MEDICAL SCIENCE MONITOR

CLINICAL RESEARCH

e-ISSN 1643-3750
© Med Sci Monit, 2024; 30: e944628
DOI: 10.12659/MSM.944628

Received: 2024.03.25
Accepted: 2024.05.07
Available online: 2024.05.21
Published: 2024.06.23

Comparative Evaluation of Digital Cephalometric Tracing Applications on Mobile Devices and Manual Tracing

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Financial support: None declared
Conflict of interest: None declared

Background: Cephalometric radiography evaluates facial skeleton development and aids in diagnosis and treatment phases (pre and post) in orthodontics. This study aimed to compare digital cephalometric tracing using a smartphone application (App), a tablet-based platform, and manual tracing in 30 orthodontic patients.

Material/Methods: Thirty orthodontic pretreatment, criteria based, lateral cephalometric radiographs were analyzed/grouped for Steiner analysis parameters (5 skeletal, 3 dentals, 1 soft tissue) by 3 tracing methods [manual – group (Gp M), smartphone (Android – OS9) – Gp S, tablet (Apple – IOS13) – Gp T) after mandatory standardization/calibration. Measurements include 5 angular (SNA, SNB, ANB, SNMPA, SNOP), 3 linear U1NA, L1NB, U1L1, and 1 soft tissue (S line) (millimeters and degrees). Inter-examiner rating was determined using Dahlberg's test. After normality distribution testing (Shapiro-Wilk), data were analyzed using one-way analysis of variance (ANOVA) for group differences. Homogeneity of variance was verified using the Levene test. Differences were determined on probability value of ($p \leq 0.05$).

Results: The results showed that Steiner's analysis parameters were similar in all groups with homogenous variances. Highest differences in mean values were found for L1NB, U1L1, and S line measurement, with higher values being observed in Gp S tracings. However, these differences were not statistically significant ($p \leq 0.05$). All parameters, irrespective of being measured in either degrees or millimeters, had means comparable to each other.

Conclusions: Smartphone and tablet-based applications produced tracings that were comparable and reliable when compared to conventional manual tracings. Standardization of images, processing, printing, and calibration of devices is important to achieve good results.

Keywords: **Diagnosis • Radiographic Image Enhancement • Radiography**

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/944628

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Introduction

Effective orthodiagnosis and treatment planning is based on a thorough understanding of the underlying skeletal, dental, and soft tissue anatomical and functional interaction of a particular patient. Important diagnostic records needed before initiating orthodontic treatment include medical and dental history (past to present), mounted diagnostic casts, and cranial radiographs (panoramic and cephalometric) [1]. To ensure a proper diagnosis and treatment plan, various methods are employed to analyze all of these records [2]. In 1931, Broadbent introduced cephalometric radiography as a means to diagnose and plan orthodontic cases [3], and it remains one of the most economic and effective tools in orthodontic treatments.

The skeletal growth pattern can be predicted by sequential cephalometric analyses, which can also help estimate orthognathic treatment outcomes [4]. This predictive capacity of cephalograms is a crucial part of treating dentofacial abnormalities, especially those that are skeletal. The process of cephalometric tracing is traditionally done by hand on acetate paper placed over a lateral radiographic film [5]. Identifying specific anatomic landmarks requires a cephalometric protractor and a mechanical pencil. The use of a reference landmark on the acetate paper helps in repositioning and fixing it over the film. Measuring the anatomical planes that run from one landmark to another is done for linear measurements, whereas angular measurements are taken when 2 planes come together [6]. The values measured (linear and angular) can be then compared to normal values to determine specific readings for skeletal, dental, or soft tissue parameters [7]. The manual tracing method has been the only method available for cephalometric tracings for many years. The proper interpretation requires angular and linear measurements. The manual method has its drawbacks, such as the time it takes to perform and the difficulty in identifying landmarks [8]. Technological advances in the 1960s, like digital radiographs with advantages of speedy processing, enhanced image quality, and storage in digital format, paved the way for computer analysis in cephalometric radiographs. Computer-assisted measurements involve using a simple basic digitizer that gives the cephalometric landmarks an X and Y coordinate axis, which were later automated using an image processing system (CLIP4) [9], but provided identification of only 2 landmarks (sella and menton). Further parallel advances in radiography and computers led to development of sophisticated orthodontic software packages [10], among which Dolphin Imaging software has become very popular since its introduction in 1994 (at the 9th Brazilian SPO Orthodontic Conference), for orthodontic diagnosis [5]. This software facilitated digital cephalometric tracing with the ability to store the radiographic soft copy on a computer storage space in the hard drive [11].

The widespread use of smartphones and tablets among healthcare providers has been influenced by the advent of portable technology [12]. Tasks that used to be cumbersome and required a lot of bigger machines and/or equipment are now easier and more convenient to do. Dentistry, including orthodontic practices, has found the value of newly developed applications in smartphones and tablets as a means to facilitate and aid diagnosis and treatment planning protocols [13]. A few free versions of smartphone and tablet applications (CephNinja and OneCeph, Google, Inc, CA) were developed specifically for cephalometric tracings using the certified analytical computerized cephalometric program (Viewbox) [14]. It became possible for the developers to create the applications on these platforms since these devices have central processing and graphic units capable of computing and analyzing different tasks, comparable to mid-range personal computers (PC). This in turn made it easier for developers to efficiently code these applications on portable devices. However, their availability depends on the operating system of the devices (iOS operating system for Apple devices; OS for Mac) [15,16]. In April 2016, NSX (Networking and Security Virtualization VMware NSX) technology in India introduced OneCeph as a smartphone-based application to perform digital cephalometric tracing [17]. Soft copy (digital) uploading to the platform allowed cephalometric analysis, including tracing parameters for skeletal, dental and soft tissue landmarks. Further updates enhanced additional analytical methods with additional parameters. Shettigar et al [18] compared OneCeph with Dolphin Imaging software using a PC, and observed 4 parameters from a total of 15 to have a significant difference. Before introduction of OneCeph, another application-based cephalometric analyzer called CephNinja (Cyncronus LLC technology) was introduced, which could perform digital cephalometric tracing on a wireless, portable tablet-based platform [19]. It provides various analyses that include the parameters of skeletal, dental, and soft tissue. Subsequent updates also allowed one to draw teeth and adjust soft tissue contour outlines. Livas et al [20] assessed its diagnostic accuracy for software Viewbox and concluded that CephNinja was the best alternative in terms of reliability with Viewbox. On the contrary, Aksakallı et al [21] reported differences in measurement for cephalometric landmarks (orbitale, porion, gonion, and apex regions).

