EVALUATION OF THE ACCURACY AND RELIABILITY OF ORTHODONTIC CEPHALOMETRY ANALYSIS USING THE WEB-BASED ARTIFICIAL INTELLIGENCE (AI) PROGRAM

Accuracy and Reliability of AI-Based Cephalometric Analysis

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Abstract

Cephalometric analysis aids in evaluating dentofacial proportions, identifying the anatomic basis of malocclusion and analysing growth and treatment-related changes. During orthodontic treatment planning, cephalometric analysis is considered an essential diagnostic method, particularly when a skeletal discrepancy exists. The introduction of Artificial Intelligence (AI) in orthodontics solved a variety of issues as it has been evidenced to be a time-saving and reliable tool to assist in developing correct diagnosis and successful treatment plans. Computerized software can automatically identify the landmarks and complete the measurements once the digital radiograph is imported using AI technology. In addition, superimposition of serial radiographs can be performed faster, and it also allows the user to obtain several analyses at a time, identify and analyse cephalometric landmarks, face analysis, tooth and mandible segmentation, bone age determination, prediction of orthognathic surgery, and temporomandibular bone segmentation. As a result, AI is increasingly being used in orthodontic treatment to improve speed, consistency, and accuracy because it is a promising tool for facilitating cephalometric tracing in routine clinical practice and analysing large databases for research purposes. Hence, it is imperative to investigate the reliability and usability of AI in cephalometric to ensure its accuracy before relying on the software for analysis.

1.0 Introduction

Cephalometric analysis can be used to analyse the facial skeleton in a two-dimensional (2D) fashion and based on specialized lateral and anteroposterior (AP) skull radiographs in certain anatomical points (Lande et al., 2022). The invention of the cephalometer was introduced by B. Holly Broadbent in 1930, and since then, various complex analytical techniques have been introduced. Cephalometry is a fundamental diagnostic tool in orthodontics. It helps the diagnosis process by determining the aetiology of a malocclusion, making the orthodontic and orthognathic treatment planning, monitoring the changes due to growth or treatment, and able to predict the orthodontic and orthognathic treatment outcomes (Koloikitha et al, 2011).

With the rapid advancement in technology, the manual tracing method is gradually being replaced by digital cephalometric analysis software. The software is being favoured as it offers various benefits, such as easy handling, allows several analyses to be performed at a time, takes up less storage space, allows superimposition of images, provides the option to manipulate the image for instance, the size and contrast of the image for better visualization of the image, reduced radiation dose, as well as the elimination of chemical and associated environmental hazards by reducing the usage of acetate tracing paper and the view box (Albarakati et al., 2012). Identifying cephalometric landmarks in lateral cephalograms can be challenging because the skull is a highly complex 3D object which in a cephalogram is projected onto a single 2D plane, leading to overlapping structures and causing the left and right outlines to not be perfectly superimposed (Lindner et al., 2015)

In the past, drawings of lateral cephalometric analysis were performed manually by orthodontists through direct measurement of cephalometric angles using a protractor on an overlay of a tracing paper secured over the radiograph. The landmarks and planes identification on the radiograph were done using pencils and rulers, with or without the aid of a view box. (Yassir, 2021). This technique is time consuming and is subject to landmark identification error, measurement error and magnification error (Zamrik et al., 2020). However, the development of computer and software technology have led to the introduction of computer-aided cephalometric analysis which bring about significant improvements in terms of speed, quality, and reliability (Coban G et al., 2022). Computerized cephalometric can automatically identify the landmarks and complete the measurements once the digital radiograph is imported using artificial intelligence (AI) technology.

Converting from a manual cephalometric analysis technique to a computer-assisted web-based cephalometric analysis provides many advantages, however, it requires professional supervision and may results in time wasted in front of a computer screen. In addition, a systemic review revealed little scientific evidence to support the use of automatic landmark identification when compared to manual tracing due to the greater number of errors (Yassir et al., 2021). Hence, studies on reliability and usability of AI still provide insufficient evidence, and more research should be done into that specific area.

