

Comparative Evaluation of an AI-Based Platform (WebCeph™) for Orthodontic Diagnosis in Children and Adolescents: A Retrospective Pilot Study

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Abstract

Background: This retrospective study assessed discrepancies in orthodontic measurements obtained through conventional and AI-based analyses in children (aged 6-13) with mixed dentition. **Methodology:** Forty-two patients undergoing lateral cephalometric radiographs were included. A single examiner measured 18 landmarks and derived measurements using both methods. Intraclass Correlation Coefficient (ICC) was performed to evaluate intra-examiner reliability. A paired t-test was done to compare the two methods. **Results:** Seven measurements showed statistically significant differences between the methods: mandibular plane angle, LAFH, facial ratio, upper incisor (U1) to nasion (NA), U1 to A-pogonion (A-Pg), lower incisor (L1) to NB, and L1 to A-pogonion. While the deep learning system offers advantages in speed, responsible application in this age group necessitates a clear understanding of its limitations and incorporation of appropriate evaluation methods into the orthodontic assessment process.

Keywords: Cephalometric radiography, Deep Learning, Artificial intelligence, Orthodontic diagnosis

Introduction

In paediatric dentistry, early diagnosis, and treatment of malocclusion in mixed dentition is accentuated. A dentist's judgment is important in formulating a treatment plan and understanding the patient's demands and expectations. These orthodontic treatment plans may vary from one dentist to another due to experience and knowledge. Inexperienced doctors have difficulty making correct decisions.¹ In 1931, Broadbent

introduced cephalometric radiography, which has been used for predicting craniofacial growth, orthodontic diagnosis, treatment planning, treatment prognosis, and evaluation of results.² Cephalometric analysis helps assess dentofacial proportions, identify dental or skeletal malocclusion, the growth of craniofacial bone and treatment-related changes. Cephalometric analysis is considered an essential diagnostic tool in orthodontic and orthognathic treatment planning,

especially when there is a skeletal discrepancy.³ In the past, lateral cephalometric analysis was performed on transparent acetate overlays tracing paper by manually identifying landmarks and measuring angular and linear values with a ruler and protractor.^{4,5} However, manual cephalometric tracing and analysis despite being the “gold standard” is cumbersome, time-consuming, and can be subjected to measurement and calculation errors in addition to errors that occur due to human fatigue.⁶ With the advancement of software engineering, cephalometric analysis began to be carried out digitally and significant improvements were achieved.⁷

Recent improvements in computer and software technology have led to the introduction of computer-aided cephalometric analysis in addition to the conventional (manual tracing) method. Digital tracing is gradually replacing manual tracing. Computer-assisted orthodontic analyses, such as Vceph (Osstem, Seoul, Korea), FACAD (Ilexis AB, Linköping, Sweden), and Dolphin (Dolphin Imaging, Chatsworth, CA, USA) are available in the market. Computer-assisted cephalometric analysis has many advantages; it is easy to process, does not require hard copies, performs multiple analysis simultaneously and is convenient during treatment prediction, easily manipulates the contrast and size of the image, provides better archiving and accessibility to digital images, produces faster results and analysis, and decreases radiation exposure.⁸⁻¹⁰ There are several factors that influence the choice of software, such as the complexity of installation procedures, high maintenance fees (subscription and update costs) and significant effort required to learn to operate the digital software.¹³ In recent research findings, the practical implementation of deep learning models in dentistry has demonstrated remarkable efficacy.¹¹⁻¹² Numerous algorithms

have been devised to autonomously identify cephalometric landmarks for orthodontic analysis, utilizing a range of artificial intelligence models.¹⁴⁻¹⁶ Machine learning stands as a prominent division of artificial intelligence, leveraging statistical patterns from prior data to anticipate novel data and scenarios. The integration of training data is imperative for the functionality of machine learning, enabling the computer model to learn from experience rather than relying on conventional explicit programming, leading to continual improvement over time. To acquire a comprehensive understanding of data features through abstractions across multiple processing levels. Notably, deep learning presents an advantage by minimizing the need for extensive engineering preprocessing of data. This technique has found prominence in tasks such as object identification and visual object recognition.¹⁴