Since its introduction in 1953, Steiner's manual cephalometric analysis remains to be one of the most common analyses for orthodontic diagnosis, mainly because it is simple and less confusing. It uses sella-nasion as the primary reference plane because they are more stable structures and are easily identified on radiographs [22]. While manual tracings consume time, they are also prone to random errors due to limitations of the human eye. Manual tracings are performed on printed radiographic images, which have been reported to have substantial distortion (1.1 mm vertical, 0.4 mm horizontal), although such enlargements were found to be clinically insignificant [23]. Despite their limitations, the novel digital cephalometric tracing

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technologies are convenient, efficient, easy to manipulate, conservative, and environmentally friendly (paperless). The ability of these digital cephalometric radiography to transfer the two-dimensional images into a digital format has additional advantages like availability of popular devices, multiple analysis using a single application, minimum storage space, and modifies image properties (eg, contrast, brightness, color saturation) [24]. Finally, the cephalometric radiographs that would otherwise deteriorate with time can now be accessed and archived with better capabilities [15]. Navarro et al [25] found lateral cephalometric radiographs were very stable but predicted that they are still liable to deteriorate, which can lead to lower quality than the original radiograph. Barbhuiya et al evaluated the accuracy and reliability of software that was on a mobile phone on 30 patients, and found angular and linear measurement accuracy to be comparable with conventional methods [26]. In an earlier study [18] too, the differences in some of the parameters relative to personal computer-based tracing software's were reported, which formed the bases of conducting this study. Therefore, the present study aimed to evaluate the reliability of 2 different digital cephalometric tracing applications (mobile and tablet) as compared to conventional manual tracing. The study also aimed to measure various parameters of Steiner's radiographic analysis using smart phone- and tablet-based application software. We also sought to identify those parameters of applicated based tracings which differed from manual tracing. We hypothesized that there would be no differences in the parameters of Steiner analysis between smartphone and tablet applications relative to manual cephalometric tracings, and that variations between the 3 methods will be homogenous. Alternately, the null hypothesis was that there would be no significant differences between the methods.

Material and Methods

Ethics

This study required ethics approval from the office of research coordination since it utilized digital archives of previously treated patients at the Department of Orthodontics, College of Dentistry of the University of the East, Manila. The study was duly approved by the committee (approval number G-2021-1-02), with particular emphasis on taking all measures to protect patient confidentiality, which was achieved through anonymization of patients' identity and personal information. All patients whose records were taken for the study had provided a signed written informed consent before their treatment was initiated.

Study Design

This study had a quasi-experimental post-test research design comparing lateral cephalometric landmarks and linear and angular values of Steiner analysis between 2 digital-based tracing applications versus manual tracing. We sought to determine whether there were any differences between manual tracing and the 2 digital tracing methods for cephalometric analysis in orthodontic diagnosis and treatment planning for performing Steiner analysis. A quasi-post-test study was designed, since the study used a random assignment of samples (cephalometric tracings of previously treated patients) in which there was assignment of a control group (manual tracing) and 2 experimental groups (smartphone/tablet applications), without using a pre-test. The independent variables were lateral cephalometric radiographs and the dependent variables were the cephalometric values of Steiner analysis obtained from manual, smart phone, and tablet cephalometric tracings.

Sample Size Estimation

The sample size for the study was guided by samples taken from previous similar studies [5,7] and verified statistically using software (Nquery, V7, Informer Technologies, USA) that calculates sample size based on the formula [$N = 2\ \sigma 2 \times (Z\ \alpha + Z\ \beta) 2/D2$] [27]. Using test power (0.8) with error buffer (15%) for calculating effect size at an α level of 0.05 and 95% confidence interval, the sample size was estimated to be 30 similar radiographic analyses for each group.

Operational Definitions

Pixels per inch (PPI) is a measurement that defines the number of pixels in 1 inch of radiographs when displayed on a monitor. Dots per inch (DPI) is a printer resolution measure defined as the number of ink dots in a particular area (1 square inch). With higher DPI, the image becomes sharper. The platform (computing or digital) is the environment in which software was used. Standardization for cephalometric radiography has been defined as adjusting the cephalometric radiograph size and resolution to match the image in the real-world on a scale of 1: 1.

Sample Selection

This cross-sectional study used a randomly selected (from digital archives) sample of 30 lateral cephalograms (of previously treated orthodontic patients) that constituted 17 male and 13 female subjects with a set of permanent natural dentition and a mean age of 22 years 9 months. These radiographs were part of the investigation process prior to diagnosis and treatment of these subjects. The selection of lateral cephalometric pretreatment radiographs was based on certain inclusion and exclusion criteria. These included an age range (18 to 35 years), regardless of sex and malocclusion type, had a complete set of natural permanent dentition, good-quality radiograph that permitted identification of desired landmarks, and

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radiographs were taken from the same machine and technique with similar calibration and display calibration ruler. Pixelated radiographs, which contain a low number of pixels, and those radiographs with gross dimensional discrepancies were excluded from the study. These inclusion criteria ensured that patient records had minimal variations and met the requirements of the study. The age range recruited ensured patients had minimal variations in teeth as a result of decay, since decay can change tooth positions. It also ensured that all radiographs used similar exposure techniques (head immobilized with cephalostat, guided by Frankfort horizontal plane parallel to the ground/perpendicular to mid-sagittal plane) [28]. Radiographs were randomly selected from digital archives by 2 independent reviewers experienced in the field of orthodontics, both of whom were blinded to the objectives and outcome of the study. The same radiographs were used for 3 independent groups [manual tracing – Gp M, smartphone tracing application (OneCeph) – Gp S and tablet tracing application (CephNinja) – Gp T].

Digital Calibration

All radiographs were digitally calibrated by using dots/pixels per inch (DPI/PPI) [29], which was obtained from the scanner device. The method does not require a high-quality printer and provides up to 300 DPI for all printers. Once the DPI settings were known, the image was calibrated to real-world size. DPI was acquired by uploading a digital cephalometric radiograph to a Photoshop file (Adobe Systems, Inc., San Jose, CA) that could be calibrated and resized to a real-world scale of 1:1 printing to hard-copy using the same interface. Hard-copy printing was done with the same software to keep the standardized settings for image size and to prevent image printing distortion if printed using other software. All radiographic images were printed from a JPEG (Joint Photographic Experts Group) file extension.

