COMPARISON OF ACCURACY AND RELIABILITY OF CEPHALOMETRIC LANDMARKS AMONG DIGITAL SOFTWARE WEB CEPH AND CARE STREAM WITH TRADITIONAL MANUAL TRACING

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ABSTRACT

OBJECTIVES

This study aimed to compare the accuracy and reliability of AI-assisted software (WebCeph, Carestream) with manual tracing.

METHODOLOGY

This cross-sectional (analytical) study was conducted using the records of patients presenting to the Orthodontic Department, Rehman College of Dentistry (RCD), Peshawar, over a period of three months. Forty-two high-quality lateral cephalograms were traced manually for four skeletal (SNA, SNB, ANB, FMA), three dental (UI-SN, IMPA, Overjet), and three soft tissue parameters (UL-Eline, LL-Eline, and NLA). The same cephalograms were later digitally analyzed using AI-assisted software (Carestream and WebCeph). One-way ANOVA test and post hoc Tukey test were applied to assess any significant differences among the groups. Bonferroni correction was employed to adjust the significance level (alpha) for each test and multiple comparisons. Pearson Correlation coefficients were used to determine the correlation among the various group values.

RESULTS

Web Ceph and manual tracing revealed a significant difference in UI-SN, overjet, and UL-Eline (P<0.05). Comparison between manual tracing and Carestream showed significant differences in FMA, IMPA, UL-E line, and LL-Eline (P<0.05). While comparing Web Ceph and Carestream, significant differences were observed in UL-Eline, IMPA, and NLA (P<0.05). It was found that the differences in the mean values between AI-driven software and manual methods were clinically insignificant. However, differences among AI-driven methods were clinically significant.

CONCLUSION

AI-driven cephalometric digital tracing software, Web Ceph, and Carestream provide sufficiently reliable measurements for clinical application. Web Ceph showed better results for specific values than Carestream. The accuracy and consistency of automated software can be improved through manual adjustments and verification. Despite the clinical applicability, manual tracing cannot be replaced by computerized cephalometric.

KEYWORDS: *Lateral Cephalometric Analysis, Artificial Intelligence, Carestream, Web Ceph*

