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COMPARATIVE EVALUATION OF MANUAL AND FACAD DIGITAL CEPHALOMETRIC TRACING: AN ASSESSMENT OF AGREEMENT AND RELIABILITY

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AIM

To evaluate the agreement and Reliability between manual and FACAD digital cephalometric tracing methods.

INTRODUCTION

Since the introduction of cephalometrics by Broadbent in 1931, it has been vital in orthodontic diagnosis and treatment planning, as well as in monitoring treatment and growth changes.[2] Traditionally, cephalometric analysis has been performed by tracing radiographic landmarks on acetate overlays and measuring linear and angular variables. However, despite its widespread use in orthodontics, the technique is time-consuming and has several drawbacks, including a high risk of error in tracing, landmark identification, and measurement (Baumrind and Frantz, 1971b; Sandler, 1988). Cephalometric errors can be divided into those related to acquisition, identification, and technical measurement. Reproducibility of measurements by the operator is also a significant factor in determining the accuracy of any method of analysis. Recently, technological advances have made it possible to perform cephalometric tracing using computers. The use of computers in treatment planning is not only expected to decrease the incidence of individual error but also to provide standardized, fast, and accurate evaluation with a high rate of reproducibility.[5] Continuous technological advances in computing combined with scientific advances in dental radiology, resulted in the development of computer programs designed to perform cephalometric tracings and measurements, and different types of analysis.[6]

A substantial number of programs are available in the domestic and international market offering a wide array of features and variable prices.[15] They have been widely used in orthodontics, especially for storing documentation and facilitating cephalometric tracings.[18] It is undeniable that Orthodontics has benefited more than any other dental specialty from computerization in structuring and developing its activities while incorporating computer resources to acquire and use information quickly and efficiently.[21] But given the constant refinement of both software and hardware, it is important for professionals to update their knowledge on an ongoing basis, since computer updates and upgrades are incontestable.[6]

A comparative study between the manual and computerized cephalometric measurement methods was performed by Richardson14 in 1981. He compared 50 lateral cranial radiographs of 12-year-old children, half male and half female. Fourteen landmarks were defined in that study: S, N, anterior nasal spine, subspinal, incisal and zenith of the maxillary incisor, incisal and zenith of the maxillary incisor, supramenton, pogonion, gnathion, molar, pterygomaxillary and articulare. The conclusion was that traditional methods were inferior in comparison to digital procedures, but not alarmingly so, and in some cases, traditional methods produced more precise results.[8]

Many offices worldwide have not yet switched to the use of direct digital cephalographs; therefore, the digitization process of conventional films is the only option if the benefits of digital cephalometric analysis are to be anticipated. Various studies have been conducted to

compare the accuracy of digitized, scanned and digitally obtained radiographs with conventional methods.[7] Few of them have compared angular and linear measurements, mostly because the analysis of the reproducibility of lines and angles is more challenging in relation to multiple sources of error than landmark studies. However, results of comparisons of digitizing methods with conventional radiographs are contradictory, probably because of the variety in the methods of obtaining digital images and the use of different cephalometric softwares.[12] Therefore, the aim of this investigation was to evaluate the agreement and reliability of computerized tracing of direct digital radiographs using FACAD and hand tracing of digital radiographic printouts, and to compare the two methods in terms of accuracy.

MATERIALS AND METHODS

The study was conducted on pre-treatment cephalometric radiographs of 30 patients collected from the archives of the outpatient clinic of the orthodontics department, PDU dental College, Solapur.

All participants were positioned in the cephalostat with the sagittal plane at a right angle to the path of the X-rays, the Frankfort plane parallel to the floor, the teeth in centric occlusion and the lips sealed lightly together. The conventional and digital tracings, as well as all the measurements were performed by the third investigator who was an experienced orthodontist with many years of cephalometric experience. Manual tracing was performed on fine-grain 0.003 inch transparent acetate papers using a 0.3 mm lead pencil (Fig B). The tracing process was performed in a dark room using a screen viewing box. The selected landmarks were traced with bilateral structures averaged to make a single structure or landmark. The digital images were stored in a computer database with the manufacturer's software and imported to the FACAD 3.12.1.1653 software program (Fig A). Before digitization of the landmarks with FACAD 3.12.1.1653, the films were calibrated by digitizing two points on the ruler within the digital cassette. All measurements were carried out manually and digitally and entered into an Excel spreadsheet for statistical evaluation. Total 15 angular and 5 linear measurement were performed and recorded in excel sheet.

