formats, absence of artifacts that might hinder anatomical point location, and presence of a clear calibration ruler for magnification determination. Exclusion criteria included lateral cephalograms with identifiable motion artifacts, resolution disparity, or insufficient contrast, as well as those exhibiting positional errors indicated by ear rod markers. Each lateral cephalogram underwent tracing and analysis using the manual method, as well as Eyes of AI™ software. Following landmark plotting, linear and angular measurements of Steiner, Downs, McNamara, and Jefferson analyses were calculated.

Results: A comparison of thirty-six cephalometric measurements of Steiner, Downs, McNamara, and Jefferson analyses obtained from manual tracing and AI-driven Eyes of AI™ revealed a Concordance Correlation Coefficient (CCC) value above 0.76 for all parameters, indicating strong agreement between manual and AI-driven cephalometric measurements. Furthermore, a CCC value exceeding 0.9 was observed for twenty-eight parameters, indicative of very strong agreement.

Conclusion: Automated lateral cephalometric measurements obtained from Eyes of AI™ are accurate when compared to manual measurements.

Keywords: Eyes of AI™; Cephalometric analysis; artificial intelligence; orthodontic diagnosis

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Introduction

Lateral cephalometric analysis stands as an indispensable tool within orthodontic practice, facilitating diagnosis, treatment planning, and the assessment of treatment outcomes. Traditionally, this analysis involves a manual process wherein a layer of acetate tracing sheet is affixed to the lateral cephalometric radiograph. Utilizing a view-box, practitioners manually identify cephalometric landmarks, subsequently conducting linear and angular measurements employing basic tools such as pencils, rulers, and protractors.[1] While this manual approach remains the gold standard for cephalometric analysis, its inherent time-intensive nature poses a significant challenge.[2] Manual lateral cephalometric analysis is prone to errors stemming from measurement inaccuracies and calculation mistakes, exacerbated by human fatigue.[3]

In recent years, there has been a growing fascination with leveraging artificial intelligence (AI) and machine learning (ML) within the realm of dentistry.[4] Notably, within orthodontics, one of the prominent applications of this technology has been the development of fully automated cephalometric analysis systems aimed at alleviating the laboriousness associated with manual techniques.[5] Advanced computerized software and web-based cephalometric applications are now capable of autonomously generating landmarks on digital lateral cephalometric radiographs and completing the analysis using artificial intelligence algorithms.

Previous research has indicated that automated cephalometric analysis programs often exhibit a higher rate of errors compared to manual tracing methods, thereby providing limited scientific support for their integration into orthodontic practice.[6] However, recent studies[5,7] have demonstrated promising results for AI-based cephalometric analysis programs when compared to manual techniques. Despite this, it remains imperative to validate the accuracy of any AI-based cephalometric analysis systems before widespread adoption in clinical settings.[4] The precise identification of cephalometric landmarks is crucial, as inaccuracies may lead to erroneous decisions in orthodontic treatment planning. Thus, there is a continued need for fully automated systems that offer both efficiency and accuracy in landmark identification.[8]

Given the diversity of AI-based programs designed for automated cephalometric analysis, there persists uncertainty regarding their ability to accurately trace cephalometric landmarks. To address this gap in knowledge, there is a pressing need to rigorously assess the accuracy of these commercially available programs. Such evaluations are essential for enabling orthodontists to make informed decisions when selecting software for precise cephalometric measurements.

Therefore, the objective of this prospective study was to evaluate the accuracy of cephalometric analyses acquired through manual tracing and the Eyes of AI™ AI-driven web-based program. The null hypothesis posited that there is no difference between measurements obtained by manual tracing and Eyes of AI™ AI-driven methods regarding accuracy.

Materials and methods

This study received approval from the Faculty of Dentistry, Ain Shams University Ethical Committee (FDASU–RecER022434) and adhered to the guidelines set forth in the Declaration of Helsinki. No alterations were made to the methods following the commencement of the study.

Experimental Design

This prospective study employed randomization conducted via computer software. Radiographs were sourced from the outpatient clinic at the Faculty of Dentistry, Ain Shams University. There was no discrimination based on age, sex, malocclusion, or skeletal classification.