In recent years, Artificial Intelligence (AI) is not solely the science and engineering of making intelligent machines like intelligent computer programs but is the software that employs AI for automatic landmark identification instead of manual identification.^{6, 17} AI is advancing in the field of orthodontics. It is increasingly being used to interpret cephalometric radiographs and identify landmarks which help with the diagnosis and treatment planning of dentoskeletal discrepancies.¹⁸ These cephalometric landmarks are readily recognizable points representing hard or soft tissue anatomical structures shown in the radiograph and these structures are used as the reference points for the identification of various cephalometric angles and cephalometric measurements.¹⁹ The various cephalometric landmarks S (Sella), Po (porion), Pog (pogonion), Gn (gnathion), Go (Gonion), N (nasion), and Me (menton) are the most common hard tissue points. Whereas, A (most posterior tegmental point of the

curvature of the maxillary sulcus) and B (the most anterior measure point of the mandibular apical base), P (pronasale), G (glabella), Sn (subnasale), Col (columella), LLA (lower lip anterior), and ULA (upper lip anterior) are common soft tissue points used in cephalometric analysis.²⁰ These fully automatic software can dramatically reduce the time and effort of orthodontists involved in the orthodontic case analysis and diagnosis.²¹ Artificial intelligence (AI) is a branch of science concerned with developing programs and computers that can gather data, reason about it, and then translate it into intelligent actions.²² For instance, fully automated cephalometric analysis software like CephX®, CEFBOT, WebCeph™, etc. Recently, few authors have evaluated the accuracy of web-based fully automated cephalometric analysis software CephX® and CEFBOT.²³⁻²⁵

CephX, Pros: Extensive analysis, CBCT analysis available, photo manager, various types of analysis can be done. Cons: Exorbitant cost and the number of cases that can be analyzed per month is limited. (3 cases for the most economical option), comparatively lesser cephalometric measurements and interpretation, only limited to cephalometric analysis and orthopantomography (OPG) cannot be used, high cost.²⁶ CEFBOT, Pros: Decent accuracy in cephalometric analysis. Cons: limited research done on its accuracy, limited accessibility.

WebCeph™ is a web-based fully automated AI-driven orthodontic and orthognathic online platform that can perform nine different cephalometric analysis and two composite analyses along with interpretation based on obtained cephalometric measurements. In addition, it can simplify orthodontic treatment planning and acquisition of patient records such as the digital images of a patient's cephalogram, orthopantomogram and photographs.⁶ These include automatic cephalometric tracing,

cephalometric analysis, image archiving, manual landmark editing with automatic calculation of measurements and a photo gallery.²⁶ Additionally, it has features like visual treatment simulation and automatic superimposition which are useful during day-to-day orthodontic practice.⁶

While landmark identification is an essential part of the diagnostic process, image-related errors and expert bias can influence the results. It is therefore required to design a study to assess whether AI can achieve similar results to clinicians in cephalometric landmark detection upon repeated detection trials.²⁷ Where most prior studies examined permanent dentition, this study focused on whether AI is clinically useful in orthodontic diagnosis in children and adolescents with mixed dentition which is obtained through both conventional and deep learning-based methods. The objectives of the study were to assess the intra-examiner reproducibility of manual cephalometric tracings, to compare cephalometric measurements obtained by manual tracing versus deep learning based automated tracing (WebCeph™) and to evaluate the level of agreement between manual and WebCeph™ tracing methods. It is hypothesized in this study that AI accurately identifies cephalometric landmarks compared with human examiners and other machine learning methods.

Methodology

Study Population

The subjects were 42 paediatric patients aged 6 - 13 years who visited Klinik Pergigian MUCM for orthodontic diagnosis between 2014 and 2023. Patients were randomly selected for this retrospective study and consisted of 42 paediatric patients with mixed dentition. The average age of the patient was 9.8 years. The percentage of females and males in this study are 57% and 43%

respectively. The exclusion criteria were specified as follows: unerupted or missing incisors and first permanent molars, unerupted teeth overlying the incisors' apices, malformed teeth, maxillofacial deformities, severe skeletal deformation.