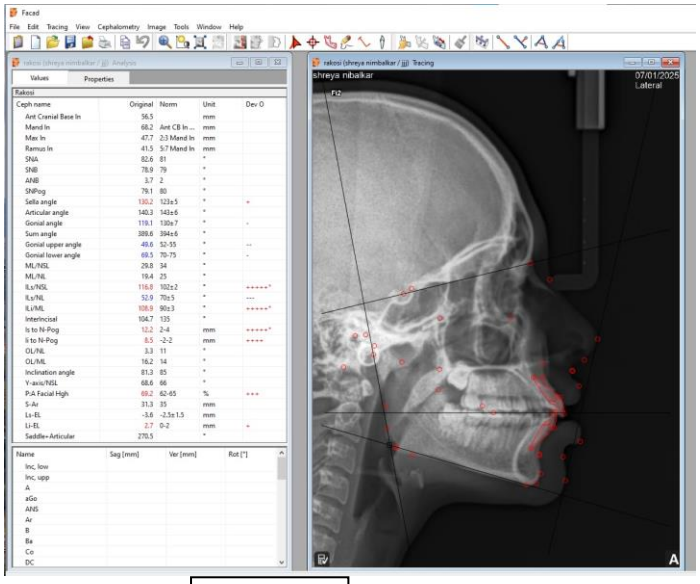

Figure A

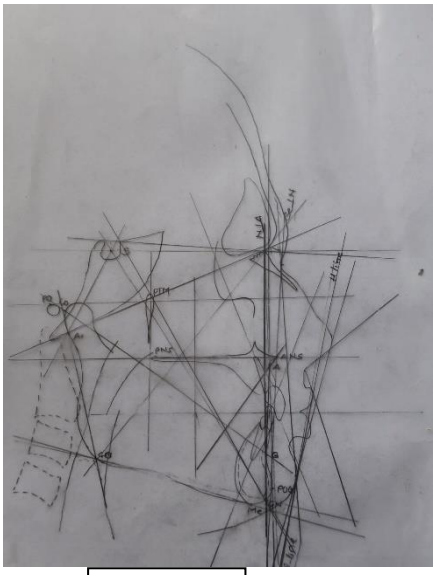

Figure B

Method of Statistical Analysis

Data obtained from manual and FACAD cephalometric tracings were entered and organized in Microsoft Excel (v.2019). Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) software (IBM Corp.) (v.26.0). Both descriptive and inferential statistical analyses were carried out for the angular and linear cephalometric parameters assessed in the study.

Descriptive statistics included calculation of mean, standard deviation, minimum, and maximum values for all cephalometric measurements obtained from manual and FACAD tracings. Data normality was assessed using the Kolmogorov–Smirnov test and Shapiro–Wilk test. Since the data followed a normal distribution, parametric statistical tests were applied. Inter-method comparison of continuous variables (angular and linear cephalometric measurements) between manual and FACAD tracings was performed using the paired t-test, as the measurements were obtained from the same subjects.

Reliability and agreement between manual and FACAD tracing methods were assessed using the Intraclass Correlation Coefficient (ICC) with a two-way mixed-effects model and absolute agreement definition, along with 95% confidence intervals. Correlation analysis

between manual and FACAD measurements for each cephalometric parameter was performed using Pearson's correlation coefficient, and scatter plots with regression lines were generated. All statistical tests were performed at a 95% confidence interval. A p-value of less than 0.05 was considered statistically significant, and $p < 0.001$ was considered highly statistically significant in the study.

RESULTS

Table 1: Comparison between the Angular Cephalometric Measurements obtained from Manual and FACAD tracings.

Variables	Manual tracing (Mean ± SD)	FACAD tracing (Mean ± SD)	Mean Difference	p-value
SNA	84.20 ± 5.27	83.86 ± 5.19	0.34	0.06*
SNB	80.52 ± 5.14	80.63 ± 5.14	-0.12	0.54*
SN-GOGN	23.50 ± 8.77	23.33 ± 8.71	0.17	0.07*
FH-GOME	22.22 ± 6.89	21.90 ± 6.74	0.32	0.09*
FMA	22.20 ± 6.86	22.03 ± 6.77	0.17	0.07*
SN-Occlusal	12.78 ± 6.21	12.30 ± 5.62	0.48	0.18*
Saddle	122.23 ± 4.67	119.09 ± 19.76	3.14	0.35*
Articular	138.46 ± 24.97	183.96 ± 25.27	-45.51	0.32*
Gonial	120.62 ± 7.70	120.49 ± 7.52	0.13	0.17*
U1-FH	116.12 ± 21.01	116.00 ± 20.95	0.12	0.33*
U1-SN	115.46 ± 12.00	114.41 ± 13.46	1.05	0.29*
U1-NA	28.94 ± 10.17	28.61 ± 10.13	0.34	0.10*
L1-NB	26.42 ± 10.71	26.13 ± 10.57	0.29	0.06*
L1-MP	99.53 ± 10.75	99.47 ± 10.29	0.06	0.75*
II Angle	120.47 ± 16.40	120.13 ± 16.29	0.35	0.07*

Paired t test SD: Standard Deviation *p value >0.05 statistically not significant

A paired t-test was applied to compare the angular cephalometric measurements obtained from manual and FACAD tracings. The results demonstrated no statistically significant difference between manual and FACAD measurements for all angular parameters ($p > 0.05$). The mean differences between the two methods were minimal across variables, indicating comparable measurement values. (**Table 1)**

Table 2: Comparison between the Linear Cephalometric Measurements obtained from Manual and FACAD tracings.