For calibration of radiographic images in Gp S and Gp T, a calibrating ruler provided with the application was used to measure 2 points on each image to reflect a real-world size on the monitor of the screen used [30]. All machines used can be accurately measured and corrected for magnification using the millimeter calibration ruler.

Radiographic Tracing

All tracings were performed by 1 blinded operator to minimize inter-examiner variations, blinded to study outcome and objectives. The operator was an experienced specialist and consultant (orthodontist) who has been working as an academician and clinician for more than 10 years. Pertaining to the study objectives, he was trained in terms of the number of radiographs to be completed in a single day and limited analysis to be performed on each radiograph. Accurate landmark identification was supervised by an experienced staff member, who also has been working as an academician/clinician for 9 years in the same specialty with the same position. Only 5 tracings were performed in a working day so as to avoid inaccuracies due to eye fatigue and strain. To prevent the measurement error and to test the magnitude of intra-examiner error, 5 randomly selected samples were retraced and re-measured by the same researcher 1 week after the initial measurements. The calculated random error was measured using Dahlberg's test.

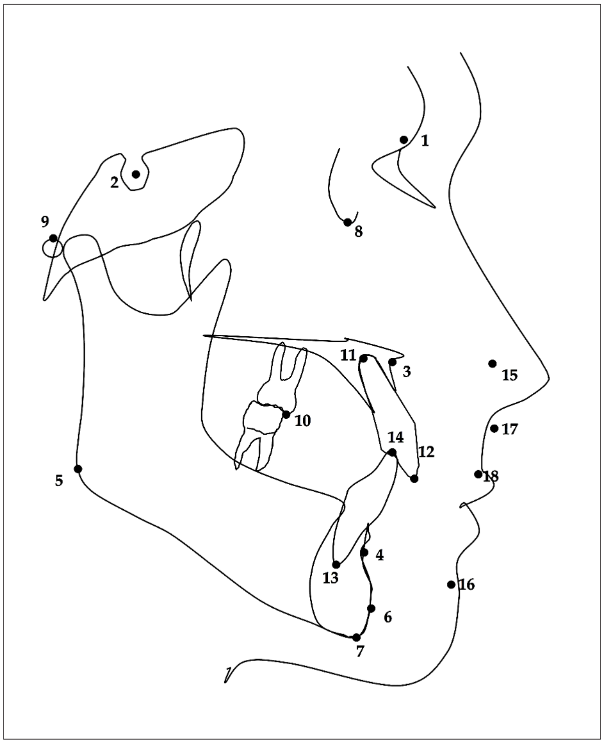

Figure 1. Cephalometric Landmarks used for analyzing various parameters of Steiners cephalometric analysis. Landmarks: Hard Tissue – 1. Nasion (N), 2. Sella Turcica (S), 3. Subspinale (A), 4. Supramentale (B), 5. Gonion (Go), 6. Pogonion (Pog), 7. Gnathion (Gn), 8. Orbitale (O), 9. Porion (P), 10. U6 (Buccal Cusp Tip Maxillary First Molar) 11. Isa (Upper Incisor Root Apex), 12. Isi (Upper Incisor Tip), 13. Iia (Lower Incisor Root Apex), 14. Iii (Lower Incisor Incisal Edge), Soft Tissue 15. Midpoint (M) (S -Shape Curve Joining Upper Lip And Nose), 16 Soft Tissue Pogonion (Pog'), 17. Labrale Superius(Ls), 18. Labrale Inferius (Li). *Compiled Figure created using MS PowerPoint, version 20H2 (OS build 19042,1466), windows 11 Pro, Microsoft corporation).*

Identifying Anatomical Landmarks for Analysis

A schematic outline of various anatomical landmarks to be identified and analyzed (Steiner analysis) for the study were organized. A digital representation of the identification of all

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Table 1. Steiner cephalometric landmarks for linear and angular measurements.

	Landmark (abbreviation)	Description
Cephalometric Landmarks	Nasion (N)	Point between the frontal bone and nasal bone
	Sella turcica (S)	Midpoint of sella turcica
	Subspinale (A)	Deepest concavity of the premaxilla
	Supramentale (B)	Deepest concavity in the curvature of mandibular alveolar process
	Gonion (Go)	The corner angle of the mandible
	Pogonion (Pog)	Most anterior point of the symphysis
	Gnathion (Gn)	Between pogonion and menton
	Orbitale (O)	Lowest point on the lower edge of the orbit
	Porion (P)	Most superior and outer bony surface point of the external auditory meatus
	U6	Buccal cusp tip of maxillary first molar
	U4	Buccal cusp tip of maxillary first premolar
	Isa	Upper incisor root apex
	Isi	Upper incisor tip
	Iia	Lower incisor root apex
	Iii	Lower incisor incisal edge
	Midpoint (M)	S-shape curve joining upper lip and nose
	Soft tissue pogonion (Pog')	Most anterior point of the soft tissue of chin
	Labrale superius (Ls)	Most anterior point of the upper lip
	Labrale inferius (Li)	Most anterior point of the lower lip
Steiners Analysis	Skeletal	SNA, SNB, ANB, SNMP, SNOP (degrees) (°)
	Dental	U1NA, L1NB, U1L1 (millimeter and degrees)
	Soft tissue	S-line

Skeltal – SNA (Sella – nasion – subspinale), SNB (sella – nasion – supramentale), ANB (subspinale – nasion – supramentale), SN – MP (sella – nasion with midpoint – porion), SNOP (sella nasion – orbitale porion); Dental – U1NA (upper incisor – nasion – subspinale), L1NB (lower incisor – nasion – supramentale), U1L1 (upper incisor – lower incisor); Soft tissue – S line.

landmarks and their coded numbers is presented in **Figure 1**. The description of each coded landmark, which includes the location of the particular point or the plane between 2 points, is presented in **Table 1**.

