ORIGINAL RESEARCH

Accuracy and Reliability of WebCeph Digital Cephalometric Analysis in Comparison with Conventional Cephalometric Analysis

Saya M Azeez[1], Fouad F Surji[2], Sara O Kadir[3], Roza Karim[4]

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Abstract

Aim: The purpose of this study was to determine the accuracy and reliability of direct digital radiograph tracing using WebCeph, comparing it to manually tracing digital printouts.

Materials and methods: A single operator measured 12 linear and angular cephalometric parameters digitally and manually, which comprised 25 digital lateral cephalometric photographs. The difference in measurements obtained from manual to digital tracings was compared using the intraclass correlation coefficient (ICC) and confidence interval (CI), while the intraexaminer error was assessed using the coefficient of variation (CV).

Results: A comparison of hand and WebCeph tracing showed an excellent level of agreement except for upper incisor (UI) to nasion-point A (NA), Frankfort-mandibular plane angle (FMA), incisor mandibular plane angle (IMPA), and lower incisor (LI) to nasion-noint B (NB), which showed moderate to good agreement. Intraexaminer reliability was excellent for both manual and digital approaches.

Conclusion: In conclusion, except for UI to NA, FMA, IMPA, and LI to NB, all measurements in this study demonstrated excellent agreement between digital and manual tracing.

Clinical significance: It can be concluded that digital tracing with WebCeph is suitable for clinical uses and equivalent to manual cephalometric tracings. For everyday use and research, digital imaging may be preferred over analog methods due to the advantages of digital imaging in terms of storage, enhancement, and transmission quality.

Keywords: Artificial intelligence, Digital cephalometric analysis, Reproducibility, Two-dimensional imaging, WebCeph.

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Introduction

Cephalometric radiography is an important tool for diagnostic purposes that looks at the development and the cause of abnormalities in the teeth or bones. It is used to plan treatment, assess its effectiveness, examine how dental and cranial structures fit together, and detect malocclusion. A computer-aided cephalometric study has been developed in addition to the traditional (manual) method as a result of recent advancements in computer and software technology.[1,2]

Traditional methods of cephalometric tracing have been readily available and commonly used in clinical practices. However, the efficiency of this method has been declining due to its being time-consuming, and its margin of error depends on the accuracy of measurements taken physically using a protractor and ruler. Therefore, human error must be taken into account when recording results taken from hand tracing and landmark identification.[3,4]

The evolution of technology brought about the development of digital cephalometric tracing. Digital cephalometric tracing can eliminate the drawbacks found through manual techniques. It is a time-effective method with a minimal margin for error because the measurements are taken with complete accuracy automatically through the computer. Even though digital cephalometric tracing has benefits, it is an expensive method that requires a real computer and the skills to properly use it.[5] Compared to traditional film-based radiography, digital imaging has a number of benefits: faster data processing, the removal of chemical and related environmental dangers, elimination of developing processes that are technique-specific, radiation dosage reduction, and digital radiography images are simple to preserve and enhance provider communication. Additionally, digital archiving is a useful strategy for addressing the issue of film deterioration.[6] Once the digital radiograph is imported utilizing artificial intelligence (AI) technology, computerized software and smartphone applications may automatically identify the landmarks and finish the measurements, or the operator can identify the landmarks by hand and then have the measurements calculated automatically.

The ability of these strategies to detect cephalometric landmarks within a clinically acceptable range is still unknown despite the wide range of suitable techniques for the automated detection of cephalometric landmarks.[7] When compared to manual tracing due

[1]Department of Orthodontics, Faculty of Dentistry, Tishk International University, Erbil, Kurdistan Region, Iraq

[2–4]Faculty of Dentistry, Tishk International University, Erbil, Kurdistan Region, Iraq

Corresponding Author: Saya M Azeez, Department of Orthodontics, Faculty of Dentistry, Tishk International University, Erbil, Kurdistan Region, Iraq, Phone: +9647504225202, e-mail: sayamustafa92@gmail.com