Variables	Manual tracing (Mean ± SD)	FACAD tracing (Mean ± SD)	Mean Difference	p-value
U1–NA (mm)	4.02 ± 2.57	3.63 ± 2.50	0.38	0.18*
L1–NB (mm)	3.55 ± 2.97	3.61 ± 2.80	-0.06	0.75*
AO–BO (mm)	2.58 ± 1.82	2.76 ± 1.97	-0.18	0.47*
U1–APOG (mm)	4.42 ± 3.35	3.91 ± 2.91	0.51	0.11*
L1–APOG (mm)	2.09 ± 3.77	1.91 ± 4.03	0.19	0.59*

Paired t test SD: Standard Deviation *p value >0.05 statistically not significant

A paired t-test was used to compare the linear cephalometric measurements obtained from manual and FACAD tracings. The analysis revealed no statistically significant difference between the two methods for any of the linear parameters ($p > 0.05$). Overall, these findings indicate that FACAD digital tracing produces linear cephalometric measurements comparable to manual tracing, with no significant systematic variation between the two methods. **(Table 2)**

Table 3: Reliability Analysis of Angular Cephalometric Measurements Between Manual and FACAD Tracing using Intraclass Correlation Coefficient.

Variables	ICC	95% CI	p-value	Strength of Agreement
SNA	0.99	0.97 – 0.99	<0.001	Excellent
SNB	0.98	0.95 – 0.99	<0.001	Excellent
SN-GOGN	0.99	0.97 – 0.99	<0.001	Excellent
FH-GOME	0.99	0.98 – 0.99	<0.001	Excellent
FMA	0.99	0.97 – 0.99	<0.001	Excellent
SN-Occlusal	0.94	0.89 – 0.97	<0.001	Excellent
Saddle	0.85	0.74 – 0.90	<0.001	Good
Articular	0.87	0.64 – 0.90	<0.001	Good
Gonial	0.99	0.97 – 0.99	<0.001	Excellent

U1-FH	1.00	0.99 – 1.00	<0.001	Excellent
U1-SN	0.91	0.82 – 0.95	<0.001	Excellent
U1-NA	0.99	0.97 – 0.99	<0.001	Excellent
L1-NB	0.99	0.96 – 0.99	<0.001	Excellent
L1-MP	0.99	0.97 – 0.99	<0.001	Excellent
II Angle	0.99	0.97 – 0.99	<0.001	Excellent

ICC: Intraclass Correlation Coefficient; CI: Confidence Interval

Intraclass Correlation Coefficient (ICC) analysis using a two-way mixed-effects model with absolute agreement was performed to assess the reliability between manual and FACAD angular cephalometric measurements.

The results demonstrated excellent reliability for the majority of angular parameters, with ICC values ranging from 0.91 to 1.00 ($p < 0.001$). Parameters such as SNA, SNB, SN-GoGn, FH-GoMe, FMA, Gonial angle, U1-FH, U1-NA, L1-NB, L1-MP, and II Angle showed ICC values ≥ 0.99, indicating near-perfect agreement between manual and digital methods.SN-Occlusal (ICC = 0.94) and U1-SN (ICC = 0.91) also demonstrated excellent reliability. Saddle (ICC = 0.85) and Articular angles (ICC = 0.87) showed good agreement, though comparatively lower than other parameters.

Overall, the findings indicate a high degree of reliability and strong agreement between manual and FACAD tracings for angular cephalometric measurements. **(Table 3)**

Table 4: Reliability Analysis of Linear Cephalometric Measurements Between Manual and FACAD Tracing using Intraclass Correlation Coefficient.

Parameter	ICC	95% CI	p-value	Strength of Agreement
U1–NA (mm)	0.81	0.64 – 0.90	<0.001	Good
L1–NB (mm)	0.94	0.88 – 0.97	<0.001	Excellent
AO–BO (mm)	0.75	0.55 – 0.87	<0.001	Good
U1–APOG (mm)	0.93	0.84 – 0.97	<0.001	Excellent
L1–APOG (mm)	0.88	0.76 – 0.94	<0.001	Good

ICC: Intraclass Correlation Coefficient; CI: Confidence Interval

Reliability between manual and FACAD linear cephalometric measurements was assessed using the Intraclass Correlation Coefficient (ICC) with a two-way mixed-effects model and absolute agreement.

The results demonstrated good to excellent reliability across all linear parameters ($p < 0.001$). L1–NB (ICC = 0.94) and U1–APOG (ICC = 0.93) showed excellent agreement between the two tracing methods. U1–NA (ICC = 0.81), AO–BO (ICC = 0.75), and L1–APOG (ICC = 0.88) demonstrated good reliability.

Overall, these findings indicate that FACAD tracing provides linear cephalometric measurements that are highly reliable and comparable to manual tracing. **(Table 4)**Figure 1 to Figure 20 illustrate the scatter plot showing the correlation between the various cephalometric parameters assessed using manual and FACAD tracing, majority showing excellent correlation.