Manual Tracing (Gp M)

Printed copies of pretreatment lateral cephalometric radiographs were used for manual tracing. Digitally standardized radiographs were printed on glossy photo paper. Manual tracings were made on acetate paper, which was attached to the printed radiograph using clear tape. The tracing sheet was attached to the printed radiograph paper with the glossy side facing away from operator and the rough surface on top, to allow marking with a pencil. Three reference crosses were marked on each printed radiograph at wide distances, but within reach of the overlying tracing paper. This was to allow the overlying tracing paper to be oriented in case the tape came loose or there was movement while recording. The outline of the bony landmarks was then traced on the acetate paper to yield surface characteristic of the cranial cephalogram. Similarly, the soft tissue outline was also traced from the printed radiograph. A 0.5-mm mechanical pencil was used for marking and drawing landmarks. For linear measurement, a line drawn from one point to another was carried by using a transparent ruler, the outer margins of which were kept on the outline

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of the particular landmarks, and then a line was drawn from one point to another. For angular measurements, a protractor was used, which was aligned on 2 lines at right angle to each other, while at the same time demonstrating the angle of the landmark in the area of interest. The angle was thus recorded by observing the line denoting the angle on the transparent protractor and underlying landmark.

Steiner analysis landmarks were placed over the prospective anatomical structures (**Figure 2**). The goal of landmark placement was to identify only those landmarks involved directly in Steiner analysis. This provided the maximum diagnostic information with the minimum number of measurements. The linear and angular values were identified and measured using a pencil and a cephalometric protractor to achieve Steiner parameters, and the values of each parameter were written on the back of the cephalometric radiograph printout.

Smartphone Application Tracing (Gp S)

Digital pretreatment lateral cephalometric radiographs were used for this application (Oneceph on Samsung S20, Beta 13, (NXS technology, Hyderabad, India) and installed on an Android (OS9) smartphone. The radiographs were uploaded into the application using a USB-C transfer port in JPEG format. The radiographs were transferred and standardized (calibrated) inside the application. Standardization was done by placing a start and end point of a known distance on the standardized ruler. The measurement was then written inside the box. Steiner analysis is an inbuilt feature that appears on analysis. All landmarks desired are placed using arrows at the bottom of the screen. All anatomic landmarks are identified and marked using a stylus pen. A guide that aids in correct positioning of the desired landmark over the structure of the digital radiographic image is also present. The result of Steiner's analysis was displayed in a PDF format.

Tablet Application Tracing (Gp T)

Digital pretreatment lateral cephalometric radiographs were uploaded into the application CephNinja on iPad 9th generation, Version 4.11 (Cyncronus LLC, WA, USA) in JPEG format using a manufacturer-provided cable. The photographs were then transferred to the application installed on an Apple tablet (IOS13). The radiographs were standardized (calibrated) inside the application by choosing an image from the gallery, and then moving the ruler (red-colored) and enlarging it to fit over the standardized (calibrated) ruler. Tracing was done by placing the correctly labeled landmark placed over the anatomic structures. All anatomical landmarks were identified using a stylus pen. At the end of the tracing, the examiner clicked on "Analysis" and the results of the measurements of the parameters were exported in a PDF format.

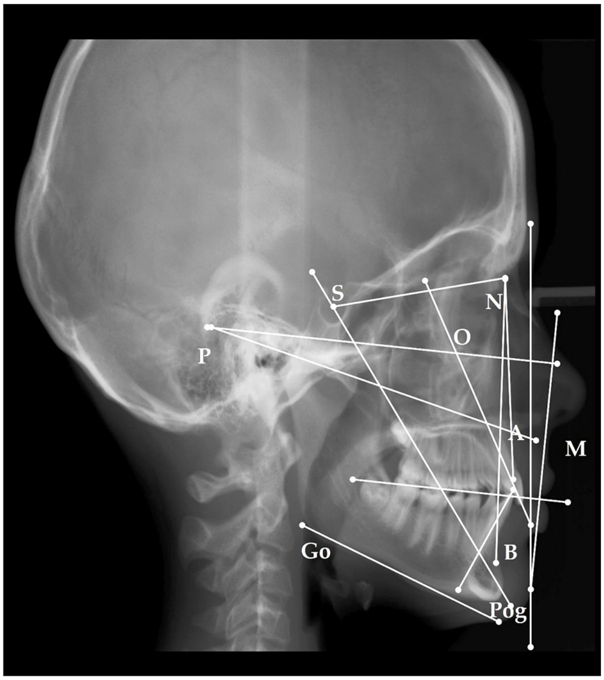

Figure 2. Radiographic Landmarks Used for Analyzing Parameters Of Steiner Analysis. Landmarks: Nasion (N), Sella Turcica (S), Subspinale (A), Supramentale (B), Gonion (Go),Pogonion (Pog), Orbitale (O), Porion (P), Soft Tissue Midpoint (M) (S -Shape Curve Joining Upper Lip And Nose)] Analysis: [Skeletal - SNA (Sella – Nasion - Subspinale), SNB (Sella – Nasion - Supramentale), ANB (Subspinale – Nasion - Supramentale), SNMP (Sella – Nasion With Midpoint - Porion), SNOP (Sella– Nasion – Orbitale Porion); Dental - U1NA (upper incisor – nasion - Subspinale), L1NB (lower incisor – nasion – Supramentale), U1L1 (upper incisor – lower incisor); Soft tissue – S line Soft tissue – S line). *Radiographic image through desktop software SIDEXIS (Sirona Dental Systems GmbH) and Carestream (Vue PACS v11.3.4, Carestream Health Inc, Rochester, NY). Compiled figure created using MS PowerPoint, version 20H2 (OS build 19042,1466), windows 11 Pro, Microsoft corporation)*

Measurement, Data Collection, and Evaluation

Analytical Measurements (Steiners Analysis) [31]: Once the respective cephalogram was uploaded, the cephalometric landmarks and their respective description were traced for Steiner analysis (**Table 1**). Each cephalometric landmark was identified, located, and marked, followed by their verification based on anatomical positions. Once a landmark was identified, the lines and planes that are depicted in **Table 1 and Figure 1** were traced. Following tracing of the landmarks, the planes and lines that represent Steiner analysis were obtained on each individual radiograph (**Figure 2**). Steiner analysis was undertaken in a sequence. Landmarks for linear measurements were identified followed by their respective measurements. Then, the landmarks for angular measurements were identified followed by

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Table 2. Descriptive statistics (mean and standard deviations) for various parameters of steiners analysis among different studied groups.