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to the higher frequency of errors, an extensive review by Leonardi et al.[8] found no scientific evidence to support the use of automatic landmark recognition. Recent research from several studies[7,9–11] has demonstrated that AI can identify landmarks with the same accuracy as human examiners and may be a practical solution for the repetitive detection of numerous cephalometric landmarks. Before AI models are used in clinical practice, it is vital to confirm their dependability and applicability, according to a systematic review by Hung et al.[12]

WebCeph is an AI-based orthodontic and orthognathic online platform that has lately gained popularity because of its numerous appealing features that might make planning orthodontic treatment and obtaining patient records easier. These include image archiving, a photo gallery, visual therapy simulation, automatic superimposition, and cephalometric analysis. Additionally, WebCeph supports manual landmark modification with measurement computation.[13]

Since computer-assisted cephalometric tracing programs are being used more and more in clinical orthodontics, it is important to evaluate the accuracy of commercially available cephalometric tracing software so that the clinician can choose the right software and analysis methods. This study compared the accuracy and reliability of direct digital radiograph tracing using WebCeph and manual tracing printouts of digital radiographs.

Materials and Methods

Samples

The study design is retrospective cross-sectional**.** A power value of 95% and a significance level of 0.05 were used to calculate the sample size. It was necessary to have a sample of at least 25 patients. A prior study served as the foundation for the impact magnitude.[14] The 25 pretreatment cephalometric radiographs (8 males and 17 females) of age range 20–25 who went to the Orthodontic Department were chosen, the study duration was two months, and the Institution's Ethical Committee approved the study. All the lateral cephalometric radiographs were taken with the cephalostat of NewTom GIANO/VG3 (Imola, Italy), which was set to the manufacturer's recommended magnification of ×1.11. We used a 1512 mm source-to-detector distance (SID), with a distance between the skin and source of >1000 mm and a scanning time of a little over 4 seconds, to orient each patient's head in such a way that their Frankfort plane was aligned with the horizontal red-light trace and their teeth in the correct position for occlusion. According to its specifications, the sensor's pixel size is 48 x 48 µm with a 6 x 220 mm area of sensitivity.

Inclusion Criteria

- High-resolution radiographs with no artifacts that could obstruct the location of anatomical landmarks.
- In the permanent dentition, there are no impacted or missing teeth.
- There are no deformities or asymmetries in the craniofacial region.
- Radiography has shown that there is no extra soft tissue that could make it harder to find anatomical points.

Exclusion Criteria

- In cases where the cephalogram exhibited excessive asymmetry of the patient's position, as shown by the ear-road markers, they were excluded.
- In the absence of excellent superimposition about the midsagittal plane, structures on both sides were omitted.

Manual Tracing

Manual tracing was done on DirectVista film with the measurements of 11 × 14 inches printed on a multi-media Codonics horizon XI imager (Ampronix Inc. in Irvine, California, United States of America). To obtain accurate measurements of the angular and/or linear dimensions, the cephalometric-specific protractor was used to measure them to within a tolerance of 0.5° and 0.5 mm, respectively. Following that, manual tracings were made on acetate paper (0.003′′ × 8′′ × 10).

Digital Tracing

A web-based digital cephalometric analysis program (WebCeph) was used to analyze all lateral cephalograms and generate digital cephalometric measures. A new patient was formed after entering the system through www.webceph.com using a typical web browser (Google Chrome 64-bit), and a cephalometric X-ray image in "jpeg" format was uploaded. The image format was 1007 × 954 pixels, 96 dpi, and 24-bit depth in grayscale. Image enhancement options were used as needed (such as brightness, contrast, and magnification) to target landmarks of cephalometric as precisely as possible using a mouse and images calibrated to crosshairs 30 mm apart. Following upload, the system instantly recognized every anatomical point. To ensure precise measurements, all the landmarks had to be corrected and recalculated. The analysis was performed on a 24" screen.