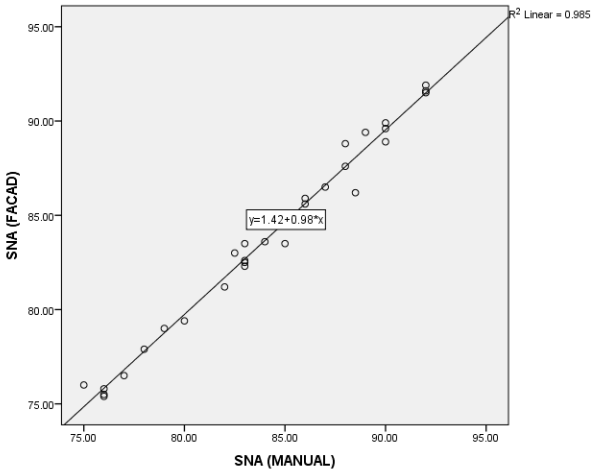

Figure 1: Correlation Analysis of SNA Measurements Obtained by Manual and FACAD Cephalometric Tracing.

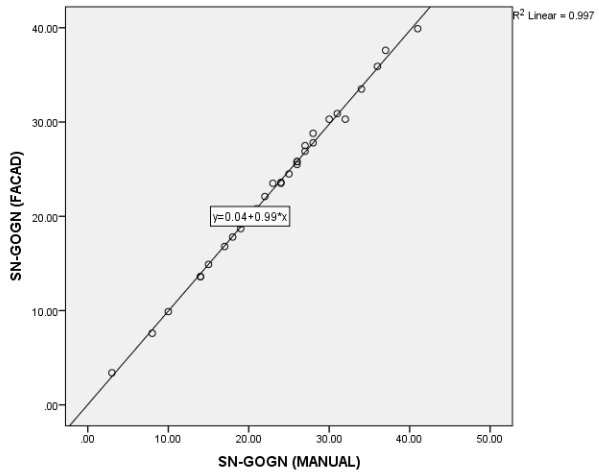

Figure 2: Correlation Analysis of SNB Measurements Obtained by Manual and FACAD Cephalometric Tracing.

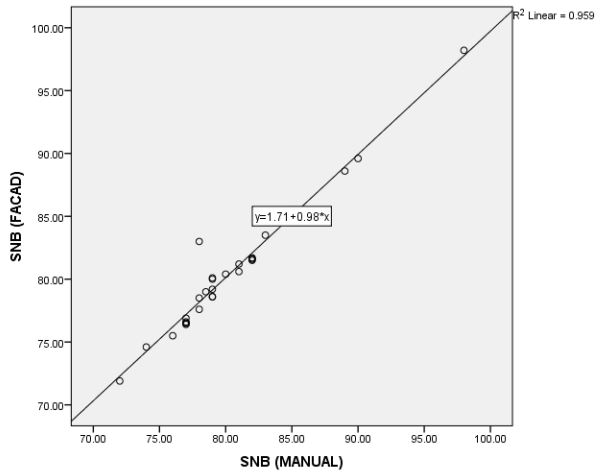

Figure 3: Correlation Analysis of SN-GOGN Measurements Obtained by Manual and FACAD Cephalometric Tracing.

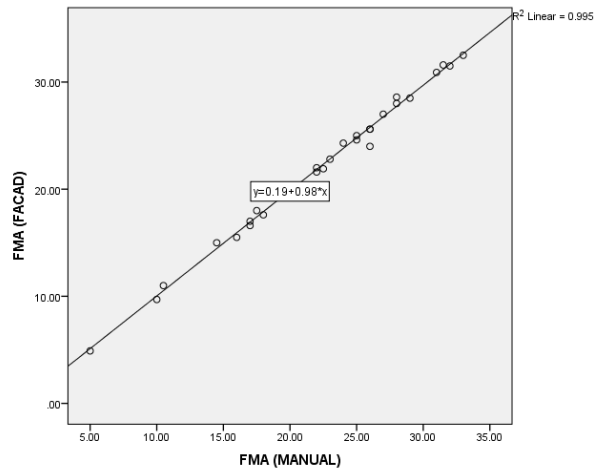

Figure 4: Correlation Analysis of FH-GOME Measurements Obtained by Manual and FACAD Cephalometric Tracing.

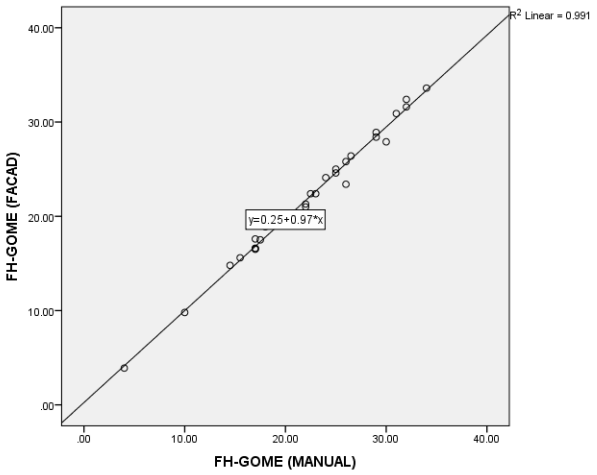

Figure 5: Correlation Analysis of FMA Measurements Obtained by Manual and FACAD Cephalometric Tracing.