Sample Size Calculation

A power analysis was conducted to ensure adequate power for applying a two-sided statistical test of the null hypothesis, which posits no difference between the groups tested regarding accuracy. Adopting an alpha (α) level of 0.05, a beta (β) level of 0.2 (i.e., power=80%), and an effect size (d) of 0.461, as calculated based on the results of the study by Saifeldin[3], the total required sample size (n) was determined to be 150 cases. Sample size calculation was performed using R statistical analysis software version 4.3.2 for Microsoft Windows.

Inclusion criteria

1. Good quality lateral cephalograms with both digital and print formats available.
2. The cephalograms were free from any artifacts that could potentially disrupt the precise identification of anatomical points.
3. Presence of a clear calibration ruler on the cephalograms to facilitate determination of magnification.

Exclusion criteria

1. Motion artifacts, resolution disparities, or inadequate contrast in lateral cephalograms hindered the identification of landmarks.
2. Lateral cephalograms of patients displayed positional errors, as evidenced by ear rod markers.

Methods

Standardized digital lateral cephalometric radiographs were captured using the same x-ray machine (Vatech, Hwaseong, South Korea), which employs a charged-couple sensor chip for image reception. The exposure parameters for digital cephalography were set at 70kV, 10mA, and 12.9 seconds. Cephalometric radiographs were taken with the patient in centric occlusion, with lips at rest. Patients were positioned in natural head posture, with the red-line indicator of the machine aligning the Frankfort horizontal plane (FH) parallel to the floor.

The lateral cephalometric radiographs were saved in JPG format and printed. Each participant's radiograph was manually traced and then digitally traced using the Eyes of AI™ software. Both conventional and digital tracings were performed on each radiograph by the same orthodontist for consistency.

Manual tracing

Manual tracing was conducted using high-quality prints of digital cephalometric radiographs, performed on a view-box (Dentaurum, Ispringen, Germany) under transillumination in a dimly lit setting. Each radiograph was affixed to the surface of the view-box, with a sheet of fine grade 8″×10″ matte acetate tracing sheet secured over the radiograph. Orientation marks were drawn on the radiograph and then traced onto the tracing sheet as a reference. Subsequently, using a pencil, all hard and soft tissue landmarks were manually traced on the tracing paper. The measurements for four commonly utilized cephalometric analyses (Steiner[9], Downs[10], McNamara[11] and Jeffersson[12]) were charted on each cephalogram. Linear and angular measurements were then computed employing a millimeter ruler and protractor, respectively, with precision to the nearest 0.5 mm and 0.5°.

Image calibration to determine the actual dimensions in each cephalogram was carried out by measuring a known distance between two fixed points on the cephalogram ruler. If any magnification of the images was detected, it was accurately determined and calculated. After adjusting the obtained linear measurements with the magnification factor, final values were documented. Then, measurements were diligently fed into Microsoft Office Excel 365 sheet.

Digital tracing

Eyes of AI™ is a cutting-edge web-based platform driven by fully automated AI, designed to conduct various cephalometric analyses and interpretations based on acquired cephalometric measurements. The model behind Eyes of AI™ is built upon a heavily customized state-of-the-art human pose estimation architecture, utilizing PyTorch as the primary deep learning framework. The input and output workflows were tailored to meet the specific requirements of the dataset, which encompasses images from diverse sources worldwide, captured with six different x-ray machines and varying in quality. This diversity reflects the expected range of inputs encountered in real-world applications. Input adaptations include the detection and removal of blank spaces on the sides of images, contrast-limited adaptive histogram equalization (CLAHE) with automatic parameter selection, and resolution normalization with aspect ratio awareness. Adjustments were also made to the output process to accommodate the dataset's high number of annotated landmarks (152).

Each digital JPG lateral cephalogram image was assigned a unique identifier and saved to the MacBook Pro used in this study before being uploaded to the Eyes of AI™ website. After logging into the website, an online account was created using Google Chrome as the standard internet browser. Each Patient was given a code that was added within the software, and digital lateral cephalogram images were then uploaded to their respective code.

The AI digitization feature of Eyes of AI™ was employed for automated landmark identification and tracing (Fig 1). Image calibration was executed using a 10 mm ruler displayed on the screen, aligned with the calibration ruler on the digital lateral cephalogram image. Subsequently, cephalometric measurement values for different parameters were downloaded and inputted into the same Microsoft Excel sheet used for manual tracing data. This sequence was repeated for all 150 digital lateral cephalograms.