INTRODUCTION

With the introduction of cephalometric analysis by Broadbent in the 1930s, orthodontists have gained a valuable diagnostic tool to quantitatively provide information, evaluate skeletal and dental relationships, determine growth and developmental abnormalities, and assess orthodontic treatment and its outcomes.[1,2,3] For decades, traditional manual cephalometric analysis has been considered the gold standard. However, this method has been reported to be laborious, time-consuming, and prone to measurement and calculation errors.[4] Recently, Artificial Intelligence (AI) has revolutionized the dental field and has been adopted over the years for automated cephalometric identification and analysis. With the advent of digital technology, a variety of tools and software have emerged, reported to provide greater accuracy and efficiency. The literature suggests that these digital systems offer several advantages, including reduced subjectivity-related errors. Time consumption, facilitating faster data analysis and acquisition, image storage, and sharing, as well as streamlining the formulation of treatment plans.[5,6,7] AI-driven cephalometric tracing system uses a deep convolutional neural network (CNN) for automatic landmark detection. For tracing soft tissue profile, the software utilizes classical image processing, specifically mathematical morphology. This integration of AI-driven algorithms and traditional image processing enhances the accuracy, speed, and consistency of cephalometric analyses.[8,9,10] Today, a wide range of software options is available, ranging from computer-assisted applications like Dolphin imaging and Viewbox to fully automated or semi-automated AI-powered solutions such as CephX®, CEFBOT, Web Ceph, and Carestream software, among others.11,12 These tools are transforming clinical workflows by reducing human error, saving time, and enhancing diagnostic consistency. Web-Ceph is a web-based, fully automated, and capable of performing nine different cephalometric analyses and interpretations. It can store, maintain, and archive patients' cephalograms, photographs, and orthopantomograms. Additionally, it includes advanced features, such as visual treatment simulation and superimposition, which are helpful in day-to-day orthodontic practice.[13,14] Carestream, a dental company, has also shown keen interest in developing automatic cephalometric landmark identification and tracking, which is widely used in clinical practice. Nowadays, companies offer advanced cephalometric imaging software that can fully trace any cephalometric radiograph taken with a Carestream cephalostat.[15,16,17] Orthodontists must locate cephalometric landmarks for the effective diagnostic outcome precisely.18 Numerous papers have been published in recent years to evaluate the accuracy of these AI- based software programs compared to the traditional manual and digital methods. Niwat et al. identified that 76% of cephalometric measurements performed automatically by the dental imaging software (Carestream Dental, Version 6.14) showed statistically significant differences compared to the manual method.19 Conversely, a study by Pamir et al concluded that CephX® (a web-based cephalometric software) was as accurate as the Ceph-Ninja 3.51 app (app-aided and Dolphin Imaging 13.01 computerized method after manual correction of the landmarks), and it also provided shorter analysis time.[20] Tsolakis et al also found fully automated cephalometric analysis by CS imaging (Care Stream Version 8) to be as reliable and accurate as the manually traced Dolphin 3D Imaging program (version 11.0). While slight differences were observed in a few measurements (FMA, L1-MP, ANS-PNS/Go-Gn, and U1-L1), they were not considered clinically significant.15 Similarly, Ravi Kumar et al also suggested Web -Ceph (a fully automated program) to be reasonably accurate, reliable, and valid as compared to manual tracing of cephalometric measurements.[21] To the best of our knowledge, no published articles have been found comparing the reliability and accuracy of artificial intelligence (AI)-based cephalometric analysis programs with the manual tracing method within Pakistan. Therefore, our study aimed to evaluate and compare the accuracy and reliability of cephalometric measurements obtained from two AI-based software programs (Carestream and WebCeph) with traditional manually traced cephalometric analysis. The null hypothesis was that there are no statistical differences among the cephalometric analysis methods in terms of accuracy and reliability.

METHODOLOGY

This cross-sectional (analytical) study was conducted on the records of patients presenting at the Orthodontic department, Rehman College of Dentistry (RCD), Peshawar, over a period of three months following the ethical approval of the research proposal from the review committee of Rehman College of Dentistry, EC Ref No: RCD-005-25-202. Informed consent was obtained from each patient prior to the collection of their records and data. The Sample size was calculated using the G*Power sample size calculator, based on a confidence interval of 95% and a statistical power of 80%.[22] A total of 42 samples were included in the study. The sampling method employed was non-probability convenience sampling. Lateral cephalograms were obtained using a CS 9000 machine, with the following acquisition and exposure parameters: software version, CS Imaging v8.0.3, exposure time: 0.40seconds, tube voltage: 64kV. For an optimal outcome, X-ray images were captured at the maximum size (18 × 24 cm), in the lateral view. The inclusion criteria for the study were high-quality cephalograms with no artifacts, captured with the patient in an upright standing position in centric occlusion and with relaxed lips. Cephalograms of patients with positional errors, unerupted teeth that could interfere with the anatomical landmarks, and craniofacial deformities (e.g., cleft lip and palate) were excluded from the study. For manual tracing, the cephalograms were printed at a 1:1 scale and traced on an acetate paper using a 0.3 mm hard lead black pencil. The same cephalogram images were imported into CS 3600 software and saved in JPEG format for subsequent automated analysis in Web Ceph software. Figure 1 (A&B). Later, digital analysis was performed using Carestream and Web Ceph software. Figure 1. The study focused on four skeletal, three dental, and three soft tissue parameters. Table 1: All the landmarks were identified by the trainee under the supervision of the supervisor. The same operator performed both manual and digital analyses. Manual adjustments of landmarks were performed for a few landmarks where required for both digital software. For the manual method, no more than 5 tracings were performed on a single day to minimize human fatigue and maintain consistency. The study was completed in 3 months. To assess the accuracy of the manual measurements, 10 to 15 randomly selected lateral cephalograms were reassessed by the same examiner two weeks after the initial measurements. The reliability of the measurements was evaluated using intraclass correlation coefficients. Data were recorded and analyzed using SPSS version 25 (IBM Corp., Armonk, NY, USA. The significance level for all statistical tests was set at P=0.05.