The various measurements done were as follows:

A web-based digital cephalometric analysis tool and a manual tracing approach were used to record ten angular and two linear parameters for each lateral cephalogram (Figs 1 and 2). A maximum of five cephalograms were evaluated each day to avoid human fatigue-related mistakes. Five radiographs were chosen and retraced manually and digitally, with a 10-day gap between evaluations, to test the intraobserver reliability and reproducibility of manual and digital approaches.

Statistical Analysis

The statistical analysis was performed using Statistical Package for the Social Sciences version 22. The standard deviation (SD) and mean were calculated. Three statistical analyses are used in this study: intraclass correlation coefficient (ICC), coefficient of variation (CV), and 95% confidence interval (CI).

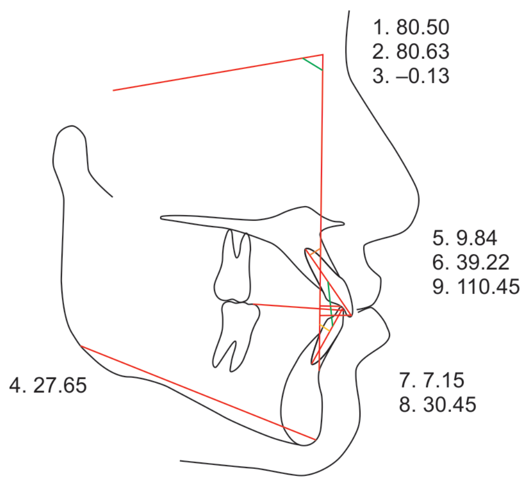

Fig. 1: Shows the following Steiner measurements; (1) SNA; (2) SNB; (3) ANB; (4) mandibular plane angle; (5) NA to UI (mm); (6). NA to UI (angle); (7) NB to LI (mm); (8) NB to LI (angle); (9) interincisal angle

The ICC is a value between 0 and 1. Values below 0.5 show poor agreement, values between 0.5 and 0.75 show moderate agreement, values between 0.75 and 0.9 show good agreement, and values above 0.9 show excellent agreement. The CV is the SD ratio to the mean, CV values <10% were considered low.

The 95% CI is a precise indicator as well. A wider CI denotes less assurance, while a smaller CI denotes higher precision. CIs can be used as an additional tool for assessing significance. Hence, the *p*-value will be higher than 0.05. If the 95% CI contains a value of zero or passes through zero, indicating that the interval spans a range from a negative to a positive number. The *p*-value, however, will be <0.05. This is because your CI will not contain zero or cross through it (meaning that the numbers go from one positive number to another positive number or from one negative number to another negative number).

The intraexam inner reliability was calculated by using the ICC and CV. The agreement between digital and manual tracings was evaluated using the ICC and the CI.

Results

The descriptive statistics, including the mean and SD of digital and hand tracing methods, were evaluated. Hand tracing results of UI to NA (linear) parameter (6.76) scored higher than digital tracing of UI to NA (linear) parameter (3.97). The SD of both tracings was (3.20) and (2.11), respectively. The mean and SD of all other parameters were fairly similar, as seen in Table 1.

The intraexaminer reliability of the manual and digital tracing was evaluated by ICC and CV statistical analysis (Table 2). In hand tracing, the ICC results showed excellent agreement between first and second tracing, except for LI to NB (linear) parameter showed good agreement. On the other hand, digital tracing showed excellent agreement between the first and second tracing of all the parameters. Manual and digital approaches had the same intraexaminer tracing error CV values of <10% (Table 2).