Parameters	Groups	N	Mean	Std. deviation
SNA (in degrees)	Gp M	30	80.73	2.95
	Gp S	30	80.76	2.95
	Gp T	30	80.86	2.88
SNB (in degrees)	Gp M	30	79.34	4.26
	Gp S	30	79.38	4.30
	Gp T	30	79.39	4.32
ANB (in degrees)	Gp M	30	1.79	2.41
	Gp S	30	1.71	2.41
	Gp T	30	1.64	2.37
SNMP (in degrees)	Gp M	30	31.91	4.59
	Gp S	30	31.89	4.44
	Gp T	30	31.93	4.57
SNOP (in degrees)	Gp M	30	16.59	4.87
	Gp S	30	16.53	4.90
	Gp T	30	16.54	4.86
U1NA (in degrees)	Gp M	30	31.83	8.13
	Gp S	30	31.68	8.25
	Gp T	30	31.64	8.44
U1NA (in mm)	Gp M	30	9.27	2.53
	Gp S	30	9.23	2.47
	Gp T	30	9.09	2.45
L1NB (in degrees)	Gp M	30	30.85	6.59
	Gp S	30	31.00	6.89
	Gp T	30	30.52	6.66
L1NB (in mm)	Gp M	30	7.50	2.12
	Gp S	30	7.45	2.14
	Gp T	30	7.39	2.11
U1L1 (in degrees)	Gp M	30	116.31	11.65
	Gp S	30	115.52	14.06
	Gp T	30	116.38	11.64
S line (in degrees)	Gp M	30	2.01	2.78
	Gp S	30	2.02	2.79
	Gp T	30	1.95	2.72

Gp – group; M – manual tracing; S – smartphone; T – tablet; SNA (Sella – nasion – subspinale), SNB (sella – nasion – supramentale), ANB (subspinale – nasion – supramentale), SN – MP (sella – nasion with midpoint – porion), SNOP (sella nasion – orbitale porion); Dental – U1NA (upper incisor – nasion – subspinale), L1NB (lower incisor – nasion – supramentale), U1L1 (upper incisor – lower incisor); Soft tissue – S line.

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Table 3. Test of homogeneity of variances between studied groups using Levene's test.

Dependent variable	Levene statistic	df1	df2	P value
SNA (in degrees)	0.01	2	87	0.99
SNB (in degrees)	0.00	2	87	0.99
ANB (in degrees)	0.02	2	87	0.99
SNMP (in degrees)	0.02	2	87	0.98
SNOP (in degrees)	0.00	2	87	1.00
U1NA (in mm)	0.04	2	87	0.97
U1NA (in degrees)	0.03	2	87	0.97
L1NB (in degrees)	0.04	2	87	0.96
L1NB (in mm)	0.00	2	87	0.99
U1L1 (in degrees)	0.15	2	87	0.86
SLINE (in degrees)	0.02	2	87	0.98

df – degree of freedom; p – probability; SNA (Sella – nasion – subspinale), SNB (sella – nasion – supramentale), ANB (subspinale – nasion – supramentale), SN – MP (sella – nasion with midpoint – porion), SNOP (sella nasion – orbitale porion); Dental – U1NA (upper incisor – nasion – subspinale), L1NB (lower incisor – nasion – supramentale), U1L1 (upper incisor – lower incisor); Soft tissue – S line. Statistical significance: if the probability 'p' value is equal to or less than 0.05 ($p \leq 0.05$); NS – not significant.

their respective measurements. Any deficiency during angular measurement was identified and the desired plane was drawn. The analysis was done for 5 skeletal, 3 dental, and 1 soft tissue cephalometric relations. Measurements included 5 angular (SNA, SNB, ANB, SNMPA, SNOP), 3 linear U1NA (mm and degrees), L1NB (mm and degrees), U1L1 (U=upper, L=lower), and 1 soft tissue (S line). The measurements on the manual tracings were done using a protractor (3M Unitek, Campinas, São Paulo, Brazil), while in the other groups the measurements were displayed on the respective screen.

Statistical Analysis

Data obtained were entered into 3 different Microsoft Excel spreadsheets that were named according to the respective groups. The data were corrected and refined for any errors, and then coded, followed by entry into SPSS version 24.0 (SPSS 24.0; SPSS, Inc., Chicago, Illinois, USA) for statistical analysis and testing. Descriptive statistics derived were means and standard deviations for each measured parameter of Steiner analysis. Results were then tested for distribution of data (normality) using Shapiro-Wilk test and Lilliefors significance correction. The null hypothesis was tested using Levene's test to assess the equality of error variance. All Steiner analysis parameters in the 3 different groups were tested using ANOVA to look for differences among groups. For all tests, the probability 'p' value was considered to be significant if it was less or equal to 0.05 ($p \leq 0.05$).

Results

Steiner Analysis: The mean and standard deviations of 11 parameters of Steiner analysis of Gp M, Gp S and Gp T, measured in degrees and millimeters, are presented in **Table 2**. Angular measurement SNA between the 3 groups fell in the range of 80.73±2.95 to 80.86±2.88, SNB (79.34±4.26 to 79.39±4.32), ANB (1.64±2.37 to 1.79±2.41), SNMP (31.89 to 31.93) and SNOP (16.53 to 16.59), indicating there were negligible differences between the 3 tracing methods. Similarly, linear measurements were well within the same range, with little differences in mean values [U1NA (range 9.09 to 9.27), L1NB (range 7.39 to 7.50)] or deviations.

Comparison of Subgroups: To assess the equality of variances for each parameter calculated in the 3 groups, Levene test results are presented in **Table 3**. The Levene test shows that the p values exceeded the significance level of 0.05, indicating that the variances observed among groups were not significantly different from each other. For angular measurements, the p value was in the range of 0.90 to 1.00, which was considered to be non-significant ($p \leq 0.05$). For linear measurement, the p values fell in the range of 0.86 to 0.99, which was again higher than the predetermined value for considering statistical significance ($p \leq 0.05$). The interpretation of these values therefore establishes that the variances observed among groups were not significantly different from each other and the homogeneity assumption of the variance was met. Therefore, the 3 methods of tracing showed no significant differences

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Table 4. One-Way Analysis of Variance (ANOVA) test results for differences between and within groups in various parameters of steiner analysis.

