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Cephalometric analysis using a mobile application

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Cephalometric Analysis: Reliability of A Mobile-Based Digital Application: A Pilot Study

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Abstract

Background: Cephalometric analysis is integral to orthodontic diagnosis and treatment planning. Although conventional manual tracing is accurate, it is time-consuming and prone to operator variability. Digital methods improve precision, yet their adoption in resource-limited settings is restricted by cost and hardware requirements. Smartphone-based applications such as OneCeph® offer a potential low-cost alternative, but independent validation of their accuracy and reliability remains limited. This study compared the reliability of cephalometric measurements obtained using OneCeph® and conventional manual analysis.

Methods: A cross-sectional comparative study was conducted using 40 high-quality lateral cephalometric radiographs. Ten standard parameters (six angular: Sella-Nasion-A point (SNA), Sella-nasion- B point (SNB), A point-Nasion- B point (ANB), Upper incisor to nasion-A point (UI- NA), Lower incisor to nasion- B point (LI- NB), Interincisal angle, and four linear: UI-NA, LI-NB, Upper lip to S-line, Lower lip to S-line) were measured manually on acetate film and digitally using OneCeph® (version beta 1.1, NXS Soft Solutions, India). Data were analyzed using intraclass correlation coefficients (ICC), Pearson correlation, and paired t-tests, with significance set at $p < 0.05$.

Results: Participants' mean age was 20.7 ± 7.8 years; 60% were female. Digital tracings demonstrated good to excellent reliability for skeletal angular and soft tissue parameters (ICC = 0.83–0.91), while manual tracings were slightly more consistent for linear dental measurements (ICC = 0.94 for UI–NA and 0.83 for LI–NB). Statistically significant correlations ($r \geq 0.90$, $p < 0.001$) were observed between both methods for 9 of 10 parameters. However, paired t-test showed a statistically significant mean difference for SNA, SNB, UI–NA°, LI–NB (mm), UL-to-S-line, and LL-to-S-line.

Conclusion: Our findings highlight the potential of OneCeph® smartphone-based digital cephalometric analysis in resource-limited settings. However, the statistically significant differences in some parameters observed between digital and nanual methods suggest that results obtained using such applications should be interpreted with caution.

Keywords: Cephalometric analysis; manual tracing; OneCeph; digital tracing; smartphone application.

ORIGINAL ARTICLE

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Introduction

Cephalometric analysis was first introduced in 1931 by Broadbent in the United States and Hofrath in Germany, and has since become an essential tool that is used in orthodontics for diagnosis, treatment planning, and monitoring. 1-3 Over time, the lateral cephalometric radiograph has become a gold standard in orthodontics, because it can give reproducible information about the teeth, as well as skeletal and soft tissue relationships. 4-6

Traditionally, the manual method of cephalometric analysis is done by tracing the relevant anatomical landmarks onto acetate film. Thereafter, the various linear and angular relationships are measured using a ruler and protractor. 1,2,7 This process is, however, time-consuming. Also, the accuracy depends on the skill of the operator, especially in being able to identify the landmarks correctly and consistently every time with minimal variation. Similarly, the same measurement performed by two different operators may give different results due to inter-examiner variability, especially in landmark identification, tracing, and measurement. 8-10

Due to the advancement of digital technology, cephalometric analysis can now be done digitally, either directly on a digital radiograph or by using scanned analogue films. This process typically requires specialized software such as Dolphin Imaging® and WebCeph®. 2,9,11,12 Digital cephalometric analysis significantly improves time efficiency and reproducibility because once the landmarks are identified, all the measurements are obtained automatically. 13-15 Recently, artificial intelligence (AI)-based algorithms have been developed and trained even to identify anatomical landmarks automatically. 16,17 This helps to improve accuracy and reliability. 18,19 In addition, digital cephalometric analysis helps with electronic storage of data, preventing the deterioration of images that can occur over time. 13-15

Despite the many benefits of digital cephalometric analysis, acquiring the required software is often expensive, especially in resource-constrained settings, and there is a need for the necessary computer hardware, which may be bulky. 13,14 To address this problem, smartphone-based applications are now being developed. Such applications enable clinicians to perform cephalometric analysis without needing any special equipment. 6,7