As shown in Table 3, there was excellent agreement (>0.9) between hand and digital tracing in the following parameters: sella-nasion-point A, sella-nasion-point B (SNB). Point A-nasion-point B (ANB), mandibular plane angle (MPA), UI to NA (angle), LI to NB (angle), interincisal angle, and Frankfort mandibular incisor angle (FMIA). A good agreement (0.75–0.9) was present in the following

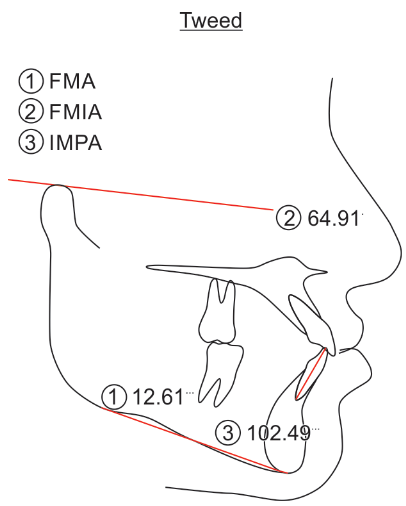

Fig. 2: Shows the following Tweed measurements; (1) FMA; (2) FMIA; (3) IMPA

Table 1: Mean and SD

Parameters	*Hand tracing (mean ± SD)*	*Digital tracing (mean ± SD)*
SNA	81.36 ± 3.95	82.03 ± 3.74
SNB	78.39 ± 4.35	78.90 ± 4.43
ANB	2.97 ± 2.61	3.25 ± 2.61
MPA	29.68 ± 5.27	27.64 ± 5.35
UI to NA (angle)	22.34 ± 6.22	23.84 ± 6.30
UI to NA (linear)	6.76 ± 3.20	3.97 ± 2.11
LI to NB (angle)	27.88 ± 7.42	27.30 ± 7.13
LI to NB (linear)	7.48 ± 2.55	5.28 ± 2.20
Interincisal angle	128.03 ± 11.31	125.59 ± 10.75
FMA	23.85 ± 5.72	19.87 ± 5.20
FMIA	59.06 ± 10.09	60 ± 9.59
IMPA	97.37 ± 9.11	100.11 ± 7.74

Table 2: Intraexaminer reliability using the CV

	Hand tracing		*Digital tracing*	
Parameters	*ICC*	*CV%*	*ICC*	*CV%*
SNA	0.998[d]	0.5	0.999[d]	0.3
SNB	0.999[d]	0.3	1[d]	0.3
ANB	0.996[d]	6.5	0.997[d]	7.2
MPA	0.992[d]	2.7	0.996[d]	2.3
UI to NA (angle)	0.993[d]	1.4	0.990[d]	7.2
UI to NA (linear)	0.994[d]	4.1	0.965[d]	7.9
LI to NB (angle)	0.954[d]	6.9	0.976[d]	7.8
LI to NB (linear)	0.889[c]	4.4	0.991[d]	9.8
Interincisal angle	0.967[d]	2.9	0.901[d]	2.9
FMA	0.983[d]	2.7	0.999[d]	2.7
FMIA	0.965[d]	7.9	0.987[d]	3.1
IMPA	0.928[d]	5.5	0.979[d]	2.1

ICC values; [a]0.5 indicates poor agreement; [b]a value between 0.5 and 0.75 shows moderate agreement; [c]a value between 0.75 and 0.9 indicates good agreement; and [d]an ICC value of over 0.9 indicates excellent agreement; CV <10 is very good, 10–20 is good, 20–30 is acceptable, and CV >30 is not acceptable

Table 3: Intraclass coefficient correlation

Parameters	*ICC*	*95% CI*
SNA	0.968[d]	0.908–0.987
SNB	0.987[d]	0.959–0.995
ANB	0.952[d]	0.891–0.979
MPA	0.915[d]	0.576–0.972
UI to NA (angle)	0.931[d]	0.816–0.971
UI to NA (linear)	0.555[a]	−0.189–0.828
LI to NB (angle)	0.966[d]	0.923–0.985
LI to NB (linear)	0.807[c]	−0.072–0.957
Interincisal angle	0.939[d]	0.839–0.975
FMA	0.808[c]	−0.110–0.945
FMIA	0.954[d]	0.896–0.980
IMPA	0.887[c]	0.689–0.954

ICC values; [a]0.5 indicates poor agreement; [b]a value between 0.5 and 0.75 shows moderate agreement; [c]a value between 0.75 and 0.9 indicates good agreement; and [d]an ICC value of over 0.9 indicates excellent agreement parameters: LI to NB (linear), FMA, and IMPA. A moderate agreement (0.5–0.75) was observed in UI to NA (linear) parameter.