Measurements of the same lateral cephalograms obtained by both manual tracing and Eyes of AI™ AI-driven tracing were conducted by an experienced orthodontist (HS) with over 20 years of experience. To mitigate errors arising from fatigue, only five cephalograms were traced each day.

Blinding

To ensure unbiased evaluation of outcomes, the outcome evaluators were effectively blinded through data concealment during the calculation process.

Statistical analysis

The statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS) version 21.0 (IBM, Armonk, NY, USA). The Concordance Correlation Coefficient (CCC) with a 95% confidence interval (CI) was employed to assess the agreement between measurements

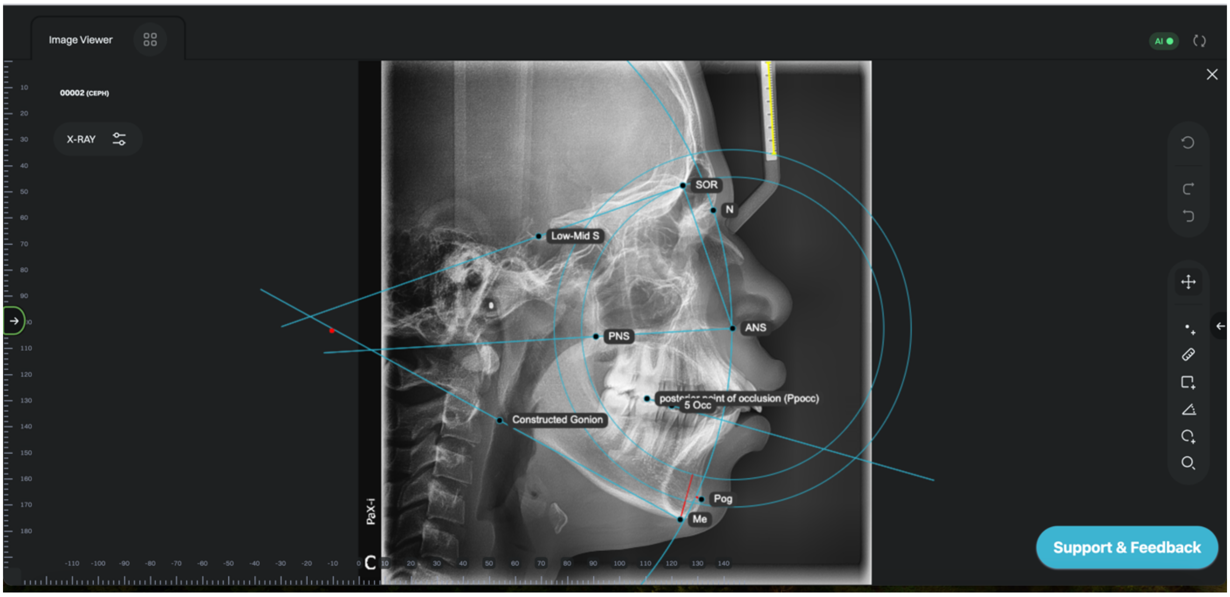

Fig (1) Landmarks and tracing done by AI driven fully automated software Eyes of AI™

obtained from manual tracing and the web based fully automated AI driven platform, Eyes of AI™.

Intra-observer reliability was evaluated by comparing the data of 20 selected lateral cephalograms by the same investigator two weeks after the initial measurement. Inter-observer reliability was assessed by another trained and qualified investigator on the same 20 randomly selected cephalograms. The Concordance Correlation Coefficient (CCC) with a 95% confidence interval (CI) was also utilized to assess reliability. The Concordance Correlation Coefficient (CCC) indicates very strong agreement when α is greater than 0.9 and strong agreement when α falls within the range of 0.7 to 0.9.

Results

The Concordance Correlation Coefficient (CCC) values for repeated cephalometric measurements demonstrated very high observer reliability, with values exceeding 0.9 for both intra-observer and inter-observer reliability.

For Steiner cephalometric measurements (Table 1), all measurements exhibited CCC values above 0.76. Notably, eight parameters, including ANB, Occlusal plane to SN angle, Mandibular plane angle (Go-Gn) to SN, Maxillary incisor position (mm), Maxillary incisor position (deg), Mandibular incisor position (mm), Mandibular incisor position (deg), and Interincisal angle, achieved CCC values exceeding 0.9. SNA and SNB showed CCC values ranging between 0.76 and 0.79.