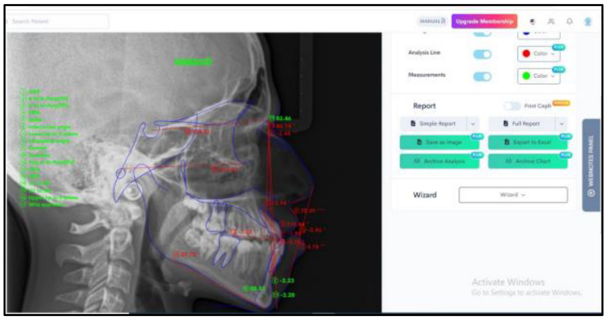

Figure 1(a): Showing Landmarks and Web Cep Software Analysis

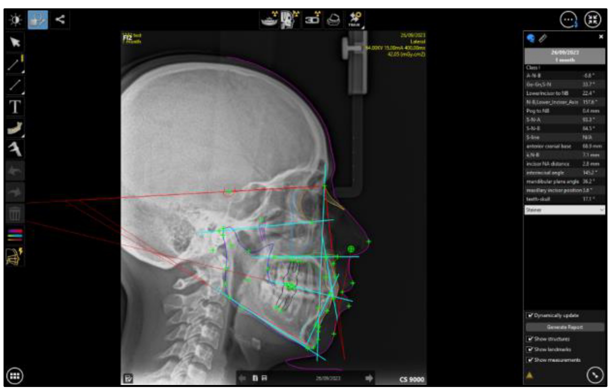

Figure 1(b): Showing Landmarks and Care Stream Software Analysis

RESULTS

Intra-examiner reliability for measurements was high (ICC = 0.83), indicating a strong correlation between the two scale items and effective measurement of the underlying construct. The Shapiro-Wilk test ($p > 0.05$) supported the normality assumption, justifying the use of parametric tests. Analysis of 42 cephalograms compared four skeletal, three dental, and three soft-tissue parameters using manual, digital (CS3600 and Web Ceph software) methods (Table 1). Descriptive statistics are shown in Table 2. Repeated-measures ANOVA revealed significant differences primarily in dental and soft-tissue parameters across intra- and inter-group comparisons (Table 3). Significant differences ($p < 0.05$) were found between manual and Web Ceph measurements for UI-SN, OVERJET, IMPA, and U L-E line, but these differences were clinically insignificant (Tables 2 and 3). Manual and Care Stream measurements showed significant differences ($p < 0.05$) in FMA, IMPA, UL-E line, LL-E line, and Overjet. Clinically significant differences were observed for IMPA (101.7 ± 7.00 vs 94.69 ± 7.49), UL-E line (-2.80 ±2.1 vs 3.81 ± 2.36), and LL-E line (-1.07 ± 2.4 vs 2.91 ± 2.31) (Tables 2 and 3). Furthermore, clinically significant differences were found between Web-Ceph and Care Stream measurements in UL-E line (-2.86 ±2.43 Vs 3.81 ± 2.36), IMPA (98.93 ± 6.77 Vs 94.69 ± 7.49), and NLA (95.7 ± 13.25 Vs 100.9 ± 11.34) ($p < 0.05$). Correlation analysis showed strong, positive, and significant correlations between Care Stream and Web Ceph variables with manual measurements, except for Overjet ($r = 0.23$, $p = 0.13$) and LL to E-line ($r = -0.26$, $p = 0.10$) from Care Stream, which showed weak and insignificant correlations (Table 4).