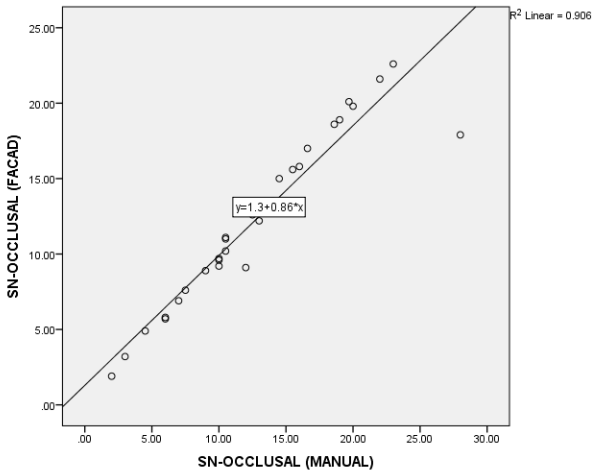

Figure 6: Correlation Analysis of SN-OCCLUSAL Measurements Obtained by Manual and FACAD Cephalometric Tracing.

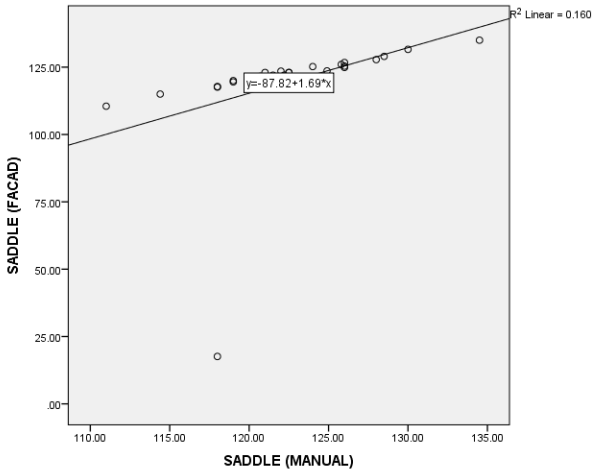

Figure 7: Correlation Analysis of SADDLE Measurements Obtained by Manual and FACAD Cephalometric Tracing.

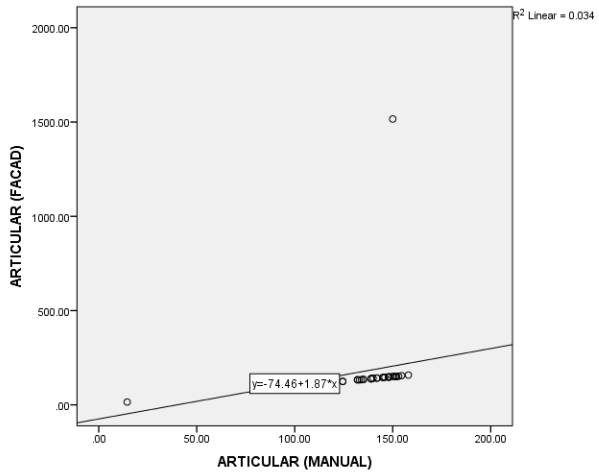

Figure 8: Correlation Analysis of ARTICULAR Measurements Obtained by Manual and FACAD Cephalometric Tracing.

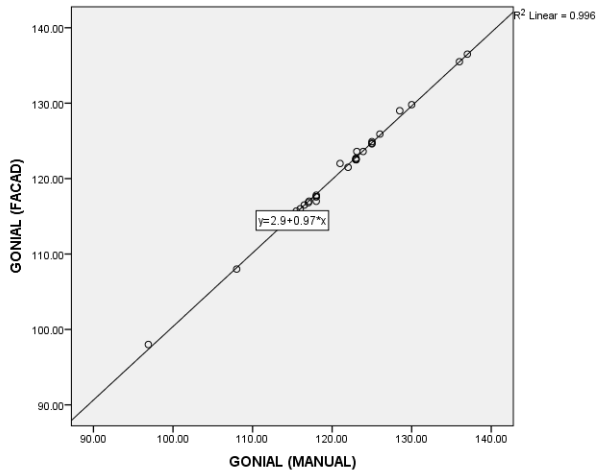

Figure 9: Correlation Analysis of GONIAL Measurements Obtained by Manual and FACAD Cephalometric Tracing.