Similarly, for Downs cephalometric measurements (Table 2), all measurements had CCC values exceeding 0.78. Eight parameters, such as Angle of convexity, A-B plane angle, Mandibular plane angle (Down), Cant of occlusion, Inter-incisal angle, Incisor occlusal plane angle, Incisor mandibular plane angle, and Protrusion of maxillary incisors, attained CCC values above 0.9. Facial angle and Growth axis demonstrated CCC values between 0.78 and 0.80.

In the case of McNamara cephalometric measurements (Table 3), all measurements exhibited CCC values above 0.76.

Table (1) displays the Concordance Correlation Coefficient (ccc) and corresponding 95% Confidence Interval for Steiner cephalometric analysis comparing manual measurments with Eyes of AI™.

Parameter	Manual tracing vs Eyes of AI	Mean	SD	CCC	95%confidence interval
SNA	Manual	86.49	5.24	0.79	0.72-0.88
	Eyes of AI	87.80	3.18		
SNB	Manual	77.21	5.51	0.76	0.68-0.82
	Eyes of AI	77.41	3.58		
ANB	Manual	3.79	2.48	0.98	0.97-0.98
	Eyes of AI	3.62	2.25		
Occlusal plane to SN angle	Manual	17.48	4.94	0.94	0.92-0.96
	Eyes of AI	17.10	4.36		
Mandibular plane angle (Go-Gn) to SN	Manual	34.01	5.72	0.94	0.91-0.96
	Eyes of AI	34.28	5.50		
Maxillary incisor position (mm)	Manual	6.62	2.33	0.95	0.92-0.97
	Eyes of AI	6.66	2.17		
Maxillary incisor position (deg)	Manual	22.11	7.40	0.96	0.94-0.97
	Eyes of AI	21.68	7.03		
Mandibular incisor position (mm)	Manual	7.06	2.32	0.98	0.97-0.99
	Eyes of AI	6.80	1.97		
Mandibular incisor position (deg)	Manual	30.06	7.14	0.96	0.94-0.97
	Eyes of AI	29.80	6.82		
Interincisal angle	Manual	124.90	10.75	0.94	0.90-0.96
	Eyes of AI	125.20	10.25		

Notably, nine parameters, including A to N-Perp(FH), Maxillomandibular differential, Mandibular Plane Angle (McNamara), Facial Axis Angle (McNamara), Pog to N-Perp(FH), Upper incisor to point A vertical, Lower incisor to A-pog (mm), Upper airway assessment, and Lower airway assessment, achieved CCC values exceeding 0.9. SNA(McNamara), Effective length of mandible, Effective length of maxilla, and Low Ant Face Height showed CCC values between 0.82 and 0.88.

For Jefferson cephalometric measurements (Table 4), all measurements demonstrated a CCC value of 0.99. Notably, all three parameters, including Ans to Anterior Arc (Maxilla), Pog to Anterior Arc (Mandible), and Vertical Arc to M, achieved CCC values exceeding 0.9.

Discussion

Artificial Intelligence (AI) stands as a significant milestone achievement in modern-day science, demonstrating a myriad of applications across various fields. Orthodontics is no exception to this trend, as AI has found its way into numerous aspects of orthodontic practice. One notable area of development is the emergence of fully automated AI-driven cephalometric analysis software. These digital techniques for lateral cephalometric analysis are rapidly gaining popularity within the orthodontic community.

Table (2) displays the Concordance Correlation Coefficient (ccc) and corresponding 95% Confidence Interval for Downs cephalometric analysis comparing manual measurments Eyes of AI™.