Table 1: Cephalometric Parameters Measured

Skeletal	Dental	Soft tissue
SNA	U1 to SN	UL to E line
SNB	IMPA	LL to E line
ANB	OVERJET	NLA
FMA		

Table 2: Descriptive Data of All the Variables (Skeletal, Dental, and Soft Tissue)

Variables		N (42)	Mean ± Std. Deviation
Skeletal	SNA	Manual	81.76 ± 3.35
		Web Ceph	81.82 ± 3.65
		CS	82.55± 4.65
	SNB	Manual	76.30± 3.59
		Web Ceph	76.32 ± 3.91
		CS	76.91 ± 4.76
	ANB	Manual	5.45± 2.51
		Web Ceph	5.57 ± 2.69
		CS	5.57 ± 2.75
	FMA	Manual	25.50 ± 6.65
		Web Ceph	24.05± 6.56
		CS	27.04 ± 5.01
Dental	OVER JET	Manual	4.50 ± 3.77
		Web Ceph	6.04 ± 3.15
		CS	6.63 ± 3.39
	UI to SN	Manual	107.47± 9.55
		Web Ceph	105.21 ± 9.68
		CS	105.45 ± 10.26
	IMPA	Manual	101.7 ± 7.00
		Web Ceph	98.93 ± 6.77
		CS	94.69 ± 7.49
Soft tissue	UL to Eline	Manual	-2.80 ±2.1
		Web Ceph	-2.86 ±2.43
		CS	3.81 ± 2.36
	LL to Eline	Manual	-1.07 ± 2.42
		Web Ceph	-1.56 ± 3.05
		CS	2.91 ± 2.31
	NLA	Manual	98.64 ± 13.20
		Web Ceph	95.7 ± 13.25
		CS	100.9 ± 11.34

Table 3: ANOVA and Post Hoc-Tukey Test Showing Inter-Group Comparisons

Variables	Groups	Groups	P-value
SNA	Manual	Web Ceph	1.00
		CS	0.212
	Web Ceph	CS	0.161
SNB	Manual	Web Ceph	1.00
		CS	0.506
	Web Ceph	CS	0.192
ANB	Manual	Web Ceph	1.000
		CS	1.000
	Web Ceph	CS	1.000
FMA	Manual	Web Ceph	0.068
		CS	0.050
	Web Ceph	CS	0.000
OVERJET	Manual	Web Ceph	0.000
		CS	0.000
	Web Ceph	CS	0.217
Upper incisor to SN plane	Manual	Web Ceph	0.001
		CS	0.145
	Web Ceph	CS	1.00
IMPA	Manual	Web Ceph	0.000
		CS	0.001
	Webceph	CS	0.002
Upper lip to E line	Manual	Web Ceph	0.00
		CS	0.00
	Web Ceph	CS	0.02
Lower lip to E line	Manual	Web Ceph	0.62
		CS	0.00
	Web Ceph	CS	0.08
NLA	Manual	Web Ceph	0.10
		CS	0.730
	Web Ceph	CS	0.044

Table 4: Showing Correlation Among Variables

Variables	Manual	Web Ceph	P-Value	Care Stream	P-Value
	R				
SNA	01	0.924**	0.000	0.840**	0.000
SNB	01	0.824**	0.000	0.819	0.000
ANB	01	0.901**	0.000	0.919**	0.000
FMA	01	0.802**	0.000	0.744**	0.000
OVERJET	01	0.923**	0.000	0.237	0.135
UI TO SN	01	0.907**	0.000	0.824**	0.000
IMPA	01	0.771**	0.000	0.396*	0.010
UL TO E LINE	01	0.827**	0.000	-0.776**	0.000
LL TO E LINE	01	0.619**	0.000	-0.260	0.101
NLA	01	0.760**	0.000	0.671**	0.000