1.1 Problem Statement

Manual cephalometric tracing and analysis can be time consuming and are frequently associated with measurement and calculation errors in addition to errors occurring due to human fatigue. Computerized cephalometric analysis software was developed to overcome these problems. This can be evident especially in research that is based on cephalometric tracing where hundreds of radiographs needed to be landmarked and measured. Furthermore, some of the cephalometric analyses involve identifying various complex anatomical landmarks that are difficult to be located. Therefore, the use of digital cephalometric analysis software is widely considered to be more convenient however the accuracy and the reliability need to be tested.

1.2 Research Questions

1. Is the accuracy of AI-based cephalometric analysis program comparable to the conventional manual cephalometric tracing method?

2. Is the reliability of AI-based cephalometric analysis program better than the conventional manual cephalometric tracing method?

1.3 Research Hypothesis

1. The accuracy of AI-based cephalometric analysis is comparable to the conventional manual cephalometric tracing method.
2. The reliability of AI-based cephalometric analysis is better than the conventional manual cephalometric tracing method.

1.4 Objective

1.4.1 General Objective

To evaluate the accuracy and reliability of AI-based cephalometric analysis programs when compared to the conventional tracing and analysis method.

1.4.2 Specific Objective

1. To investigate the accuracy of AI-based cephalometric analysis programs when compared to the conventional tracing and analysis method.
2. To investigate the reliability of AI-based cephalometric analysis programs when compared to the conventional tracing and analysis method.

2.0 Literature Review

2.1 Orthodontics Cephalometric Analysis

Cephalometric is an interpretation of measurements of the skull made on standardized radiographs of the living head. Since the introduction of cephalometric by Broadbent and Hofrath in the 1930s, the cephalometric technique has been regarded as an important tool for orthodontists and maxillo-facial surgeons engaged in studying dental malocclusions and the underlying skeletal discrepancies (P.Hlongwa, 2019). Cephalometric analysis aids in evaluating dentofacial proportions, diagnosis of anteroposterior and vertical discrepancies, identifying the anatomic basis of malocclusion and the evaluation of the relationship between soft tissue and dental structures (Yassir et al, 2021). It is an indispensable tool for prediction of growth, treatment planning and evaluating treatment results. It is also used to predict changes that will occur for orthodontics patients after their treatment in the future. A cephalometric tracing can be prepared and analysed manually or by a computer using a web-based artificial intelligence (AI) program. Therefore, the method used for cephalometric analysis must be accurate, safe, and highly reproducible.

2.2 Manual Tracing Vs Web-Based AI Program Cephalometric

Manual cephalometric analysis consumes valuable time due to the tedious procedures associated with it. The risks include misreading values and the measurements obtained may be susceptible to error (P Hlongwa, 2019). The reliability of the landmark identification is also questionable as it is hard to locate the tips of the caliper exactly on to the same point during every measurement to achieve consistency result (Umut Ozsoy et al, 2009). Based on the observer's experience, manual tracing can take 15-20 minutes to complete depending on the quality of the radiographs and the number of parameters assessed (Aravind K.S et al, 2022). In addition, manual tracing technique requires the printing of radiographic films and are more prone to poor quality printing and are susceptible to magnification errors (H. Alqahtani, 2020).

To overcome these problems, AI-based fully automated cephalometry was developed. Automated cephalometric analysis is one of the major applications of AI in the field of orthodontics. In recent years, various automated cephalometric software has been developed like CephX, WeDoCeph, CHEFBOT and WebCeph which utilizes artificial intelligence for automatic landmark identification instead of manual identification (Ravi K.M et al, 2022). This can significantly reduce the time and improve the efficiency of orthodontists in carrying out cephalometric analysis and diagnosis in routine clinical practice and research. Errors due to faulty identification of landmarks can result in inaccurate cephalometric interpretation which might lead to errors during orthodontic diagnosis and treatment planning.

The term AI is mostly associated with robotics which describes the development of software or machine by technology that can easily mimic human cognitive skills and perform specific activities (Sanjeev B.K, 2021). AI is now being used more frequently in orthodontics as it helps in data mining, automated diagnostics, and landmark detection of craniofacial morphometric studies. AI can identify landmarks as accurately as human examiners and it is a viable choice for a repeated recognition of numerous cephalometric landmarks. These AI-based fully automated cephalometry are gaining popularity among orthodontists because of their ability to obtain the information of patients quickly and has significantly influenced image analysis as it helps detect the anatomical landmark points consistently.