All cephalometric radiographs used in this study were obtained from subjects for orthodontic diagnosis prior to orthodontic treatment. The cephalometric radiographs were obtained with the following specifications: dose, 10 mAs; tube voltage, 64-66 kV; scanning time, 9.9 sec; and field of view, 300x270 mm. Cephalometric radiographs were downloaded from an imaging system (Romexis; Planmeca, Helsinki, Finland) and stored as JPEG images for WebCeph. The original image was 2092×1938 pixels with 300 dpi resolution.

Study design

Evaluation of the Cephalometric radiograph using conventional tracing

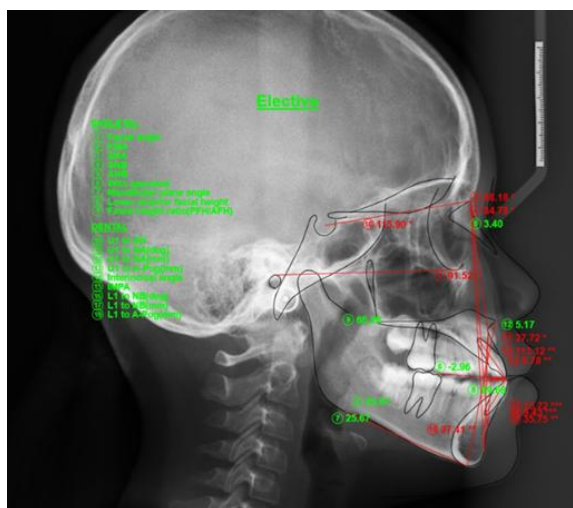
All 42 cephalometric radiographs were traced by 1 dental student using conventional manual tracing and retraced by the same examiner 2 weeks later for the intra-examiner reproducibility. Inter-examiner variability was not a concern as all tracings were done by single examiner. Landmark identification for cephalometric analysis was performed manually on an acetate paper over printed lateral cephalogram. A total of 13 landmarks were defined on each cephalometric radiographs and 18 selected skeletal and dental parameters were measured. (Table 1)

Evaluation of the Cephalometric radiograph using deep learning-based programs

An individual account was created on the WebCeph website for this study. The cephalometric radiographs were uploaded to the WebCeph

website and traced by the website within a few seconds. The scaling of each image was unaltered and uploaded into WebCeph. Images were traced automatically by the deep learning-based program, and the examiner did not modify the orthodontic analysis results. All measurements were obtained from the WebCeph database for each image. (Figure 1).

Figure 1. Measurements from WebCeph database



Statistical analysis

The mean differences and standard deviation of the differences between the repeated measurements for each patient group were calculated. The intra-examiner reproducibility was evaluated by the intraclass correlation coefficient (ICC). Systematic errors were calculated by paired measurement comparisons of conventional and deep learning-based tracings by paired t-test, respectively. Bland Altman plot was used to assess the agreement of two different cephalometric tracing methods. The data were analysed by IBM SPSS Statistics software (ver. 29.0.2, SPSS Inc., Chicago, IL, USA).

Table 1. Cephalometric landmarks

Measurements	Definition
Facial angle	Angle between Po-Or and N-Pg
FMA angle	Angle between Frankfurt horizontal plane and Mandibular plane
SNA	Angle between S-N and N-A
SNB	Angle between S-N and N-B
ANB	Angle between A-N and N-B
Wits appraisal (mm)	Distance between a point on A and B, projected perpendicularly on the occlusal plane
Mandibular plane angle	Angle between S-N and Go- Gn
LAFH (mm)	Distance between ANS and Me (lower anterior facial height)
Facial ratio (PFH/AFH)	Ratio percent of PFH and AFH measurements
SN to Occlusal plane	Angle between the S-N and the Functional occlusal plane
U1 to SN angle	Angle between long axis of upper incisor and S-N
U1 to NA angle	Angle between long axis of upper anteriors and N-A
U1 to NA (mm)	Distance from Upper incisor edge to N-A
U1 to A-Pog (mm)	Distance from Upper incisor edge to A-Pg
Interincisal angle	Angle between long axis of upper and lower incisors
IMPA angle	Angle between long axis of lower incisor and the mandibular plane
L1 to NB angle	Angle between long axis of lower incisor and N-B
L1 to NB (mm)	Distance from long axis of lower incisor and N-B
L1 to A-Pog (mm)	Distance from long axis of lower incisor and A-Pg

Results

Table 2 gives the reproducibility of repeated measurements by a single examiner for the manual tracing. In general, the correlation coefficients of all measurements in mixed dentition groups were

above 0.9 (excellent agreement), except Facial Angle which had a correlation of 0.851 (good agreement). As indicated by the correlation coefficients, intra-examiner reproducibility was high.