DISCUSSION

This study compared the accuracy and reliability of manual cephalometric analysis with AI-driven software (Web Ceph and Carestream). While statistically significant differences were observed in some variable measurements (FMA, UI-SN, Overjet, UL-E line, LL-E line, NLA, IMPA) between the AI-based software groups, though clinically insignificant, the differences were clinically significant among the digital software variables. However, strong positive correlations were found among all variables from Carestream and Web Ceph, as well as the manual cephalometric variables, supporting the practical reliability and validity of these automated methods in research and clinical settings. Minor digital-to-manual differences, often within decimal points or a few degrees, further support the clinical acceptability of AI-based programs. The existing literature compares manual cephalometric analysis with digital automated and semi-automated software such as WebCeph, Carestream, AutoCAD, OneCeph, and ViewBox. Software selection depends on user familiarity, interface capabilities, and specific features. The shift to digital software allows for automated landmark identification, minimizing bias and improving efficiency and reproducibility, with the potential for 3D analyses. Despite these benefits, some meta-analyses suggest that while digital tracing offers reliable and efficient measurements, semi-automated methods that allow landmark modifications may be preferable.[2,5,15] It can be concluded that automated cephalometric measurements obtained from the WebCeph program are reasonably accurate compared to manual tracing. Likewise, a study by Ravi Kumar et al. reported a strong correlation (r=0.75) and good agreement between the two methods across the parameters. Although it is to be noted that minor differences observed for these variables might be attributed to an automated landmark identification issue, despite manual adjustments.[21]-According to the current literature, a 2 mm variation is generally clinically adequate, accurate, and, therefore, acceptable and within the range of diagnostic accuracy.[2] Furthermore, each cephalometric parameter has a mean norm value and a standard deviation value for every measurement that acknowledges some degree of variability acceptance. The literature reports that AI-driven, fully automated landmark detection can be misleading at times. Like, in our study, adjustments were needed in the Web Ceph for specific landmarks, i.e., the incisal edge and nasion point. Yassir A et al. compared Web Ceph and computer-based AutoCAD software; differences were found among the soft-tissue variables, especially the nasolabial angle (NLA).[22] The difference could be attributed to poor landmark identification, mainly in soft tissue tracing that is inherent to the automatic Web Ceph. This issue can be mitigated by using semi-automatic software options that utilize manual corrections. Similarly, a study by Gokhan Serhat et al. evaluating Dolphin, orthodox, and Web Ceph software found good, significant consistency in angular measurements, but linear and soft-tissue parameters showed low consistency.[23] These findings align with the findings of Khattri's study, comparing Web Ceph with V15.0 FACAD Manual tracing, suggesting that fully automated versions are not yet ready to replace semi-automated computer-aided methods and reinforcing the importance of semi-automated versions.[24] In our study, a comparison between Manual tracing and Carestream (CS) software measurements revealed that the mean values of only IMPA, UL-E line, and LL-E line showed a clinically significant difference despite manual correction of the landmarks in the CS software. It can be attributed to mathematical or directional errors, as CS software does not indicate to the operator whether the values are positive (+ive) or negative (-ive), which can affect Interpretation. Some adjustments were needed for Nasion, point A, point B, the Sella point, and the incisal edge to improve accuracy. Ioannis A. Tsolakis et al. compared a digital manual method using (Dolphin 3D Imaging program version 11.0) with automated, CS imaging V8 software and reported an excellent intra-class reliability (>0.97) and a strong agreement between the two approaches, showing statistically significant differences in the mean values, FMA, L1-MP, ANS-PNS/GoGn, and U1-L1 ($p < 0.0027$) were observed,[15] that are consistent with the findings of our study. Similar to the results of our study, many other studies have reported significant With the introduction of cephalometric analysis by Broadbent in the 1930s, orthodontists have gained a valuable diagnostic tool to quantitatively provide information, evaluate skeletal and dental relationships, determine growth and developmental abnormalities, and assess orthodontic treatment and its outcomes.[1,2,3] For decades, traditional manual cephalometric analysis has been considered the gold standard. However, this method has been reported to be laborious, time-consuming, and prone to measurement and calculation errors.