WebCeph is a web-based fully automated AI driven platform that can perform nine different cephalometric analysis and two composite analyses along with interpretation. In addition, it can be used to store and maintain an archive of digital images of a patient's cephalogram, orthopantomogram and photographs. The major advantage of using this software is that multiple cephalometric analyses can be accomplished within seconds after digital cephalogram is uploaded. Apart from quick cephalometric analyses and interpretation, features like cloud-based storage of patient's records, visual treatment simulation and superimposition can make WebCeph an efficient and promising tool for routine clinical orthodontic practice. AI-based fully automated cephalometry is more precise because once the images are detected on-screen, measurements and data processing will occur automatically.

WeDoCeph is a fully automated cephalometric online portal that can be used anytime and anywhere and the easiest way to get cephalometric stack analyse in minutes. It is an x-ray imaging software and diagnostic tool for cephalometric analysis that has features for data analysis. It is powered by AI and widely accepted AudaxCeph technology (Peter Kobal,2021). There is an incredible editing tools added in WeDoCeph which permits for converting visibility nation and move cephalometric landmarks. This AI-based fully automated cephalometry can used by simply uploading lateral or periapical x-ray of the patient for tracing and enter the analysis' parameters such as analysis type, patient's identifier, age, and sex. Then, algorithms of AI engine will automatically trace cephalometric landmarks, planes, arch and each soft and hard tissue silhouettes which form a strong base for cephalometric analysis. Then, the orthodontist will get the results within seconds in the forms of different reports, and they can view the results, save it, print, and analyse the results. There is no monthly or yearly subscription fee needed.

2.3 Evaluation of The Accuracy and Reliability of Automated Cephalometry Analysis Software

A study by Anuwangnukroh et al. (2018) evaluated the reliability of the cephalometric analysis using the dental imaging software (Carestream Dental). They found that the automated cephalometric analysis software has significant difference of more than 2 degrees when compared to the manual hand-based analysis. They also found that the differences come mainly from the angular parameters.

On the other hand, another study by Katyal et al., (2022) investigated the automated tracing software using the WebCeph software. They found there is no significant difference in the skeletal, dental and the soft-tissue parameters between the two methods. However, it takes shorter time for the automated tracing to analyse the data when compared to the manual tracing where the time taken is 30.2 ± 6.4 s and 472 ± 40.4 s respectively (Katyal et al., 2022). Another study by Tsolakis (2022) compared the digital automatic method and digital manual method of cephalometric analysis and found small difference between the two methods but it was not clinically significant.

3.0 Materials and Methods

3.1 Study Population

This prospective study includes 40 cephalometric radiographs of orthodontic patients seen in Orthodontic Specialist Clinic of Kulliyyah of Dentistry, IIUM Kuantan.

The sample size calculation was done with a significance level of 0.05 and a power value of 95%. A sample of a minimum of 37 radiographs was needed.

3.2 Inclusion criteria:

- Pretreatment OR post-treatment lateral cephalometric radiographs
- Orthodontic patients treated at the Orthodontic Specialist Clinic, IIUM
- Radiographs obtained between January 2023 and June 2023
- High-quality cephalograms without flaws affecting anatomical landmark positions

3.3 Exclusion criteria:

- Patients with surgical rigid fixations visible on radiographs
- Presence of orthodontic appliances on radiographs
- Presence of dental prostheses on radiographs
- Patients with syndromes and craniofacial deformities.

3.4 Methodology

Ethical approval will be obtained before the commencement of the study. Forty cephalometric radiographs will be selected. Calibration will be done prior to landmark identification to ensure agreement between the examiners.