Parameters		Sum of squares	df	Mean square	F statistic	P value
SNA	Between groups	0.27	2	.14	.02	0.98 (NS)
	Within groups	749.44	87	8.61		
	Total	749.71	89			
SNB	Between groups	.05	2	.02	.00	0.99 (NS)
	Within groups	1606.63	87	18.47		
	Total	1606.67	89			
ANB	Between groups	.32	2	.16	.03	0.97 (NS)
	Within groups	503.04	87	5.78		
	Total	503.37	89			
SNMP	Between groups	.03	2	.01	.00	0.99 (NS)
	Within groups	1793.88	87	20.62		
	Total	1793.90	89			
SNOP	Between groups	.06	2	.03	.00	0.99 (NS)
	Within groups	2075.14	87	23.85		
	Total	2075.19	89			
U1NA (mm)	Between groups	.62	2	.31	.01	0.99 (NS)
	Within groups	5964.82	87	68.56		
	Total	5965.44	89			
U1NA MM	Between groups	.54	2	.27	.04	0.96 (NS)
	Within groups	539.56	87	6.20		
	Total	540.10	89			
L1NB (mm)	Between groups	3.65	2	1.83	.04	0.96 (NS)
	Within groups	3927.27	87	45.14		
	Total	3930.92	89			
L1NB MM	Between groups	.18	2	.09	.02	0.98 (NS)
	Within groups	394.08	87	4.53		
	Total	394.26	89			
U1L1	Between groups	13.46	2	6.73	.04	0.96 (NS)
	Within groups	13591.64	87	156.23		
	Total	13605.09	89			
SLINE	Between groups	.08	2	.04	.01	0.99 (NS)
	Within groups	664.22	87	7.64		
	Total	664.29	89			

Abbreviations: mm – millimeters; df – degree of freedom; p – probability; SNA (Sella – nasion – subspinale), SNB (sella – nasion – supramentale), ANB (subspinale – nasion – supramentale), SNMP (sella – nasion with midpoint – porion), SNOP (sella nasion – orbitale porion); Dental – U1NA (upper incisor – nasion – subspinale), L1NB (lower incisor – nasion – supramentale), U1L1 (upper incisor – lower incisor); Soft tissue – S line. Statistical significance: if the probability 'p' value is equal to or less than 0.05 ($p \leq 0.05$); NS – not significant.

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for any of the parameters of Steiner analysis. The Levene test also tests the null hypothesis that the error variance of the dependent variable is equal across groups. **Table 4** presents the one-way ANOVA test results from differences among and within groups for all parameters of Steiner analysis. ANOVA indicated no significant difference existed between the 3 methods for any of the parameters of Steiner analysis. All parameters analyzed showed p values greater than the threshold of 0.05, suggesting that the 3 methods did not differ significantly for any parameter.

Discussion

This study investigated the compatibility of manual lateral cephalometric tracing with a smart phone- and tablet-based tracing applications. The study was conducted using various parameters of Steiner analysis, which is not only more common but also most popular in current digital analytical applications. Lateral cephalometric radiography is an important diagnostic procedure since it allows analysis of skeletal, dental, and soft tissue facial composition in a single view and, more importantly, their relation to each other. Applications that perform tracings of cephalograms are either automatic or semiautomatic, and the latter was chosen for this study since that would have kept the balance with the manual method. The overall results show that for all parameters of Steiner analysis, all 3 methods were comparable for linear and angular measurements. Therefore, the null hypothesis was rejected, which stated that differences existed between the 3 methods. The results also show that the differences in variations between groups were homogeneous rather than heterogenous. The results also indicate that when standardization of lateral cephalometric radiographs is done correctly on a scale of 1: 1, a reliable measurement of Steiner analysis in manual and digital applications can be achieved. The results, however, are dependent upon the methods used, which included the standardization and/or calibration of each individual method according to the recommendations.

These results agree with a study by Erkan et al [33], who stated the importance of standardization when comparing the reliability of cephalometric tracing methods (computerized tracing programs like Dolphin Imaging, Vistadent, Nemoceph, and Quick Ceph), and they also reported no significant differences between manual and computerized tracings. Our results on tablet-based cephalometric tracings also agree with the findings of Kumar et al, [34] who compared CephNinja (a tablet-based platform) and NemoCeph on (a PC-based platform) using Down analysis, and found no difference between both applications and manual tracings. On the contrary, Aksakallı et al [21], while comparing 2 tablet-based applications (CephNinja and SmartCeph pro) against computer software (Dolphin Imaging) for Bland – Altman analysis (21 landmarks, 16 measurements), reported only 7 measurements matching with CephNinja and 6 measurements with SmartCeph pro, but they attributed these errors to lack of calibration and the operator lacking skills in identifying correct landmarks. Angular measurement is considered to have more variations than linear measurements, regardless of tracing method, used due to certain landmarks (porion, orbitale, gonion) showing inconsistency while tracing. Errors and uncertainties in landmark identification of cephalometric tracing are common, whether using manual or digital tracing applications. Cephalometric tracing is susceptible to inter-examiner error during the process of locating the landmarks, as well as linear and angular measurements [7]. While our study ensured minimum variations due to inter-examiner error by utilizing statistical testing (Dahlberg), there are other factors that may have contributed to such errors while measuring.

Our results show that for all analysis of Steiner parameters, there was no difference found between manual, smartphone, and tablet methods for any parameter measured in either degrees or in millimeters. Our results partially agree with other studies using smartphone-based applications. Sayar et al [35] compared manual tracing with use of a smartphone method (iPhone 5 with IOS 9.3.2) and found differences for ANB, SNA, SNB, and soft tissue analysis. Manual tracings in their study reported lower significant values. Although they attributed these differences to the tools used for manual tracings (protractor, ruler, and pencil), they performed 11 tracings/day using 1 observer, while we performed only 5 tracing/day to avoid physical and eye fatigue. Looking at small objects for a long time has been reported to be a major cause of eye fatigue [36]. Kılınç et al [37] evaluated and compared smartphone application tracing (CephNinja) with manual, driven, and web-based artificial intelligence tracing for 4 linear and 7 angular measurements on a sample of 110 radiographs. They found differences in 4 measurements of degrees (SNA, SNB, SNMP, U1SN) and 2 measurements of millimeters (L1NB mm, E Line). The lowest agreement was for the measurement U1NA between smartphone and manual methods. Artificial intelligence web-based cephalometric tracing using software has also been found to have better tracing accuracies than smartphone and manual tracings [38]. Other platforms that have been investigated are an online cloud tracing service (WebcephX) [39] and an artificial intelligence (AI) algorithm [40].