[4] Recently, Artificial Intelligence (AI) has revolutionized the dental field and has been adopted over the years for automated cephalometric identification and analysis. With the advent of digital technology, a variety of tools and software have emerged, reported to provide greater accuracy and efficiency. 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This integration of AI-driven algorithms and traditional image processing enhances the accuracy, speed, and consistency of cephalometric analyses.[8,9,10] Today, a wide range of software options is available, ranging from computer-assisted applications like Dolphin imaging and Viewbox to fully automated or semi-automated AI-powered solutions such as CephX®, CEFBOT, Web Ceph, and Carestream software, among others.[11,12] These tools are transforming clinical workflows by reducing human error, saving time, and enhancing diagnostic consistency. Web-Ceph is a web-based, fully automated, and capable of performing nine different cephalometric analyses and interpretations. It can store, maintain, and archive patients' cephalograms, photographs, and orthopantomograms. Additionally, it includes advanced features, such as visual treatment simulation and superimposition, which are helpful in day-to-day orthodontic practice.[13,14] Carestream, a dental company, has also shown keen interest in developing automatic cephalometric landmark identification and tracking, which is widely used in clinical practice. Nowadays, companies offer advanced cephalometric imaging software that can fully trace any cephalometric radiograph taken with a Carestream cephalostat.[15,16,17] Orthodontists must locate cephalometric landmarks for the effective diagnostic outcome precisely.[18] Numerous papers have been published in recent years to evaluate the accuracy of these AI- based software programs compared to the traditional manual and digital methods. Niwat et al. identified that 76% of cephalometric measurements performed automatically by the dental imaging software (Carestream Dental, Version 6.14) showed statistically significant differences compared to the manual method.19 Conversely, a study by Pamir et al concluded that CephX® (a web-based cephalometric software) was as accurate as the Ceph-Ninja 3.51 app (app-aided and Dolphin Imaging 13.01 computerized method after manual correction of the landmarks), and it also provided shorter analysis time.20 Tsolakis et al also found fully automated cephalometric analysis by CS imaging (Care Stream Version 8) to be as reliable and accurate as the manually traced Dolphin 3D Imaging program (version 11.0). While slight differences were observed in a few measurements (FMA, L1-MP, ANS-PNS/Go-Gn, and U1-L1), they were not considered clinically significant.15 Similarly, Ravi Kumar et al also suggested Web -Ceph (a fully automated program) to be reasonably accurate, reliable, and valid as compared to manual tracing of cephalometric measurements.[21] To the best of our knowledge, no published articles have been found comparing the reliability and accuracy of artificial intelligence (AI)-based cephalometric analysis programs with the manual tracing method within Pakistan. Therefore, our study aimed to evaluate and compare the accuracy and reliability of cephalometric measurements obtained from two AI-based software programs (Carestream and WebCeph) with traditional manually traced cephalometric analysis. The null hypothesis was that there are no statistical differences among the cephalometric analysis methods in terms of accuracy and reliability. tracing. CephX analysis combined with manual correction was found to be promising for clinical use, as its accuracy is comparable to CephNinja and Dolphin. In addition, the analysis time was found to be significantly shorter for Ceph Ninja and Dolphin compared to manual tracing.[20] In comparison with previous studies, both the digital Web_Ceph and Carestream (CS) software were found to be accurate and reliable, although there were significant differences among a few variables, mainly dental and soft tissue measurements. The literature suggests that it is due to faulty landmark identification by automated software programs that require manual adjustments. Our study confirmed that Web Ceph required less landmark adjustment than the CS program. Besides quick cephalometric analyses and Interpretation, features such as cloud-based storage of patients' records, visual treatment simulation, and superimposition can make "WebCeph"™ an efficient and promising tool for routine clinical orthodontic practice. AI-based methods show considerable potential; they have been recommended for use as a supportive rather than definitive diagnostic tool. Even with automated methods and approaches, the operator needs to review, verify, and adjust the software's landmark positions as required before finalizing the cephalometric analysis to ensure accuracy.