For manual tracing, 18cm x 24cm of radiographic film images of lateral cephalograms will be obtained and traced manually on a view box using transilluminated light under dark room. Each cephalograms will be secured over the view box first, and then a sheet of matte acetate tracing paper sized 22cm x 28cm are taped over the radiographic film. Three orientation marks will be placed as a reference point over the film and the tracing paper. After that, hard and tissue landmarks will be traced onto the tracing paper manually using a HB pencil. A total of 11 anatomical landmarks will be plotted on each cephalograms which are the A point (subspinale, or A), B point (B), sella (S), nasion (N), orbitale (O), porion (Po), anterior nasal spine (ANS), posterior nasal spine (PNS), gonion (Go), menton (Me) and pogonion (Pog).

Measurements of the cephalometric parameters (8 angular and 8 linear) will be taken with the help of millimetre ruler and a protractor. All measurements will be performed twice by the same investigator with intervals of 4 weeks from the first measurements. Angular measurements (°) include the SNA, SNB, ANB, FMPA, MMPA, UIA, LIA, IIA. While the linear measurements (mm) include the NA, NPog, ANS-Me, SN, LFH, UFH, MxPI, MnPI.

Table 1: Definition of the relevant cephalometric points

Cephalometric points	Definition
Point A (A)	The deepest point in the concavity of the anterior maxilla between the ANS and alveolar crest
Point B (B)	The deepest point in the concavity of the anterior mandible between the alveolar crest and Pog
Sella (S)	The midpoint of sella turcica
Nasion (N)	Junction of the frontal and nasal bones at the frontonasal suture
Orbitale (O)	The most inferior point on the infra- orbital margin
Porion (Po)	The most superior point of the external auditory meatus
Anterior Nasal Spine (ANS)	The anterior limit of the nasal floor
Posterior Nasal Spine (PNS)	The posterior limit of the nasal floor
Gonion (Go)	The most posterior and inferior point on the angle of the mandible
Menton (Me)	The most inferior point on the bony chin
Pogonion (Pog)	The most anterior point on the bony chin

For AI-based fully automated cephalometric analysis, we will be utilizing the WeDoCeph (Audax d.o.o., software version 3.2.2). WeDoCeph software is a fully automated cephalometric portal that works on the web and can be used anytime and from anywhere. WeDoCeph software complies with essential landmark tracing and measurement. To operate the analyses, firstly lateral or periapical radiographs of the patients will be uploaded into the WeDoCeph software. Then, patient profile will be created in the system and digital images of cephalograms with high quality resolution of 300DPI will be uploaded. After the x-ray was uploaded, key-in the analysis' parameters such as analysis type, patient's identifier, age and sex. Each of the cephalometric landmarks will automatically be traced by the AI digitization of

WeDoCeph. Finally, the cephalometric measurements value will be obtained for the different parameters and the tracing analysis were saved as JPEG files. Then, it will be downloaded in portable document format (pdf) and entered into the same Microsoft Office Excel spreadsheet used for manual tracing values. The same process will be applied for all 40 digital cephalograms. Then, all of the radiographs measurements will be performed once again by the same investigator with intervals of 4 weeks from the first measurements to test for the reliability.

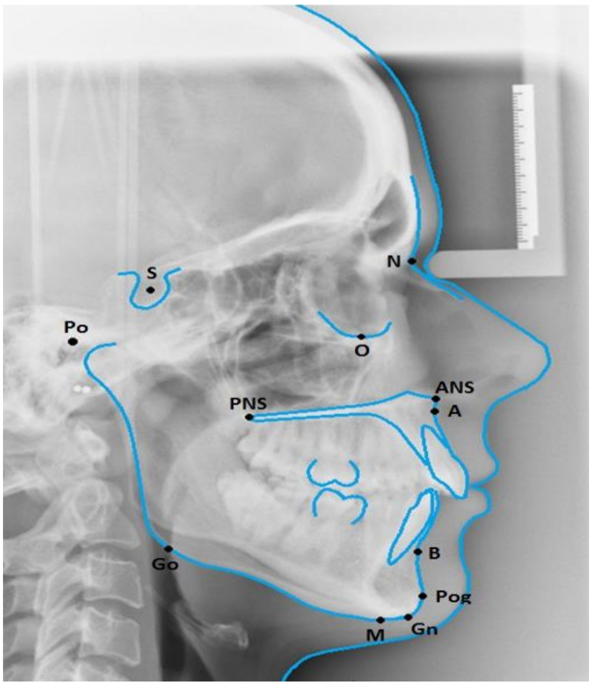

Figure 1: Landmarks through AI-based fully automated tracing software.