Table 2. Reproducibility of repeated measurements using a manual tracing analysis method (intra-examiner error)

Measurement	Intraclass correlation coefficient (ICC)	95% Confidence Interval		p- value
		(Lower bound)	(Upper bound)	
Facial angle	0.851	0.708	0.922	<0.001
FMA	0.923	0.825	0.963	<0.001
SNA	0.949	0.905	0.973	<0.001
SNB	0.950	0.908	0.973	<0.001
ANB	0.984	0.971	0.992	<0.001
Wits appraisal (mm)	0.996	0.992	0.988	<0.001
Mandibular plane angle	0.914	0.815	0.957	<0.001
LAFH (mm)	0.987	0.976	0.993	<0.001
Facial ratio (PFH/AFH)	1.000	0.999	1.000	<0.001
U1 to SN	0.998	0.997	0.999	<0.001
U1 to NA angle	0.999	0.998	1.000	<0.001
U1 to NA (mm)	0.994	0.989	0.997	<0.001
U1 to A-Pog (mm)	0.992	0.986	0.996	<0.001
Interincisal angle	0.998	0.997	0.999	<0.001
IMPA	0.988	0.978	0.994	<0.001

L1 to NB (angle)	0.982	0.966	0.99	<0.001
L1 to NB (mm)	0.991	0.982	0.995	<0.001
L1 to A-P (mm)	0.994	0.989	0.997	<0.001

p values from intraclass correlation coefficient

Table 3. Measurement differences between manual tracing analysis and deep learning-based cephalometric analysis (WebCeph™)

Measurement	Manual Tracing Mean (SD)	WebCeph™ Tracing Mean (SD)	Mean difference (95% CI)			<i>p</i>
			Mean value difference	Lower Bound	Upper Bound	
Facial angle	87.79 (3.1)	87.92 (2.99)	-0.13	-0.36	0.08	0.215
FMA	26.02 (5.78)	25.90 (5.72)	0.11	-0.21	0.45	0.473
SNA	82.19 (3.28)	82.40 (3.35)	-0.21	-0.45	0.02	0.076
SNB	79.56 (2.79)	79.72 (3.03)	-0.16	-0.45	0.12	0.256
ANB	2.64 (3.27)	2.63 (3.09)	0.009	-0.32	0.34	0.955
Wits Appraisal (mm)	-1.821 (3.99)	-1.80 (4.77)	-0.02	-0.71	0.67	0.953
Mandibular plane angle	31.38 (5.92)	25.90 (5.72)	5.47	4.30	6.65	<0.001
LAFH (mm)	45.21 (2.91)	63.72 (7.55)	-18.50	-20.49	-16.53	<0.001
Facial ratio (PFH/AFH)	58.84 (9.32)	65.29 (4.64)	-6.45	-9.05	-3.85	<0.001
U1 to SN	110.32 (9.71)	107.91 (7.52)	2.41	-0.60	5.42	0.113
U1 to NA angle	28.26 (10.66)	25.55 (7.07)	2.70	-0.60	6.02	0.106
U1 to NA (mm)	4.06 (2.48)	4.85 (2.67)	-0.79	-1.46	-0.13	0.021
U1 to A-Pog (mm)	5.38 (2.39)	6.59 (4.00)	-1.21	-1.99	-0.44	0.003
Interincisal angle	123.64 (12.48)	125.67 (11.48)	-2.02	-5.02	0.97	0.061
IMPA	93.57 (8.07)	92.52 (7.17)	1.05	-0.32	2.42	0.129
L1 to NB angle	26.62 (6.41)	26.14 (6.41)	0.47	-0.02	-0.97	0.061
L1 to NB (mm)	4.42 (1.98)	5.71 (2.76)	-1.29	-1.67	-0.92	<0.001
L1 to A-Pog (mm)	3.42 (2.17)	3.99 (2.94)	-0.57	-1.06	-0.08	0.023