Preliminary studies show that these smartphone-based applications show good reliability and accuracy when compared with conventional manual methods or digital web-based systems. 11,16,19 However, variable results have been obtained for some of the measured linear and angular parameters. Furthermore, how each of these mobile applications performs in clinical settings may be influenced by the particular landmark detection algorithm, as well as the display resolution of the mobile phone being used. As a result, there is a need to independently validate these smartphone-based applications before they can be recommended for clinical use. This study, therefore, aimed to evaluate the reliability of cephalometric measurements obtained with the OneCeph® smartphone application, compared to conventional manual tracing.

Materials and Methods

Study Design and Setting

This was an analytical cross-sectional study conducted at the orthodontic unit of the Department of Child Dental Health, University of Port Harcourt Teaching Hospital. Ethical approval was obtained from the Institution's Health Research and Ethics Committee [Protocol number: UPTH/ADM/90/S.11/VOL.XI/1896]. Following an age-appropriate explanation of the study design and objectives, informed consent was obtained from prospective participants. For children, assent was obtained in addition to informed parental consent.

Sample Size Determination

The minimum sample size for this study was estimated based on the formula proposed by Walter, Eliasziw, and Donner (1998) for reliability studies using the intraclass correlation coefficient (ICC) as the primary outcome measure. 20 Assuming two raters (manual and digital tracing methods), an expected ICC of 0.85 (good reliability), a minimum acceptable ICC of 0.60, a significance level (α) of 0.05, and 80% statistical power (β = 0.20), the required sample size was calculated to be approximately 35 paired radiographs. To improve precision, a total of 40 radiographs were included in this study.

Sample Selection

A total of 40 lateral cephalometric radiographs were selected using convenience sampling from prospective orthodontic patients who had cephalometric radiographs taken between January 2024 and December 2024. Inclusion criteria were: high-quality lateral cephalograms with clear visibility of craniofacial landmarks, as well as the central incisors and first molars, and no history of previous orthodontic or orthognathic treatment. Poor-quality radiographs, those with significant artifacts, or incomplete anatomical structures were excluded.

Manual Cephalometric Tracing

Each selected cephalogram was printed on acetate film and traced manually using acetate paper, a 0.5 mm pencil, and a protractor, by one of the authors (MOO), a Dental Surgeon with training and clinical experience in cephalometric analysis. Before the cephalometric tracings, the examiner was calibrated using randomly selected cephalograms to ensure standardization of landmark identification and measurement procedures. A standardized light box was used for uniform backlighting. The operator was blinded to the digital results at the time of tracing.

Digital Cephalometric Tracing

Each selected cephalogram was printed on acetate film, and high-resolution photographs (300 dpi, 24-bit depth) of the printed cephalograms were obtained using a Samsung Galaxy A14 5G smartphone (Samsung Electronics Co., Ltd., Seoul, South Korea). The smartphone camera was positioned perpendicular to the radiograph at a fixed distance under standardized lighting conditions and without using the zoom feature. The images were subsequently imported into the OneCeph application. Before tracing was performed, each image was calibrated within the OneCeph application using the embedded scale reference. Manual and digital tracings were performed by the same investigator (MOO) to minimize variability in the measurements. The digital software used was OneCeph® (version beta 1.1; NXS Soft Solutions, Hyderabad, India), a freely available Android application designed for digital cephalometric analysis. Anatomical landmarks were identified using the software's point-and-click tool, and all measurements were computed automatically by the software. To minimize bias, digital analyses were done after completion of all manual tracings, and the investigator was blinded to the manual measurements during digital analysis.

Landmarks and Measurements

Measurements of ten cephalometric parameters were done using both manual and digital methods. (Table 1) These included:

Angular: SNA, SNB, ANB, UI to NA (°), LI to NB (°), interincisal angle

Linear: UI to NA (mm), LI to NB (mm), UL to S-line, LL to S-line

All landmarks were identified according to standard cephalometric protocols.5 Measurements obtained using both manual and digital tracings were then compared.