Discussion

To diagnose malocclusion and analyze treatment outcomes, it is necessary to interpret cephalometric films. Digital methods for tracing and analyzing cephalometric films are becoming used more frequently as computer technology advances. Lower radiation exposure and better data storage, access to information, and picture editing are the key benefits of digital radiology.[15] To guarantee that errors are kept to a minimum, regardless of whether the application is AI-based, mobile phone-based, or semi-automated, it must be accurate, precise, and repeatable in both tracing and analysis.

The main aim of this study was that AI-based software WebCeph is just as trustworthy and accurate as manual tracing for cephalometric analysis. For the analysis of the cephalograms, ten angular and two linear measurements were used. To account for all conceivable changes in anteroposterior and vertical jaw relationships that could be encountered during cephalometric tracing and analysis, various parameters were incorporated in this study.

According to Santoro et al.,[16] any study focusing on demonstrating the reliability of digital cephalometrics should concentrate on the usage of measurements rather than marked landmarks. Given that measurements are a byproduct of the tracing procedure of cephalometric and give specific information for treatment planning. Since the variations in landmark locations used in conjunction to obtain measurements could either cancel each other out or amplify the disagreement.[16,17]

In the current study, tracing was done manually on color, high-resolution laser-printed digital radiographs were obtained at 1:1, and the digital images had to be calibrated prior to digitalization on the screen. The landmark identification on digital images was performed manually by a mouse-driven indicator, and the measurements were automatically computed by the software. In contrast, on-screen digitizing relied solely on the operator's mouse clicks, and manual tracing allowed for the construction of different reference planes to aid in the identification of landmarks, which was not possible with this digital method. A single investigator did all the tracings to reduce error due to the higher interexaminer than an intraexaminer error in landmark recognition and tracing and to attain standardization.[18] In addition, to avoid fatigue-related errors, no more than five cephalograms were traced each day.

Intraexaminer reliability was determined using ICC and CV computations, with the findings revealing that the CV values of all the parameters for both first and second tracing of the manual and digital tracing were <10%, which is low and very good, and the ICC value showed excellent agreement between the first and second tracing. Representing that the landmarks were simple to identify in each method and that the investigator had no trouble repeating measurements accurately. The results are consistent with earlier research that showed good measurement reliability.[15,16,19]

The ICC and CI calculations were used to compare the digital WebCeph tracing results with the manual tracing results to evaluate which was more accurate and dependable. The CI results showed that all the parameters had a value of zero or pass-through zero. Accordingly, the *p*-value was higher than 0.05, hence not significant. The ICC value of all the angular parameters showed excellent agreement, except FMA and IMPA angles showed good agreement between hand and digital tracing. The current study agrees with Tsolakis et al.[20] and Bulatova et al.,[21] which showed statistically significant differences in FMA and IMPA angles between manual and digital tracings. Precision and accuracy issues have also been documented in the past with the use of porion.[15] Several studies have found that it is hard to find landmarks like the gonion, porion, menton, gnathion, orbitale, articulare, lower incisor apex, and point "A."[15,22–24]

On the other hand, the linear measurements meaning the UI to NA (linear) measurement, showed moderate agreement, while LI to NB (linear) measurement showed good agreement between hand and digital tracing. Several studies found significant differences in mean values of UI to NA and LI to NB.[22,24,25] On the contrary, other studies did not find a significant difference between manual and digital tracing for these parameters.[4,26] Certain hard tissue landmarks, including the lower incisor apex, have exhibited poor reproducibility and could account for the discrepancy in measurements between these two approaches.[23] The ANS and upper incisors overlap in the two-dimensional skull projection, making it difficult to find point A.[15] This type of measurement inaccuracy can occur with either a digital or a manual method. According to Sekiguchi and Savara,[27] when the frontonasal suture isn't visible enough, Nasion (N) can be difficult to detect. Additionally, incisor tracing difficulties were noted by Baumrind and Frantz,[1] as well as the difference in angular measurements between tracing methods. Few studies found a significant difference in mandibular plane angle.[16,28,29] On the contrary, several studies found no difference in mandibular plane angle between manual and digital methods.[24,25,30–33]