Parameters	Manual tracing vs Eyes of AI	Mean	SD	CCC	95%confidence interval
Facial angle	**Manual**	**88.18**	**4.28**	**0.78**	**0.70-0.85**
	Eyes of AI	**87.80**	**3.18**		
Angle of convexity	**Manual**	**7.09**	**5.64**	**0.99**	**0.99-0.99**
	Eyes of AI	**6.92**	**5.42**		
A-B plane angle	**Manual**	**-6.24**	**3.80**	**0.99**	**0.98-0.99**
	Eyes of AI	**-5.98**	**3.57**		
Mandibular plane angle (Down)	**Manual**	**27.63**	**5.79**	**0.95**	**0.93-0.97**
	Eyes of AI	**27.30**	**5.20**		
Growth axis	**Manual**	**60.48**	**4.57**	**0.80**	**0.72-0.85**
	Eyes of AI	**60.37**	**3.12**		
Cant of occlusion	**Manual**	**7.11**	**3.70**	**0.99**	**0.98-0.99**
	Eyes of AI	**7.02**	**3.63**		
Inter-incisal angle	**Manual**	**124.91**	**10.75**	**0.94**	**0.90-0.96**
	Eyes of AI	**125.20**	**10.25**		
Incisor occlusal plane angle	**Manual**	**25.36**	**7.11**	**0.96**	**0.94-0.97**
	Eyes of AI	**25.29**	**6.80**		
Incisor mandibular plane angle	**Manual**	**5.28**	**7.17**	**0.99**	**0.99-1.00**
	Eyes of AI	**5.00**	**6.89**		
Protrusion of maxillary incisors	**Manual**	**8.34**	**2.85**	**0.96**	**0.94-0.98**
	Eyes of AI	**8.17**	**2.66**		

Table (3) displays the Concordance Correlation Coefficient (ccc) and corresponding 95% Confidence Interval for McNamara cephalometric analysis comparing manual measurments with Eyes of AI™.

Parameter	Manual tracing vs Eyes of AI	Mean	SD	CCC	95%confidence interval
A to N-Perp(FH)	**Manual**	**1.12**	**3.28**	**0.99**	**0.98-0.99**
	Eyes of AI	**1.11**	**3.07**		
SNA(McNamara)	**Manual**	**81.49**	**5.24**	**0.85**	**0.79-0.89**
	Eyes of AI	**81.00**	**3.78**		
Effective length of mandible	**Manual**	**115.07**	**10.00**	**0.88**	**0.83-0.92**
	Eyes of AI	**115.19**	**7.75**		
Effective length of maxilla	**Manual**	**88.16**	**7.00**	**0.82**	**0.75-0.87**
	Eyes of AI	**87.23**	**5.34**		
Maxillomandibular differential	**Manual**	**27.94**	**5.32**	**0.91**	**0.87-0.94**
	Eyes of AI	**27.96**	**4.42**		
Low Ant Face Height	**Manual**	**69.55**	**6.39**	**0.86**	**0.80-0.91**
	Eyes of AI	**68.99**	**5.34**		
Mandibular Plane Angle (McNamara)	**Manual**	**27.90**	**5.56**	**0.92**	**0.88-0.95**
	Eyes of AI	**27.30**	**5.20**		
Facial Axis Angle (McNamara)	**Manual**	**-3.28**	**4.53**	**0.99**	**0.99-0.99**
	Eyes of AI	**-3.12**	**4.32**		

Table (4) displays the Concordance Correlation Coefficient (ccc) and corresponding 95% Confidence Interval for Jefferson cephalometric analysis comparing manual measurments with Eyes of AI™.

Parameter	Manual tracing vs Eyes of AI	Mean	SD	CCC	95%confidence interval
Ans to Anterior Arc (Maxilla)	Manual	2.75	3.76	0.99	0.99-1.00
	Eyes of AI	2.61	3.66		
Pog to Anterior Arc (Mandible)	Manual	2.78	4.87	0.99	0.99-1.00
	Eyes of AI	2.72	4.67		
Vertical Arc to M	Manual	5.54	5.55	0.99	0.99-1.00
	Eyes of AI	5.39	5.35		

Whether these programs are computer-based or web-based, the accuracy of tracing is paramount. Indeed, it is the most critical factor to consider before engaging with any digital cephalometric analysis program on the market. Errors stemming in identifying landmarks can result in flawed cephalometric interpretation, potentially leading to inaccurate orthodontic diagnosis and treatment planning. Therefore, it is important to rigorously assess the accuracy of these AI-driven software solutions. Such evaluations ensure that orthodontists can confidently rely on these digital tools to aid in their clinical decision-making processes, ultimately improving patient care outcomes.