Table 1.The cephalometric landmarks and measurements utilized in this study. [21]

Category	Parameter	Definition
Points	S (Sella)	The midpoint of the cavity of the Sella turcica
	Na (Nasion)	The anterior point of the intersection between the nasal and frontal bones
	Point A:	The innermost point on the contour of the premaxilla between the anterior nasal spine and the incisor tooth
	Point B:	The innermost point on the contour of the mandible between the incisor tooth and the bony chin
Angular	SNA (°)	Angle between the Sella–Nasion line and Nasion–Point A line
	SNB (°)	Angle between the Sella–Nasion line and Nasion–Point B line
	ANB (°)	The difference between SNA and SNB
	UI to NA (°)	The angle between the long axis of the upper incisor and the NA line
	LI to NB (°)	The angle between the long axis of the lower incisor and the NB line
	Interincisal angle (°)	The angle between the long axes of the upper and lower incisors
Linear	UI to NA (mm)	The perpendicular distance from the upper incisor tip to the NA line
	LI to NB (mm)	The perpendicular distance from the lower incisor tip to the NB line
	UL to S-line (mm)	The distance from the upper lip to Steiner's S-line
	LL to S-line (mm)	The distance from the lower lip to Steiner's S-line

Reliability Assessment

Cephalometric analysis using both manual and digital methods was performed over a 14-day period to minimize examiner fatigue, with an average of 3 radiographs analyzed each day. To assess intra-examiner reliability, 10 radiographs were randomly selected and re-traced using both methods after a 2-week interval. Intra-examiner reliability was assessed using the intraclass correlation coefficient (ICC), applying a two-way mixed-effects model with absolute agreement definition. Grading of ICC was done using the model proposed by Koo and Li 22.

Statistical Analysis

Data were entered into a spreadsheet and analyzed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (means, standard deviations) were computed for each parameter. Paired sample t-tests were used to compare the mean differences between manual and digital measurements. Pearson's correlation coefficients were calculated to assess the strength of association between the two methods. A p- value ≤ 0.05 was considered statistically significant.

Results

Sample Characteristics

A total of 40 lateral cephalograms were analyzed in this study. The mean age of the participants was 20.7 ± 7.8 years, with a range from 9 to 42 years. Out of the 40 participants, 24 (60.0%) were females and 16 (40.0%) were males.

Reliability assessments

Reliability estimates for manual and digital tracings are summarized in Table 2. Digital tracings demonstrated good to excellent reliability for skeletal angular parameters such as SNA, SNB and ANB (ICC = 0.83–0.91). Manual tracings showed a similar range (0.71–0.91) but displayed slightly lower consistency for the ANB and SNB angles. In contrast, certain linear dental parameters such as UI–NA (mm) and LI–NB (mm) yielded higher reliability with manual tracings (ICC = 0.94 and 0.83, respectively) compared with the corresponding digital values (ICC = 0.74 and 0.72). For angular dental measurements (UI–NA° and LI–NB°), both techniques showed good reliability, while the interincisal angle displayed excellent agreement (ICC = 0.91) across both methods. Soft tissue parameters (upper and lower lip to the S-line) also demonstrated excellent consistency for both manual and digital tracings (ICC ≥ 0.92).

Although most ICC values suggested good reproducibility, several parameters exhibited wide confidence intervals, particularly for ANB and SNB angles, indicating variability likely related to sample size and operator factors. Overall, both methods yielded comparable levels of measurement reliability, with the manual method showing marginally greater precision for certain linear dimensions.

Correlation Between Manual and Digital Measurements

Descriptive statistics were computed for each of the 10 paired cephalometric parameters assessed manually and digitally. Pearson correlation coefficients showed strong, statistically significant positive correlations ($p < 0.001$) between values obtained from manual tracings compared with those obtained from digital tracing for 9 out of the 10 parameters studied (Table 3). The only exception was UI to NA linear, which showed a weaker correlation ($r = 0.244$, $p = 0.129$).