Paixão et al.,[4] Bruntz et al.,[26] and Uysal et al.[30] did not find a significant difference between ANB, SNA, SNB, interincisal angle, LI to NB, and UI to NA angles, like findings of the present study. Chen et al.[15] and Lai et al.[33] found a significant difference in interincisal angle; however no significant difference for ANB, SNA, and SNB. Santoro et al.[16] discovered significant variations for SNA, ANB, and interincisal angle but not for SNB; in contrast, Polat-Ozsoy et al.[24] demonstrated significant variations for SNB alone, with no significant changes discovered for the other parameters.

Whereas Agarwal et al.[29] discovered significant differences for SNA, ANB, and UI to NA, and no difference was found for SNB, LI to NB, and interincisal angle, Krishnaraj et al.[25] found a substantial difference in UI-NA, and no differences were found for SNA, SNB, and LI to NB. The only significant variation discovered by Gregston et al.[22] and Celik et al.[31] was in the angular value of LI to NB; the other parameters did not show any difference. While SNA, ANB, UI to NA, and Interincisal angle did not demonstrate any variations between the two approaches, Singh and Davies[32] discovered a significant difference between SNB and LI to NB.

The digital technique provided a better view of difficult-to-locate features like the tips of the incisors because the view isn't obstructed by tracing paper or lacks sufficient contrast in radiographs. The digital methods had the advantage that the cephalometric images were improved. Changing the brightness and contrast can make it easier to find some landmarks, which may lead to a more accurate cephalometric analysis. The operator must calibrate the system. If the system is not calibrated, the digital program will produce the wrong data. The linear measurements of a radiograph will be more affected by bad calibration than the angular measurements. This is because cephalometrics is a science that deals with millimeters and fractions of millimeters.

It is noteworthy that none of the metrics that showed a statistically significant difference between the two approaches also did not seem to show a clinically relevant difference. In cephalometrics, there is a norm value and a SD for each measurement. Except for FMA, IMPA, and UI to NA and LI to NB, the parameters' mean and SD between the manual and automatic tracing only differed by a few decimal places or degrees (linear). Our final diagnosis won't be impacted by these cephalometric measurements as a result because the discrepancies in the results are so modest and will keep the final diagnosis within the range of the norms. As a result, we can say that when utilized as a diagnostic approach, the automatic tracing method is trustworthy and precise for most of the parameters and should be used with caution.

In nine out of 12 parameters, the WebCeph algorithm demonstrated excellent accuracy.

Other benefits were—WebCeph is free and available in multiple languages; it can be used with computers or smartphones (iOS and Android); it calibrates images; it allows for manual correction of digital tracing; it offers a template for documenting patients' photos and radiographs; it allows for the addition of new definitions for any unavailable landmark and the creation of a custom analysis; and it allows for the export of all results in one file. As most of the parameters are often utilized in clinical practice, WebCeph digital imaging software can be used to measure them precisely and consistently.

To guarantee its dependability and reproducibility and to prove that this program is error-free, digital cephalometric software needs to be tested on a larger sample size.

Conclusion

In conclusion, all measurements in this investigation showed great agreement between digital and manual tracing, except for UI to NA, FMA, IMPA, and LI to NB. Cloud-based storage, online archiving, instant analysis, no need for special installation or software, and compatibility with any operating system are all benefits of online, AI-based software. These elements combine to create WebCeph, a dependable, efficient, and useful tool for cephalometric study.

Clinical Significance

As a result, digital tracing using WebCeph is clinically acceptable and equivalent to manual cephalometric tracings. Because of the advantages of digital imaging in terms of storing, enhancing, and transmitting, the digitized technique may be preferred for everyday use and study without sacrificing quality.