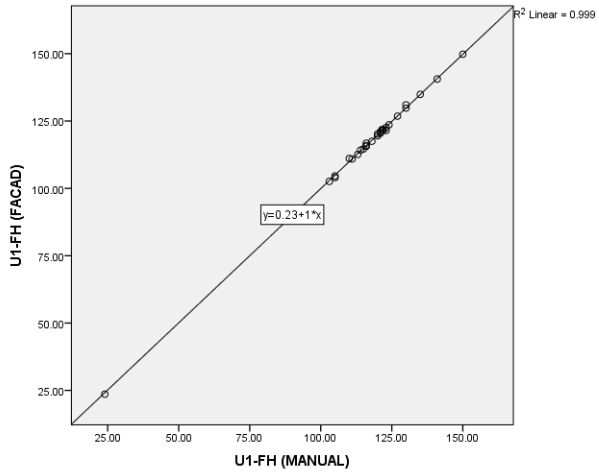

Figure 10: Correlation Analysis of U1-FH Measurements Obtained by Manual and FACAD Cephalometric Tracing.

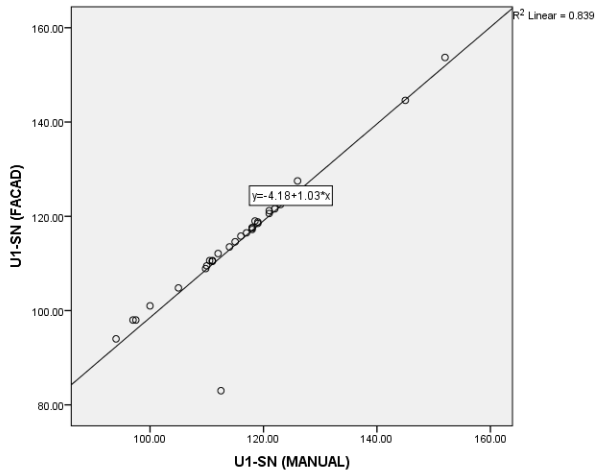

Figure 11: Correlation Analysis of U1-SN Measurements Obtained by Manual and FACAD Cephalometric Tracing.

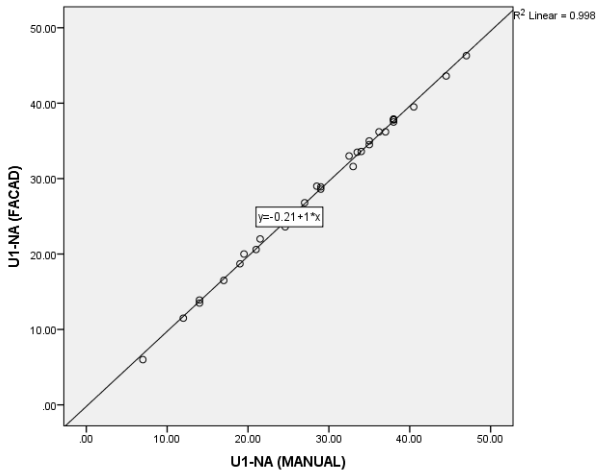

Figure 12: Correlation Analysis of U1-NA Measurements Obtained by Manual and FACAD Cephalometric Tracing.

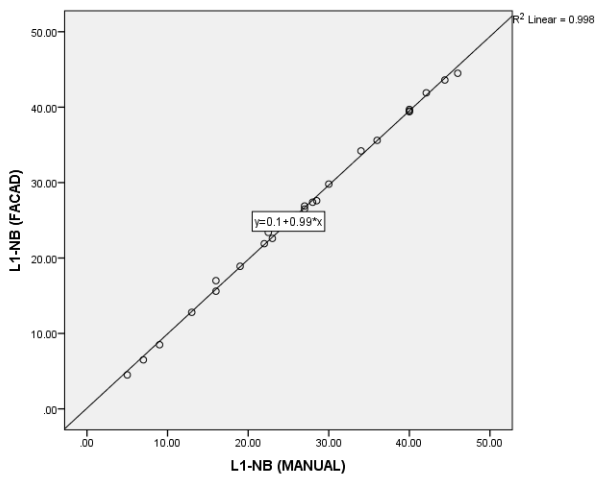

Figure 13: Correlation Analysis of L1-NB Measurements Obtained by Manual and FACAD Cephalometric Tracing.

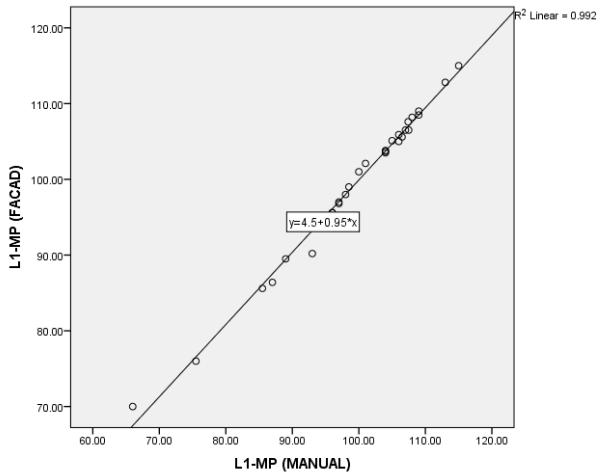

Figure 14: Correlation Analysis of L1-MP Measurements Obtained by Manual and FACAD Cephalometric Tracing.