p- values from paired t-test

Table 3 shows the measurement differences between the manual and deep learning based (WebCeph™) methods in the mixed dentition group. Statistically significant differences were detected for mandibular plane angle ($p < 0.001$), LAFH ($p < 0.001$), facial ratio ($p < 0.001$), U1 to NA (mm) ($p = 0.021$), U1 to A-Pg (mm) ($p = 0.003$), L1 to NB (mm) ($p < 0.001$) and L1 to A-Pog (mm) ($p = 0.023$).

Table 4 shows the agreement between two different cephalometric tracing methods. Absolute agreements were detected for Facial angle, FMA, SNA, Mandibular plane angle, LAFH, Facial ratio, U1 to SN, U1 to NA angle, U1 to NA (mm), Interincisal angle and L1 to NB angle.

Discussion

Lateral cephalometric image analysis was first introduced by Broadbent in 1931.² It has been used as a tool to aid in diagnosing malocclusion, treatment planning, growth pattern, and treatment outcome analysis. In the past, anatomical landmarks were manually traced on acetate overlay by clinicians. Despite being the most crucial step in cephalometric analysis, landmark identification is error-prone and time-consuming.²⁸ After the introduction of computer-aided analysis, cephalometric analysis using deep learning models was developed.

Table 4. Bland Altman Plot of agreement between manual tracing analysis and deep learning- based cephalometric analysis (WebCeph™)

Measurements	Within Mean +/-2SD Frequency
Facial angle	41 (97.6)
FMA	41 (97.6)
SNA	40 (95.2)
SNB	39 (92.8)
ANB	38 (90.4)
Wits Appraisal (mm)	38 (90.4)
Mandibular plane angle	40 (95.2)
LAFH (mm)	41 (97.6)
Facial ratio (PFH/AFH)	40 (95.2)
U1 to SN	41 (97.6)
U1 to NA angle	42 (100)
U1 to NA (mm)	41 (97.6)
U1 to A-Pog (mm)	39 (92.8)
Interincisal angle	40 (95.2)
IMPA	38 (90.4)
L1 to NB angle	41 (95.2)
L1 to NB (mm)	39 (92.8)
L1 to A-POG (mm)	38 (90.4)

Deep learning algorithms use convolution neural networks and pooling layers to determine patterns and landmarks from images.²⁹ The previous studies only investigated the accuracy of WebCeph in patients with permanent teeth.²³ There is no sufficient data on accuracy of WebCeph in young patients with mixed dentition.

In this study, WebCeph was chosen among several deep learning-based programs to evaluate the accuracy of landmark identification of lateral cephalogram in children and adolescents. Clinicians can easily access it from mobile and computers in 22 languages. If the accuracy of the landmark identification in both paediatric and adolescent patients' lateral cephalogram is proven, it will help clinicians in actual clinical practice as the landmark identification might be time consuming.

According to previous studies, the differences between manual and digital tracing methods were not clinically significant, and both methods were reliable.^{23,8} This study evaluated the reliability by comparing deep learning-based tracing and manual tracing. The measurements repeated with the manual tracing method showed high reproducibility (Table 2). This data ensures the examiner could accurately reproduce measurements, and there was no difficulty in identifying the landmarks equally. These results correspond with previous studies that showed high reliability of the repeated measurements.^{29,30,10} However, a more accurate assessment of intra-observer reliability can be obtained if repeated measurements were performed 3 times.

Table 3 shows the results of two different methods of measurements by paired t-test in mixed dentition group. Out of 18 parameters, 7 cephalometric variables {Mandibular plane angle, LAFH, Facial ratio, U1 to NA (mm), U1 to A-Pg (mm), L1 to NB (mm) and L1 to A-Pog (mm)} show statistically significant differences between the 2 methods. In table 4, agreement between two different cephalometric tracing methods were assessed. In mixed dentition group, there were absolute agreement between the two methods for most of the cephalometric variables except SNB, U1 to A-Pg (mm), L1 to NB (mm) and L1 to A-Pg (mm).