Comparison of Manual and Digital Cephalometric Measurements

Digital values for SNA, SNB, and UI to NA angle were higher than manual values. A similar trend was observed for both soft tissue parameters (UL to S-Line and LL to S-Line). Statistically significant ($p < 0.05$) differences of the paired samples t-tests were found in six of the ten measured parameters: SNA, SNB, UI to NA angle, LI to NB linear, UL to S-Line, and LL to S-Line. On the other hand, no significant differences were observed between manual and digital values for: ANB, UI to NA linear, LI to NB angle, and Interincisal angle (Table 4).

Table 2. Reliability assessment using the intraclass correlation coefficient (ICC) for both manual and digital cephalometric tracings

Parameter	Manual ICC (95% CI)	Digital ICC (95% CI)
SNA angle, °	0.83 (0.48-0.95)	0.86 (0.57-0.96)
SNB angle, °	0.78 (0.20-0.94)	0.88 (0.20-0.97)
ANB angle, °	0.71 (0.11-0.93)	0.83 (0.41-0.96)
UI – NA, mm	0.94 (0.78-0.98)	0.74 (0.28-0.93)
UI – NA angle, °	0.91 (0.65-0.98)	0.86 (0.55-0.96)
LI – NB, mm	0.83 (0.45-0.96)	0.72 (0.06-0.93)
LI – NB angle, °	0.89 (0.63-0.98)	0.87 (0.59-0.97)
Interincisal angle, °	0.91 (0.65-0.99)	0.91 (0.87-0.99)
Upper lip to S-line, mm	0.95 (0.82-0.99)	0.92 (0.59-0.98)
Lower lip to S-line, mm	0.95 (0.82-0.99)	0.93 (0.82-0.99)

ICC < 0.50: Poor reliability; 0.50 – 0.75: Moderate reliability; 0.75 – 0.90: Good reliability; > 0.90: Excellent reliability

Table 3. Correlation between manual and digital cephalometric measurements

Paired sample (Manual vs Digital)	Correlation coefficient [a]	p-value
SNA	0.913	< 0.001
SNB	0.959	< 0.001
ANB	0.916	< 0.001
UI to NA (Linear)	0.244	0.129
UI to NA (Angular)	0.605	< 0.001
LI to NB (Linear)	0.984	< 0.001
LI to NB (Angular)	0.945	< 0.001
Interincisal Angle	0.953	< 0.001
UL to S-Line	0.916	< 0.001
LL to S-Line	0.946	< 0.001

[a] Pearson correlation coefficient (r > 0 ≤ 0.19, very weak; r ≥ 0.2 ≤ 0.39, weak; r ≥ 0.4 ≤ 0.59, moderate; r ≥ 0.6 ≤ 0.79, strong; r ≥ 0.8 very strong)

Table 4. Paired sample t-test comparison between cephalometric values obtained via manual and digital tracing

Parameter	Manual tracing			Digital (One Ceph) tracing			Mean difference	*p*-value
	Mean	SD	SE	Mean	SD	SE		
SNA angle, °	88.51	5.61	0.89	89.66	5.32	0.84	-1.1450	0.003
SNB angle, °	86.36	5.41	0.86	87.29	4.83	0.76	-.9250	0.001
ANB angle, °	2.19	3.67	0.58	2.24	3.36	0.53	-.0525	0.822
UI – NA, mm	11.82	6.45	1.02	16.92	18.90	2.99	-5.1000	0.088
UI – NA angle, °	26.81	11.57	1.83	31.70	9.63	1.52	-4.8825	0.003
LI – NB, mm	14.42	6.61	1.04	14.95	6.81	1.08	-.5250	0.009
LI – NB angle, °	33.94	8.58	1.36	34.73	8.81	1.39	-.790	0.093
Interincisal angle, °	112.62	8.51	1.34	112.49	8.26	1.31	0.1300	0.751
Upper lip to S-line, mm	10.44	7.65	1.21	11.86	7.36	1.16	-1.4200	0.006
Lower lip to S-line, mm	12.08	7.67	1.21	13.64	7.48	1.18	-1.5650	0.000

SD = Standard deviation, SE = Standard Error of mean

Discussion

In this study, we evaluated the reliability of cephalometric measurements obtained using a mobile-based digital application when compared with those gotten by conventional manual tracing. The level of agreement between methods was assessed using paired sample t-tests, while reproducibility of the digital measurements was assessed using intra-class correlation coefficients (ICCs). Our results show that both digital and manual methods were reliable when used for repeated measurements. Furthermore, the mobile-based digital application gave results that were not significantly different from those obtained by manual tracing in 40% of the measured parameters.