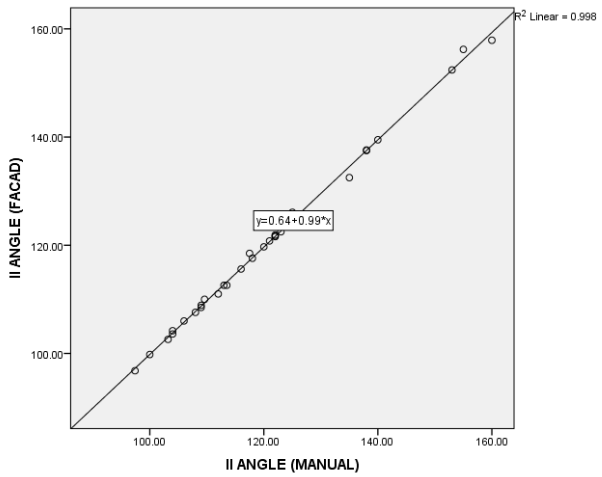

Figure 15: Correlation Analysis of II ANGLE Measurements Obtained by Manual and FACAD Cephalometric Tracing.

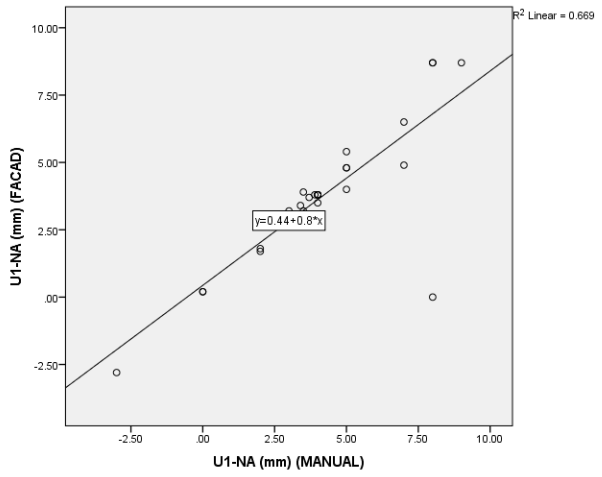

Figure 16: Correlation Analysis of U1-NA (mm) Measurements Obtained by Manual and FACAD Cephalometric Tracing.

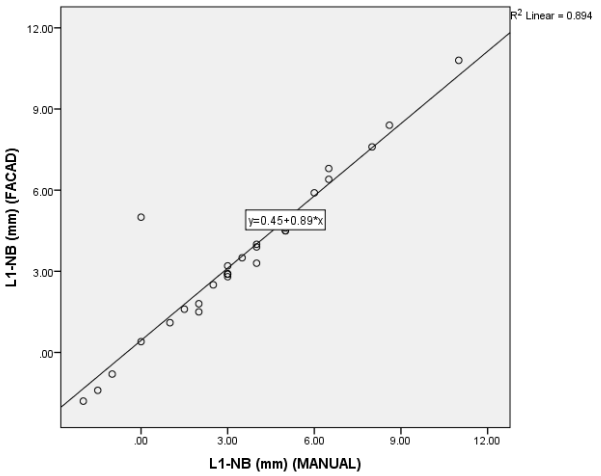

Figure 17: Correlation Analysis of L1-NB (mm) Measurements Obtained by Manual and FACAD Cephalometric Tracing.

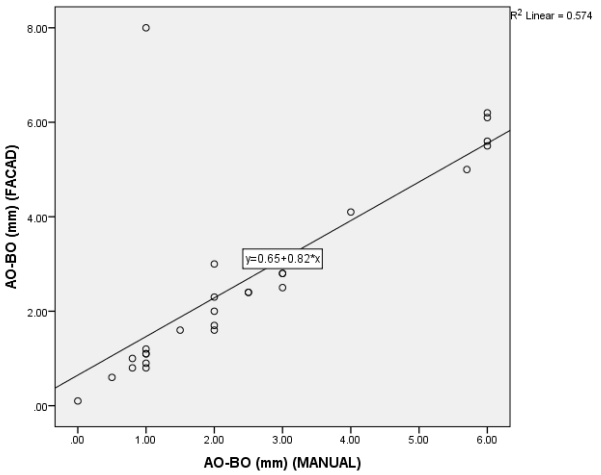

Figure 18: Correlation Analysis of AO-BO (mm) Measurements Obtained by Manual and FACAD Cephalometric Tracing.

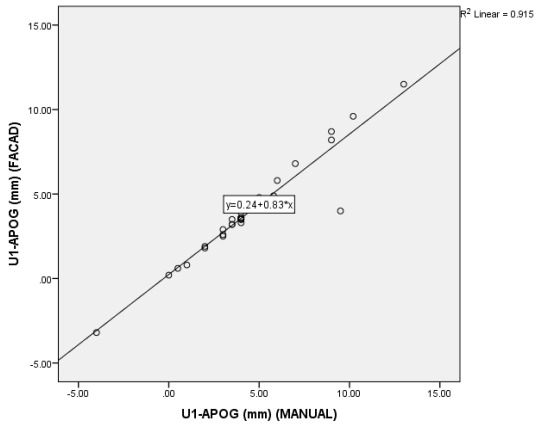

Figure 19: Correlation Analysis of U1-APOG (mm) Measurements Obtained by Manual and FACAD Cephalometric Tracing.