References

1. Baumrind S, Frantz RC. The reliability of head film measurements. 1. Landmark identification. Am J Orthod 1971;60(2):111–127. DOI: 10.1016/0002-9416(71)90028-5
2. Sandler PJ. Reproducibility of cephalometric measurements. Br J Orthod 1988;15(2):105–110. DOI: 10.1179/bjo.15.2.105
3. Chen SK, Chen YJ, Yao CC, et al. Enhanced speed and precision of measurement in a computer-assisted digital cephalometric analysis system. Angle Orthod 2004;74(4):501–507. DOI: 10.1043/0003-3219(2004)074<0501:ESAPOM>2.0.CO;2
4. Paixão MB, Sobral MC, Vogel CJ, et al. Comparative study between manual and digital cephalometric tracing using Dolphin Imaging software with lateral radiographs. Dental Press J Orthod 2010;15(6):123–130. DOI: 10.1590/S2176-94512010000600016
5. Iseri H, Acikbas A, Yilmaz O. The evaluation of accuracy and reliability of the measurement of cephalometric radiographs by tracing and direct digitization. Turk J Orthod 1992;5(1):1–6. DOI: 10.13076/1300-3550-5-1-1
6. Kalra A, Goel S, Thadani M, et al. Comparison of cephalometric measurements obtained with conventional and digital methods and their reproducibility. J Indian Acad Oral Med and Radiology 2010;22(5):S9–S12. DOI: 0.5005/jp-journals-10011-1060
7. Arık SÖ, Ibragimov B, Xing L. Fully automated quantitative cephalometry using convolutional neural networks. J Med Imaging (Bellingham) 2017;4(1):014501. DOI: 10.1117/1.JMI.4.1.014501
8. Leonardi R, Giordano D, Maiorana F, et al. Automatic cephalometric analysis. Angle Orthod 2008;78(1):145–151. DOI: 10.2319/120506-491.1
9. Kunz F, Stellzig-Eisenhauer A, Zeman F, et al. Artificial intelligence in orthodontics : Evaluation of a fully automated cephalometric analysis using a customized convolutional neural network. J Orofac Orthop 2020;81(1):52–68. DOI: 10.1007/s00056-019-00203-8
10. Hwang HW, Park JH, Moon JH, et al. Automated identification of cephalometric landmarks: part 2-might it be better than human? Angle Orthod 2020;90(1):69–76. DOI: 10.2319/022019-129.1
11. Kim H, Shim E, Park J, et al. Web-based fully automated cephalometric analysis by deep learning. Comput Methods Programs Biomed 2020;194:105513. DOI: 10.1016/j.cmpb.2020.105513
12. Hung K, Montalvao C, Tanaka R, et al. The use and performance of artificial intelligence applications in dental and maxillofacial radiology: A systematic review. Dentomaxillofac Radiol 2020;49(1):20190107. DOI: 10.1259/dmfr.20190107
13. Yassir YA, Salman AR, Nabbat SA. The accuracy and reliability of WebCeph for cephalometric analysis. J Taibah Univ Med Sci 2022;17(1):57–66. DOI: 10.1016/j.jtumed.2021.08.010
14. Alqahtani H. Evaluation of an online website-based platform for cephalometric analysis. J Stomatol Oral Maxillofac Surg 2020;121(1):53–57. DOI: 10.1016/j.jormas.2019.04.017
15. Chen YJ, Chen SK, Chang HF, et al. Comparison of landmark identification in traditional versus computer-aided digital cephalometry. Angle Orthod 2000;70(5):387–392. DOI: 10.1043/0003-3219(2000)070<0387:COLIIT>2.0.CO;2
16. Santoro M, Jarjoura K, Cangialosi TJ. Accuracy of digital and analogue cephalometric measurements assessed with the sandwich technique. Am J Orthod Dentofacial Orthop 2006;129(3):345–351. DOI: 10.1016/j.ajodo.2005.12.010
17. Ongkosuwito EM, Katsaros C, van 't Hof MA, et al. The reproducibility of cephalometric measurements: a comparison of analogue and digital methods. Eur J Orthod 2002;24(6):655–665. DOI: 10.1093/ejo/24.6.655
18. Sayinsu K, Isik F, Trakyali G, et al. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. Eur J Orthod 2007;29(1):105–108. DOI: 10.1093/ejo/cjl065
19. Naoumova J, Lindman R. A comparison of manual traced images and corresponding scanned radiographs digitally traced. Eur J Orthod 2009;31(3):247–253. DOI: 10.1093/ejo/cjn110
20. Tsolakis IA, Gizani S, Panayi N, et al. Three-dimensional printing technology in orthodontics for dental models: a systematic review. Children (Basel) 2022;9(8): DOI: 10.3390/children9081106
21. Bulatova G, Kusnoto B, Grace V, et al. Assessment of automatic cephalometric landmark identification using artificial intelligence. Orthod Craniofac Res 2021;24 Suppl 2:37–42. DOI: 10.1111/ocr.12542
22. Gregston MD, Kula T, Hardman P, et al. Comparison of conventional and digital radiographic methods and cephalometric analysis software: I. Hard tissue. Semin Orthod 2004;10(3):204–211. DOI: 10.1053/j.sodo.2004.05.004
23. Houston WJ, Maher RE, McElroy D, et al. Sources of error in measurements from cephalometric radiographs. Eur J Orthod 1986;8(3):149–151. DOI: 10.1093/ejo/8.3.149
24. Polat-Ozsoy O, Gokcelik A, Toygar Memikoglu TU. Differences in cephalometric measurements: a comparison of digital versus hand-tracing methods. Eur J Orthod 2009;31(3):254–259. DOI: 10.1093/ejo/cjn121
25. Krishnaraj R, Balasubramaniam MR, Shetty RS, et al. A comparison of conventional, digitized and digital methods of hard tissue cephalometric parameters. SRM University J Dent Sci 2010;1(1):68–74.