3.5 Data Analysis

The mean, standard deviation, and standard error of the difference between the repeated measurements for each method and between the two methods will be calculated. The reliability of each method will be defined using the Pearson correlation coefficient (r^2). The level of statistical significance will be set at $P< 0.05$.

4.0 Expected Outcome

Table 2: Angular and Linear Measurement of Cephalometric Values

	AI-based (WeDoCeph)			Manual			
Measurements	**Mean**	**S.D**	**r^2**	**Mean**	**S.D**	**r^2**	**P-value**
SNA (^{0})	n	n	n	n	n	n	n
SNB (^{0})	n	n	n	n	n	n	n
ANB (^{0})	n	n	n	n	n	n	n
FMPA (^{0})	n	n	n	n	n	n	n
MMPA (^{0})	n	n	n	n	n	n	n
UIA (^{0})	n	n	n	n	n	n	n
LIA (^{0})	n	n	n	n	n	n	n
IIA (^{0})	n	n	n	n	n	n	n
A-N perpendicular (mm)	n	n	n	n	n	n	n
POG-N perpendicular (mm)	n	n	n	n	n	n	n
ANS-Me perpendicular (mm)	n	n	n	n	n	n	n
SN (mm)	n	n	n	n	n	n	n
LFH (mm)	n	n	n	n	n	n	n
UFH (mm)	n	n	n	n	n	n	n
MxPI (mm)	n	n	n	n	n	n	n
MnPI (mm)	n	n	n	n	n	n	n

Table 3: Intraclass Correlation Coefficient

	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	sig
Single Measures							
Average Measures							

5.0 Gantt Chart

Project Activities	2022		2023												2024	
Months	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
Distribution of research titles																
Literature review & proposal preparation																
Proposal presentation																
Hand-in written proposal																
Ethical Approval																
Data collection																
Data analysis																
Final research writing																
Complete report submission																
Draft for publication																

Presentation at DSSC																

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RESEARCH CONSENT FORM
INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

PATIENT'S DETAILS:
NAME:
DATE OF BIRTH:
GENDER:
IDENTITY CARD NUMBER:

RESEARCH DETAILS:

TITLE: The Accuracy and Reliability of Orthodontic Cephalometry Analysis Using The Web-Based Artificial Intelligence (AI) Program

Researchers:
1. Asst Prof Dr Siti Hajjar Nasir
2. Assoc Prof. Dr Noraini Abu Bakar
3. Nur Farisah Aliah Binti Jamaludin
4. Nur Fatin Syahirah Binti Abdullah

INFORMED PATIENT CONSENT (To be completed by patient/ parent/ guardian)
I fully understand of my/my child's involvement in this research. The benefits and all likely risks, effects, discomforts or inconvenience arising from participation in the project have been explained to me by clinician.
I know that I/ my child can withdraw from this research at any time without any effect on my ongoing orthodontic treatment.
I understand that any information or material (blood, body fluids or other body material) I provide will be kept confidential and reported in an aggregated/ non attributed form.
I am aware of the procedures and commitment required and allows my/ my child's records to be used in this research and publication.
I have been given the opportunity to ask questions and time to digest the information before proceeding with the decision.

SIGNATURE:
NAME:
(Status: patient/ parent/ guardian)
IDENTITY CARD NUMBER:
DATE:

Statement by the researcher/ person taking consent

I have accurately read the information sheet to the potential participant, and to the best of my ability made sure that the participant understands that the following will be done:

1. Interview
2. Clinical examination

I confirm that the participant was given the opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this Informed Consent Form has been provided to the patient.

Signature of Researcher/ person taking the consent

____

Print the Name of Researcher/ person taking the consent

____

Identity card number: ______________________________

Date: _____________________

Witness:

Signature of the Witness: ___________________________

Print the Name of the Witness: ______________________

Identity card number: _______________________________

Date: _____________________