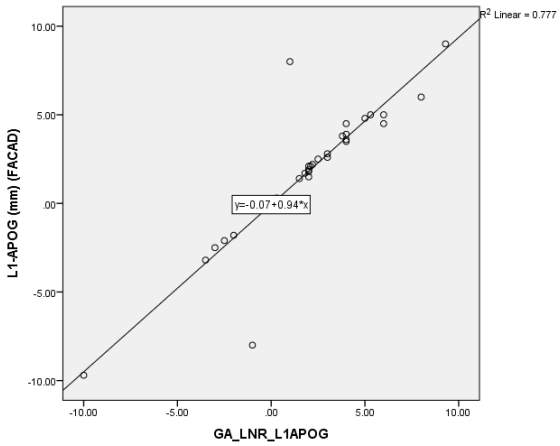

Figure 20: Correlation Analysis of L1-APOG (mm) Measurements Obtained by Manual and FACAD Cephalometric Tracing.

DISCUSSION

Cephalograms have been used widely, both as clinical tool and as a research technique for the study of craniofacial growth and orthodontic treatment. Precision and reproducibility in data obtained from cephalometrics is important for the orthodontist. But there are some errors arises from landmark identification and measurments; To overcome the errors of conventional radiography, digital cephalometry, which allowed the operator to manipulate data on the computer thereby facilitating the complex analysis and organization became popular. Hence, this study was conducted with an aim of comparing the digital and conventional tracing methods. Furthermore, reliability and accuracy of linear and angular cephalometric measurements obtained from indigenously developed computerized cephalometric software FACAD was compared with manual tracing.

The skeletal, dental, and soft tissue parameters used in this study were commonly used cephalometric variables for orthodontic diagnosis, treatment planning, and evaluation of treatment results shown in table 1 and table 2. In addition, the parameters used included all the areas of the cephalogram for a more meaningful and reliable comparison between digital and manual tracing techniques given in table 3.

Grybauskas et al., stated that measurements obtained from digital tracing and manual tracing were shown to have adequate reproducibility.[17] These findings coincide with the present study result. In this study, the analysis of the results obtained comparing the cephalometric measurements in digital and manual tracings revealed values that were close to the means and standard deviations supporting those of Chen et al., Correia et al., and Vasconcelos et al., results.[19] Prabhakar et al., provides support for computerized tracing method as these are easier and less time consuming with same reliability.[22] In a recent study conducted by Hardik et al., concluded that digital tracing with FACAD software is similar to manual cephalometric tracings and sufficient for clinical purposes.[24] However, this study has few drawbacks, as in the present study there was a slight difficulty in identifying some anatomical structures differently when projected on screen, even if they could be repeated consistently in each method.

Albuquerque-Júnior and Almei da and Chen et al argue that the computerized method is reliable as it exhibits lower error variance than the conventional method. Nonetheless, since no significant differences were found in this study, the authors consider the digital method sufficiently reliable for use in Orthodontics.

Assessment of the linear and angular values obtained in digital and manual tracings (Table 1 and table 2) showed that this comparison did not yield statically significant differences. Collins et al7 found statistically significant differences in linear measurements but these authors compared the Dolphin measurements of scanned and photographed images and found linear distortions in the latter.

The results shows excellent reliability for the majority of angular parameters, with ICC values ranging from 0.91 to 1.00 ($p < 0.001$). Parameters such as SNA, SNB, SN-GoGn, FH-GoMe, FMA, Gonial angle, U1-FH, U1-NA, L1-NB, L1-MP, and II Angle showed ICC values ≥ 0.99, indicating near-perfect agreement between manual and digital methods.SN-Occlusal (ICC = 0.94) and U1-SN (ICC = 0.91) also demonstrated excellent reliability. Saddle (ICC = 0.85) and Articular angles (ICC = 0.87) showed good agreement, though comparatively lower than other parameters. The results demonstrated good to excellent reliability across all linear parameters ($p < 0.001$). L1–NB (ICC = 0.94) and U1–APOG (ICC = 0.93) showed excellent agreement between the two tracing methods. U1–NA (ICC = 0.81), AO–BO (ICC = 0.75), and L1–APOG (ICC = 0.88) demonstrated good reliability.

Overall, these findings indicate that FACAD tracing provides angular and linear cephalometric measurements that are highly reliable and comparable to manual tracing.

CONCLUSION

The findings indicate a high degree of reliability and strong agreement between manual and FACAD tracings for angular cephalometric measurements while good to excellent reliability across all linear parameters showed excellent agreement between the two tracing methods.

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