The digital tracing method was reliable for all the assessed parameters, with the reliability ranging from moderate to excellent. This shows that the mobile-application produced consistent measurements when used by the same examiner under standardized conditions. In a previous systematic review, Narkhede et al, reported that digital methods were sufficiently reliable for most cephalometric parameters. 18 Similarly, other authors have shown excellent reliability for both web-based 11 and mobile-based 8 digital cephalometric analysis tools. The digital method was slightly less reliable for some linear measurements of incisal position (UI–NA mm, LI–NB mm), which is similar to the findings of Hassan et al 8, and this may be due to the sensitivity of this landmark to changes in placement position, as well as poor radiographic clarity that may occur in jaws when visualizing structures around the midline. 4,23 AI-based platforms that incorporate automated landmark detection may help reduce this potential source of error, thereby improving reliability. 18 Other authors 9,11,13 have also shown that digital cephalometric analysis gives more reliable and consistent results for angular measurements than for linear ones. Both methods gave excellent reproducibility for soft tissue parameters.

Our results also show strong positive correlations between manual and digital methods for nine of the ten evaluated parameters ($r \geq 0.9$), with the exception being the UI–NA (linear), which showed a weak correlation ($r = 0.244$, $p = 0.129$). However, paired t-test analyses showed that, for some of the skeletal and dental parameters assessed (ANB, LI – NB angular, UI – NA, linear, and interincisal angle), there were no statistically significant differences between the mean values obtained from manual and digital tracing. This suggests that, for these parameters, the two methods yield comparable mean measurements. On the other hand, statistically significant differences were observed in six out of ten (SNA, SNB, UI to NA, angular, LI to NB (linear), UL to S-Line, and LL to S-Line) cephalometric parameters when comparing the mean values obtained using manual and digital methods. This indicates that the agreement between manual and digital techniques may vary depending on the specific cephalometric parameter being evaluated. Our findings contrast with those of Kunz et al, who did not find any difference between cephalometric analysis done by humans and that done using artificial intelligence algorithms. 24 The differences observed may be because, in the current study, landmark identification was done manually. AI-based algorithms for automated landmark identification may be less error-prone, as their accuracy has been shown to approach 98%. 25

Some angular measurements (SNA and SNB), as well as the soft tissue measurements (UL to S-Line and LL to S-Line), showed higher values in results obtained using digital analysis. A similar pattern was seen in some previous studies 6,7, and may be the result of subtle variations in landmark identification, method of manual tracing, or placement of the protractor during measurements. 23 Since digital cephalometric images can be enhanced (e.g., by adjusting the brightness/contrast or by being able to zoom in and out), this may improve the ability to visualise subtle anatomical landmarks. 18 This increased precision may explain the slightly higher angular measurements for SNA and SNB when using digital tools. The significant differences observed in the upper and lower lip to S-line measurements suggest that soft-tissue landmarks may be less consistently identified when using digital tools, probably because of their lower contrast on radiographs. 4

In this study, only one examiner performed all the cephalometric tracings and analyses. Although this was deliberate, to avoid inter-examiner variability, this may limit the generalizability of our findings. Further studies with a larger sample size may be useful in validating the findings to this study or adding to the body of evidence.

Conclusion

Although our findings highlight the potential of smartphone-based digital cephalometric analysis in resource-limited settings, we cannot conclude about the ability of the mobile-based digital application assessed in this study to serve as a substitute for the manual method. Instead, the findings of this study show that while the digital application gives reproducible results, agreement with manual tracing may vary depending on the specific parameter being measured. Thus, the results obtained with such applications should be interpreted with caution.

Conflict of interest

The authors declare that they have no conflict of interest

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Authors' contributions

SSE conceptualized the study, MOO did all the cephalometric tracings, EVO did the data analysis, MOO and EVO wrote the initial draft of the manuscript. All authors reviewed the final draft of the manuscript.

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