The measurements that showed a significant difference were mandibular plane angle, lower anterior facial height (LAFH), facial ratio, U1-NA (mm), U1-APog (mm), L1-NB (mm), and L1-APog(mm). It is associated with difficulties in landmark identification itself. Differences criteria in landmark identification might increase the magnitude of the discrepancy. Regarding the Mandibular plane angle, it is measured as the angle between S-N and Go-Gn.³¹ However, WebCeph measured it with a different approach. The

mandibular plane angle by WebCeph is measured as the angle between SN plane and the line tangent to the lower border of the mandible.

U1-NA (mm), U1-APog (mm), L1-NB (mm), and L1-APog(mm) are variables associated with the incisors. In previous studies, it was reported that the tracing of incisor location was difficult, and the incisor angular measurement was likely to change depending on the tracing methods.^{28,32,33}

Facial ratio is the ratio percent of posterior facial height (PFH) and anterior facial height (AFH) measurements. AFH extends from nasion to menton and PFH extends from sella to gonion. The lines are constructed perpendicular to the maxillary plane. AFH is therefore subdivided into upper anterior facial height (nasion to maxillary plane) and lower anterior facial height (maxillary plane to menton).³¹ PFH is subdivided into upper posterior facial height (sella to maxillary plane) and lower posterior facial height (maxillary plane to gonion). However, WebCeph is using a different approach to measure facial ratio and LAFH, hence the results are statistically significant.

Since WebCeph™ is a web-based fully automated AI-driven orthodontic and orthognathic online platform trained only with permanent teeth, errors may be detected in analysing and measuring for primary and mixed dentition. It would be a challenge to detect skeletal and dental measurements accurately and precisely on cephalometric radiographs of paediatric and adolescent patients. Thus, the performance and accuracy of these diagnostic systems could be improved by fine-tuning existing deep learning models.³⁴

In a previous study, Alqahtani²³ compared measurements obtained from the analysis of the computer program FACAD® (Ilexis AB, Linköping, Sweden) and that of the deep learning-based algorithm CephX® (CephX Inc., Las Vegas,

USA) in permanent dentition group. Alqahtani found statistically meaningful differences in 3 of 16 measurements between the 2 methods. Similarly, this study showed statistically significant differences in 7 out of 18 measurements in the mixed dentition between the 2 methods (Table 3 and 4).

This study had the limitation of being conducted in a single institution with limited patient data. Only 42 patient records were chosen based on the selection criteria, 18 samples short of targeted sample size of 60. If the study entailed collecting data from multiple institutions with more samples, more general conclusions could have been drawn. This study was conducted using a single program for cephalometric analysis in paediatric patients. Subsequent studies on the comparative evaluation of various deep learning programs for cephalometric analysis will be more meaningful. Although manual tracing is regarded as the gold standard, there is still a probability of human error during tracing.

The evaluation of deep learning-based orthodontic analysis, which provides immediately useful data for treatment planning, is meaningful for clinical applications. In the cephalometric radiographs of mixed dentition, there may be errors in tooth-related landmarks and measurements due to the overlapping of deciduous teeth and the permanent tooth germ. When performing the orthodontic analysis of children and adolescents using the deep learning-based program, it is important for dentists to be aware of the above limitations and do not rely entirely on this program. In clinical practice, dentists make individual corrections by repositioning the landmarks after obtaining the results of orthodontic analysis from WebCeph. In using a deep learning-based analysis program as an auxiliary tool for orthodontic diagnosis of paediatric and adolescent patients, the dentist's

judgment and abundant clinical experience remain important. Understanding the above limitations, using this program appropriately can help paediatric dentists decide whether to begin orthodontic treatment.

Conclusion

Most of the measurements analysed by manual tracing and WebCeph did not show a significant difference in mixed dentition groups, except for a few variables. However, some measurements showed statistically significant differences between the two methods due to the different approach of measuring the cephalometric variables. Therefore, when using WebCeph for orthodontic analysis of paediatric and adolescent patients with mixed dentition, it is best to recognize the limitations and use it with the proper judgment to produce more accurate and reliable results.

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