LIMITATIONS

Future research can benefit from a larger sample size with additional parameters, involvement of multiple investigators for the reduction of bias, and determining inter-examiner reliability, and to further validate the accuracy and reliability of AI-based software. Time efficiency was a key finding of our study: AI-based digital software proved to be faster than manual tracing. Future studies should compare time requirements for different methods. Furthermore, the need for a stable internet connection may limit the use of software in specific clinical settings. Though it is pertinent to identify that this software needs manual correction of specific landmarks, and orthodontists should ideally supervise that for accuracy.

CONCLUSIONS

Cephalometric measurements performed with Web Ceph and Carestream demonstrated high reliability, making them a viable option for integration into the clinical routine; however, they should be used with proper supervision and manual corrections as needed. Web-Ceph was found to be better than Carestream software, as Carestream software required more manual corrections of the landmarks and did not indicate the operator's positive (+) or negative (–) values, potentially affecting the results and Interpretation.

CONFLICT OF INTEREST: None

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REFERENCES

1. Nielsen IL. Cephalometric analysis: history and clinical application. Taiwan J Orthod. 2022 Dec 27;34(4):1–10.
2. Schwendicke F, Chaurasia A, Arsiwala L, Lee JH, Elhennawy K, Jost-Brinkmann PG, et al. Deep learning for cephalometric landmark detection: systematic review and meta-analysis. Clin Oral Investig.2021 Jul;25(7):4299-309.https://doi.org/10.1007/s00784-021-03997-4.PMID:33886143
3. Sennimalai K, Selvaraj M, Kharbanda OP, Kandasamy D, Mohaideen K. MRI-based cephalometrics: a scoping review of current insights and future perspectives. Dentomaxillofac Radiol.2023 Jul;52(5):20230106.https://doi.org/10.1259/dmfr.20230106. PMID: 37365724
4. Alsubai S. A critical review on the 3D cephalometric analysis using machine learning. Computers (Basel). 2022 Oct 28;11(11):154. https://doi.org/10.3390/computers11110154.
5. Narkhede S, Rao P, Sawant V, Sachdev SS, Arora S, Pawar AM, et al. Digital versus manual tracing in cephalometric analysis: a systematic review and meta-analysis. J Pers Med. 2024 May 25;14(6):566. https://doi.org/10.3390/jpm14060566. PMID: 38892926
6. AlBarakati S, Kula K, Ghoneima A. The reliability and reproducibility of cephalometric measurements: a comparison of conventional and digital methods. Dentomaxillofac Radiol. 2012 Jan;41(1):11-7.https://doi.org/10.1259/dmfr/81804525. PMID: 22116109
7. Subramanian AK, Chen Y, Almalki A, Sivamurthy G, Kafle D. Cephalometric analysis in orthodontics using artificial intelligence-A comprehensive review. Biomed Res Int. 2022;2022:1-10.https://doi.org/10.1155/2022/9075785.PMID:35223134
8. Gil SM, Kim I, Cho JH, Hong M, Kim M, Kim SJ, et al. Accuracy of auto-identification of posteroanterior cephalometric landmarks using a cascade convolutional neural network algorithm. Am J Orthod Dentofacial Orthop.2022Apr;161(4):e361-71.https://doi.org/10.1016/j.ajodo.2021.08.026. PMID: 35364377
9. Gurbade VV, Pacharaaney U, Puri C. Advancements in AI-driven cephalometric analysis for orthodontic applications: a review on automated landmark detection and angle assessment. In: 2025 4th International Conference on Sentiment Analysis and Deep Learning (ICSADL). IEEE;2025.p.1731-6.https://doi.org/10.1109/ICSADL58257.2025.10496547.
10. Bulatova G, Kusnoto B, Grace V, Tsay TP, Avenetti DM, Sanchez FJC. Assessment of automatic cephalometric landmark identification using artificial intelligence. Orthod Craniofac Res. 2021Dec;24(S2):37-42.https://doi.org/10.1111/ocr.12529.PMID:34927440