Hence, in our study, we undertook a comparison to ascertain the accuracy of cephalometric analysis conducted using conventional technique versus a novel AI-based program tailored for lateral cephalometric analysis, namely Eyes of AI™. This web-based platform requires only an internet browser for access and analysis.

To evaluate the accuracy of Eyes of AI™, we focused on cephalometric measurements rather than landmark identification. This choice was made because measurements represent the final outcome of the cephalometric tracing process and furnish crucial data for treatment planning.[3]

The selection of Steiner[9], Downs[10], McNamara[11] and Jeffersson[12] analyses for our study was based on their widespread implementation in orthodontics. These analyses offer a comprehensive range of linear and angular measurements for assessing skeletal, dental, and soft tissue structures. They represent common cephalometric parameters used for orthodontic diagnosis and formulation of treatment plan.

It's worth noting that all tracings, landmark identification, and analysis measurements were conducted by the same operator. This decision was made in consideration of previous research[13] indicating that the experience of the orthodontist plays a crucial role in preventing errors during landmark identification on cephalograms.

In previous studies, the paired t-test was commonly employed to compare measurements obtained by different tracing techniques.[3] However, in our study, we utilized the Concordance Correlation Coefficient (CCC). CCC is recognized as the statistical method of choice for assessing the agreement between test measurments.[14] This approach provides a more comprehensive evaluation of the agreement between measurements obtained by different tracing methods, enhancing the robustness and reliability of our findings.

In our study, we compared thirty-six cephalometric measurements between manual tracing and AI-driven Eyes of AI^{TM}, with all parameters demonstrating a Concordance Correlation Coefficient (CCC) value above 0.76, indicating strong agreement between manual and AI-driven cephalometric measurements. A higher CCC value (>0.9) was observed for twenty-eight parameters, indicative of very strong agreement. Therefore, the null hypothesis was accepted as this demonstrates that cephalometric measurements obtained from Eyes of AI^{TM} are comparable in accuracy to the gold standard of manual tracing.

These results align with Saifeldin[3] findings, which concluded that two AI-driven web-based platforms are comparable to manual tracing. However, recent studies have continued to delve into the accuracy of various AI-driven lateral cephalometric software platforms showing mixed outcomes. Alqahtani[15] examination of FACAD and CephX software revealed significant differences within both programs for specific measurements such as SNA, FMA, and Pg to NB. Similarly, MeriÃ et al[16] comparison of Dolphin Imaging software, automated CephX and manual tracing highlighted the need for further enhancements to improve the reliability of CephX. Additionally, Yassir et al[17] comparison of fully automated WebCeph measurements to those of AutoCAD uncovered challenges with poor landmark identification and measurement inconsistency in WebCeph. Furthermore, Mahto et al.[18] argued that orthodontic diagnosis and treatment planning reliant on cephalometric measurements acquired from WebCeph, utilizing AI fully automated features, may occasionally lead to misinterpretation.

These findings highlight the importance of thorough evaluation and validation of AI-driven lateral cephalometric software to ensure their reliability and accuracy in clinical practice.

Indeed, accurate cephalometric analysis is paramount in orthodontic treatment planning, enabling practitioners to diagnose cases precisely, assess various treatment modalities, monitor treatment progress, and forecast treatment outcomes.

Therefore, our study underscores the significance of Eyes of AI^{TM}, demonstrating its capability to perform cephalometric analysis accurately compared to conventional manual tracing, and notably, in a much shorter duration. This finding suggests that Eyes of AI^{TM} holds promise as a valuable tool for orthodontists, potentially streamlining workflow and improving efficiency without compromising accuracy.

As with any study, our research has certain limitations. Although we noted that automated tracing with Eyes of AI^{TM} was quicker in comparison to manual tracing, we did not directly contrast the time needed to perform cephalometric measurements using both methods. Exploring this aspect in future studies could offer a more comprehensive understanding of the efficiency of automated cephalometric analysis.

Conclusion

Based on the findings of this study, it can be concluded that AI automated lateral cephalometric measurements obtained from Eyes of AI^{TM} are accurate when compared to manual measurements. The advantages offered by an online, AI-driven web-based platform for cephalometric analysis, such as online storage, online archiving, fast analysis, no need for specific software or hardware, and compatibility with any operating system and device, position Eyes of AI^{TM} as an efficient and practical tool for orthodontic practice.

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