26. Bruntz LQ, Palomo JM, Baden S, et al. A comparison of scanned lateral cephalograms with corresponding original radiographs. Am J Orthod Dentofacial Orthop 2006;130(3):340–348. DOI: 10.1016/j.ajodo.2004.12.029
27. Sekiguchi T, Savara BS. Variability of cephalometric landmarks used for face growth studies. Am J Orthod 1972;61(6):603–618. DOI: 10.1016/0002-9416(72)90109-1
28. Naini FB, Otasevic M, Vasir NS. A comparison of manual tracing, digitizing, and computer cephalometric analysis. Virtual J Orthod 2001;3(4):94–99.
29. Agarwal N, Bagga DK, Sharma P. A comparative study of cephalometric measurements with digital versus manual methods. J Ind Orthod Soc 2011;45(2):84–90. DOI: 10.5005/jp-journals-10021-1014
30. Uysal T, Baysal A, Yagci A. Evaluation of speed, repeatability, and reproducibility of digital radiography with manual versus computer-assisted cephalometric analyses. Eur J Orthod 2009;31(5):523–528. DOI: 10.1093/ejo/cjp022
31. Celik E, Polat-Ozsoy O, Toygar Memikoglu TU. Comparison of cephalometric measurements with digital versus conventional cephalometric analysis. Eur J Orthod 2009;31(3):241–246. DOI: 10.1093/ejo/cjn105
32. Singh P, Davies TI. A comparison of cephalometric measurements: a picture archiving and communication system versus the hand-tracing method–a preliminary study. Eur J Orthod 2011;33(4):350–353. DOI: 10.1093/ejo/cjq087
33. Lai EHH, Chen CSK, Chang ZC, et al. Cephalometric analysis using digital radiography acquired by a storage phosphor imaging system e a comparison of reading soft- and hard-copies. J Dent Sci 2007;2(2):65–67. DOI: 10.30086/JDS.200706.0003