11. Foroozandeh M, Salemi F, Shokri A, Farhadian N, Aeini N, Hassanzadeh R. Comparative accuracy of AI-based AudaxCeph software, Dolphin software, and the manual technique for orthodontic landmark identification. Imaging Sci Dent. 2024;55(1):11–8. https://doi.org/10.5624/isd.20240004.
12. Maniyar N, Prakash AT, Kumar HCK, Yavagal PC. Accuracy of Dolphin Imaging software in predicting soft tissue changes of Class II Division 1 cases treated by all first premolar extraction. J World Fed Orthod.2024 June;13(3):128-35.https://doi.org/10.1016/j.ejwf.2024.02.003.
13. Raby I, Rojas V, Celis A, García-Duhalde C, Martinac M. Accuracy and reliability of two artificial intelligence platforms for cephalometric analysis compared with a semi-automatic computer program. Am J Orthod Dentofacial Orthop. 2025 Oct;168(4):505–14. https://doi.org/10.1016/j.ajodo.2025.03.019.
14. Kazimierczak W, Gawin G, Janiszewska-Olszowska J, Dyszkiewicz-Konwińska M, Nowicki P, Kazimierczak N, et al. Comparison of three commercially available AI-driven cephalometric analysis tools in orthodontics. J Clin Med. 2024 Jun 26;13(13):3733. https://doi.org/10.3390/jcm13133733.
15. Tsolakis IA, Tsolakis AI, Elshebiny T, Matthaios S, Palomo JM. Comparing a fully automated cephalometric tracing method to a manual tracing method for orthodontic diagnosis. J Clin Med.2022 Nov 20;11(22):6854.https://doi.org/10.3390/jcm11226854.PMID:36430506
16. Debelmas A, Ketoff S, Lanciaux S, Corre P, Friess M, Khonsari RH. Reproducibility assessment of Delaire cephalometric analysis using reconstructions from computed tomography. J Stomatol Oral Maxillofac Surg. 2020 Feb;121(1):35–9. https://doi.org/10.1016/j.jormas.2019.08.006. PMID: 31611054
17. Tanellari O, Toti C, Baruti Papa E, Ghanim S, Savin C, Romanec C, et al. The link between obstructive sleep apnea syndrome and cephalometric assessment of upper airways and hyoid bone position. Medicina (Kaunas). 2022 Sep;58(9):1213. https://doi.org/10.3390/medicina58091213. PMID: 36141968
18. Polizzi A, Leonardi R. Automatic cephalometric landmark identification with artificial intelligence: an umbrella review of systematic reviews. J Dent 2024 Jul;146:105056.https://doi.org/10.1016/j.jdent.2024.105056.
19. Anuwongnukroh N, Dechkunakorn S, Damrongsri S, Nilwarat C, Pudpong N, Radomsutthisarn W, et al. Assessment of the reliability of automatic cephalometric analysis software. Int J Mech Eng Robot Res. 2017;6(6):61–5.
20. Meric P, Naoumova J. Web-based fully automated cephalometric analysis: comparisons between app-aided, computerized, and manual tracings. Turk J Orthod.2020 Sep;33(3):142-9.https://doi.org/10.5152/TurkJOrthod.2020.19072.
21. 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;22(1):132.https://doi.org/10.1186/s12903-022-02175-2.PMID:36531291
22. Yassir YA, Salman AR, Nabbat SA. The accuracy and reliability of WebCeph for cephalometric analysis. J Taibah Univ Med Sci.2022 Feb;17(1):57-66.https://doi.org/10.1016/j.jtumed.2021.10.010.
23. Duran GS, Gökmen Ş, Topsakal KG, Görgülü S. Evaluation of the accuracy of fully automatic cephalometric analysis software with an artificial intelligence algorithm. Orthod Craniofac Res. 2023 Aug;26(3):481-90.https://doi.org/10.1111/ocr.12644.PMID:37409109
24. Khattri N, Nasim NN, S V, N T, J N. Comparison of reliability and accuracy of AI-based fully automated cephalometric tracing software with computer-aided semi-automatic cephalometric software. J Dent Med Sci. 2023;22(1):26–33.

AUTHORS CONTRIBUTION

Ayesha Iftikhar - *Concept & Design; Data Acquisition; Data Analysis/Interpretation; Drafting Manuscript; Critical Revision; Supervision; Final Approval*

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The authors accept responsibility for all aspects of the work and will ensure that any concerns regarding the accuracy or integrity of any part are properly investigated and resolved.