Our results, however, are in agreement with the results obtained by Paixão et al [5], Tikku et al [41], Celik et al [42], and Shah Akbari et al [43], who found that all parameters were similar between digital and manual tracing applications. It is important to note that these studies used different software than we used. The similar values between manual and digital methods in our study can be explained by improvements in digital radiography, as well as processing and formatting of images and

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printing. Other factors that have contributed significantly to printed lateral radiographs include image resolution and standardization, which are easily controlled in software like Adobe Photoshop. Variations in PPI/DPI during printing of a radiograph can induce errors in landmarks between 2 prints. Low resolution of an image is a major cause for poor printing of clearly defined landmarks in printed radiographs [44]. Obtaining an accurate and standardized printout for lateral radiographs is better done using Adobe Photoshop because it has the tools needed to calculate the number of millimeters on a standard cephalometric ruler [23]. In this study, the standardization process of the images was made accurate with the calibrated ruler on the digital radiographs. The number of pixels of one starting point to an end point was calculated to measure the pixels in this confined area. After that, the printout and the resolution were checked for each radiograph. Higher accuracy of digital cephalometric tracings has been attributed to its ability to produce clear radiographic images using either direct or indirect digitization [45]. Both digitization methods have been found to show reliable analysis except for a few (U1/L1, S-Go, N-Me) [45]. The reason for the difference was the difficulty in accurately identifying these landmarks, as they are associated with bilateral superimposition. Power et al [11] reported direct digitization was more reproducible and accurate than indirect digitization, but the differences were statistically significant under only a few conditions (use of particular software). One of the limitations of digitized cephalometric tracing is identification of the apices of the incisors [46]. These specific areas are inherently hard to trace because the digital image can include gray shades that are easily misinterpreted [11]. The inconsistency in the measurements of the various parameters in the cephalometric analysis may be due to reduced reliability, which is often affected by superimposition of bilateral structures [18].

Strength and limitations of the study: The results of this study further substantiate the already existing evidence of digital cephalometric applications being reliable in terms of cephalometric tracings for orthodontic patients. Digital photographs that are uploaded in applications have a very significant advantage of image enhancement and enlargement (zoom) that allows less errors while tracing. The study has its own limitations, which include lack of screen size difference determination between smartphone and tablet, only 1 analysis (Steiner analysis) was performed due to the availability of common analysis in smartphones and tablets, the small sample size, and the standardization for each group was different because there is no common standardization that can be applied to all. Further limitations of using digital applications generally are that they receive updates for various purposes, which might influence the results before and after updates. Manual tracing has its own limitations, which include modifications in the printout based on printer settings, and printer vibrations inducing errors in printing. The assumptions made during the research included that the new updates for both the applications (smartphone-based and tablet-based), and fixes (including performance issues, some improvements in soft tissue analysis) for previous issues.

Clinical Implications: For many years, manual tracing has been the only available method for cephalometric tracing, despite having many drawbacks. With the advancement of technology and the availability of digitizing X-rays, it has overcome some of the issues related to manual tracing. Smartphone-based and tablet-based digital cephalometric tracing applications provide a new alternative for clinicians, combining faster tracing time with more contrast of colors and the ability to zoom in/out. As a result, it reduces or prevents eyestrain when using these devices.

Conclusions

Within the scope and limitation of this study, it can be concluded that digital tracing using smartphones and tablets is equally good at performing a reliable cephalometric analysis for orthodontic diagnosis and treatment planning. The study also found that calibration and standardization are important for proper results. The study also concludes that, irrespective of techniques used, standardization and calibration procedures play significant roles in the final outcome of such comparisons. The manual method for cephalometric tracing can be replaced by any digital method described in this study. Also, it is important to note that when digital modes are not available, the manual method should be performed; it should not be discarded completely until proven otherwise, for it is still as reliable as digital methods.

Acknowledgements

We thank the Department of Oral Diagnosis and Radiology for selfless cooperation during the course of this study, and the staff of the Department of Orthodontics for their valued contributions in completing this research.

Department and Institution Where Work Was Done

This work was carried out at University of the East Manila Dentistry.

Declaration of Figures' Authenticity

All figures submitted for this research article have been taken and created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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References:

1. Brennan J. An introduction to digital radiography in dentistry. J Orthod. 2002;29(1):66-69
2. Proffit WR, Fields H, Larson B, Sarver DM. Contemporary orthodontics: Contemporary orthodontics-e-book. Elsevier Health Sciences; 2018
3. Hans MG, Palomo JM, Valiathan M. History of imaging in orthodontics from Broadbent to cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2015;148(6):914-21
4. Kolokitha OE, Topouzelis N. Cephalometric methods of prediction in orthognathic surgery. J Maxillofac Oral Surg. 2011;10:236-45
5. Paixão MB, Sobral MC, Vogel CJ, Araujo TM. Comparative study between manual and digital cephalometric tracing using Dolphin Imaging software with lateral radiographs. Dental Press J Orthod. 2010;15:123-30
6. Stephan CN, Claes P. Craniofacial identification: Techniques of facial approximation and craniofacial superimposition. In Blau, J. (ed.). Handbook of Forensic Anthropology and Archaeology (1st ed.). Routledge. 2009;25:304-21
7. Albarakati SF, Kula KS, Ghoneima AA. The reliability and reproducibility of cephalometric measurements: A comparison of conventional and digital methods. Dentomaxillofac Radiol. 2012;41(1):11-17
8. Panj Noush M, Esmaily M. Comparison between digital and ordinary methods in analyzing cephalometric radiographic images. Iran J Orthod. 2015;10(1):1-5
9. Cohen AM. Uncertainty in cephalometrics. Br J Orthod. 1984;11(1):44-48
10. Halazonetis DJ. Computers in orthodontic research. In Research Methods in Orthodontics: A Guide to Understanding Orthodontic Research 2012 Nov 5 (pp. 81-111). Springer Berlin, Heidelberg
11. Power G, Breckon J, Sherriff M, McDonald F. Dolphin Imaging Software: An analysis of the accuracy of cephalometric digitization and orthognathic prediction. Int J Oral Maxillofac Surg. 2005;34(6):619-26
12. Wattanapisit A, Teo CH, Wattanapisit S, et al. Can mobile health apps replace GPs? A scoping review of comparisons between mobile apps and GP tasks. BMC Med Inform Decis Mak. 2020;20(1):5
13. Vaid NR, Hansa I, Bichu Y. Smartphone applications used in orthodontics: A scoping review of scholarly literature. J World Fed Orthod. 2020;9(3):S67-73
14. Mamillapalli PK, Sesham VM, Neela PK, et al. A smartphone app for cephalometric analysis. J Clin Orthod. 2016;50:694-33
15. Siddiqui NR, Hodges S, Sharif MO. Availability of orthodontic smartphone apps. J Orthod. 2019;46(3):235-41
16. Sharif MO, Siddiqui NR, Hodges SJ. Patient awareness of orthodontic mobile phone apps. J Orthod. 2019;46(1):51-55
17. Mohan A, Sivakumar A, Nalabothu P. Evaluation of accuracy and reliability of OneCeph digital cephalometric analysis in comparison with manual cephalometric analysis – a cross-sectional study. BDJ Open. 2021;7(1):22
18. Shettigar P, Shetty S, Naik RD, et al. A comparative evaluation of reliability of an android-based app and computerized cephalometric tracing program for orthodontic cephalometric analysis. Biomed Pharmacol J. 2019;12(1):341-46
19. Gayatri G, Harsanti A, Zenab Y, Sunaryo IR. Steiner cephalometric analysis discrepancies between conventional and digital methods using Cephninja application software. Padjajaran J Dent. 2016;28(3):13671
20. Livas C, Delli K, Spijkervet FK, Vissink A, Dijkstra PU. Concurrent validity and reliability of cephalometric analysis using smartphone apps and computer software. Angle Orthod. 2019;89(6):889-96
21. Aksakallı S, Yılancı H, Görükmez E, Ramoğlu Sİ. Reliability assessment of orthodontic apps for cephalometrics. Turk J Orthod. 2016;29(4):98
22. Ahmed M, Shaikh A, Fida M. Diagnostic validity of different cephalometric analyses for assessment of the sagittal skeletal pattern. Dental Press J Orthod. 2018;23:75-81
23. Bruntz LQ, Palomo JM, Baden S, Hans MG. A comparison of scanned lateral cephalograms with corresponding original radiographs. Am J Orthod Dentofacial Orthop. 2006;130(3):340-48
24. Doi K, Li Q, Nishikawa RM. Historical overview. In Computer-Aided Detection and Diagnosis in Medical Imaging 2015 Mar 17 (pp. 1-17). Taylor & Francis Group, LLC, CRC Press
25. Navarro RD, Oltramari-Navarro PV, Fernandes TM, et al. Comparison of manual, digital and lateral CBCT cephalometric analyses. J Appl Oral Sci. 2013;21:167-76
26. Barbhuiya MH, Kumar P, Thakral R, et al. Reliability of mobile application-based cephalometric analysis for chair side evaluation of orthodontic patient in clinical practice. J Orthod Sci. 2021;10:16
27. Borm GF, Fransen J, Lemmens WA. A simple sample size formula for analysis of covariance in randomized clinical trials. J Clin Epidem. 2007;60(12):1234-38
28. Silva CA, Ferreira AP. Frankfort plane vs. natural head posture in cephalometric diagnosis. Dent Med Probl. 2003;40(1):129-34
29. 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):345-51
30. Liu JK, Chen YT, Cheng KS. Accuracy of computerized automatic identification of cephalometric landmarks. Am J Orthod Dentofacial Orthop. 2000;118(5):535-40
31. Song GY, Li G, Lu WH, Han B, Xu TM. Distortion and magnification of four digital cephalometric units. Niger J Clin Pract. 2019;22(12):1644-53
32. Steiner CC. Cephalometric for you and me. Am J Orthod Dentofacial Orthop. 1953;30(10):729-55
33. Erkan M, Gurel HG, Nur M, Demirel B. Reliability of four different computerized cephalometric analysis programs. Eur J Orthod. 2012;34(3):318-21
34. Kumar M, Kumari S, Chandna A, et al. Comparative evaluation of CephNinja for android and NemoCeph for computer for cephalometric analysis: A study to evaluate the diagnostic performance of CephNinja for cephalometric analysis. J Int Soc Preven Commun Dent. 2020;10(3):286-91
35. Sayar G, Kilinc DD. Manual tracing versus smartphone application (app) tracing: A comparative study. Acta Odontol Scand. 2017;75(8):588-94
36. Wu HC, Chiu MC, Peng CW. Visual fatigue occurrence time when using hand-held intelligent devices. J Ambient Intell Humaniz Comput. 2016;7:829-35
37. Kılınç DD, Kırcelli BH, Sadry S, Karaman A. Evaluation and comparison of smartphone application tracing, web based artificial intelligence tracing and conventional hand tracing methods. J Stomatol Oral Maxillofac Surg. 2022;123(6):e906-15
38. Gupta S, Shetty S, Natarajan S, et al. A comparative evaluation of concordance and speed between smartphone app-based and artificial intelligence web-based cephalometric tracing software with the manual tracing method: A cross-sectional study. J Clin Experimen Dent. 2024;16(1):e11
39. Alqahtani H. Evaluation of an online website-based platform for cephalometric analysis. J Stomatol Oral Maxillofac Surg. 2020;121(1):53-57
40. Kunz F, Stellzig-Eisenhauer A, Zeman F, Boldt J. 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
41. Tikku T, Khanna R, Maurya RP, et al. Comparative evaluation of cephalometric measurements of monitor-displayed images by Nemoceph software and its hard copy by manual tracing. J Oral Biol Craniofac Res. 2014;4(1):35-41
42. Celik E, Polat-Ozsoy O, Memikoglu TU. Comparison of cephalometric measurements with digital versus conventional cephalometric analysis. Eur J Orthod. 2009;31:241-46
43. Shahakbari R, Pahlevankashi M, Eshghpour M, Ataii A. Comparison of digital cephalometric tracing by onyx ceph software versus manual method. Int J Contemp Dent Med Rev. 2018;1:1-5
44. Rakhshan V. Image resolution in the digital era: Notion and clinical implications. J Dent. 2014;15(4):153
45. 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):345-51
46. Sayinsu K, Isik F, Trakyali G, Arun T. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. Eur J Orthod. 2007;29(1):105-8

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