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Evaluation of Reliability and Validity of Linear and Angular Parameters via Analog and Digital Methods: A Lateral Cephalometric Analysis

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Abstract

Aim: The study aimed at determining the variability of landmark identifications and its reproducibility by manual and digital methods of cephalometric tracing.
Methods: Pre-treatment cephalograms of sixty subjects recommended for orthodontic treatment were taken in the natural head position with the teeth in maximum intercuspation and were traced by a single operator. Statistical analysis was performed, and the mean, standard deviations, and coefficients of variation were calculated for each parameter and imaging modality. For all the variables, the Shapiro-Wilk's test for normality was conducted to identify the distribution of each variable. The Wilcoxon signed rank test was used where distribution was non-normal for at least one of the comparing variables and the repeated sample t-test was used where normal distribution was detected for both the variables.
Results: For digital tracing, the coefficients of variation were less than 1, suggesting high reliability. For most manually traced images, the landmarks with high coefficients of variation were Porion, Basion, Sella, Point B, and Gonion. Coefficients of variation were invariably higher for the manual method than the digital method, implying readings were more consistent in the digital method for the above landmarks under observation. Out of the 29 parameters, the mean difference of sixteen of them was calculated to be statistically significant with each other, which shows that the digital method of cephalometric tracing can be relied upon for the reliability.
Conclusion: The digital method of landmark identification gives a more consistent reading.

Keywords: Digital tracing, Lateral cephalograms, Manual tracing.

1. Background

Cephalometric radiography is a vital clinical tool in orthodontics to evaluate the craniofacial complex, determine morphology and growth, diagnose anomalies, forecast relationships, plan treatment modalities, and evaluate the results of growth and the effects of treatment (1,2). On the other hand, hand-traced cephalometric analysis on traditional radiographic film has been the gold standard for many years to analyze cephalometric radiographs and collect cephalometric values, but manual tracing is time-consuming, and the risk of human error is high.

With the advent of the computer age and today's ever-changing technological environment new methods have been emerged for obtaining radiographic images. Proponents of digitally acquired cephalometric imaging cite numerous advantages, including the immediate availability of the image, elimination of the chemical darkroom process, reduced radiation dose, improved landmark identification through image enhancement techniques, faster cephalometric data acquisition and analysis, more efficient storage and archiving, more effortless transfer of the image to distant sites, and easy and cost-efficient duplication of radiographs. Furthermore, three-dimensional imaging of dentofacial records in orthodontics is quickly developing as a practical diagnostic tool. Hence, digital images of the lateral and frontal cephalograms are integral to this promising technology.

Reproducibility of measurements is a prerequisite for determining the accuracy of any analysis method. Several studies (3,4,5,6) have been undertaken to compare the accuracy of measurements of scanned, digitized, and digitally obtained radiographs with traditional analog radiographs; however, no clear consensus can be arrived.

Therefore, the present study was carried out to determine landmark identification variations by two cephalometric systems, i.e., conventional by manual tracing and digital by digitization using the Nemoceph software, and to investigate the validity and reproducibility of angular and linear measurements by the above two methods.

2. Methods

The study consisted of 60 subjects (30 males, 30 females) aged 18-25 years who came to the dental OPD for orthodontic treatment to correct mild crowding. Prior written consent was taken from all the participants, and they were subjected to the conventional cephalogram and the digital cephalogram in the natural head position with the teeth in maximum intercuspation. The following were the selection criteria:

1. Patients who had not undergone orthodontic treatment previously
2. Patients with ideal Angle's class I molar relation, minimal crowding, absence of crossbite, and minimal spacing
3. Adult patients with no anticipated growth remaining

Two lateral cephalograms (one conventional and one digital) were taken of each individual. Digital cephalograms were taken with the state-of-the-art Planmeca cephalostat using the software Promax, and conventional cephalograms were taken with an AMS cephalostat. Calibration was done for both types of cephalograms. For the conventional method, a 10 mm stainless steel wire was placed within the field of radiographic exposure, the image of which could be projected on the conventional cephalogram. The image of the wire was used to calibrate the image. For the digital method, a measurement scale was incorporated into the cephalostat (Fig. 1). Both types of cephalograms were taken in the natural head position (7), which is defined as the head orientation of the subject perceived by the clinician, in a standing, relaxed body and head posture, when the subject is looking at a distant point at eye level or into his own eyes in a mirror.

The whole cephalometric data was isolated for tracings. Ten cephalometric landmarks were identified along with the six linear and five angular

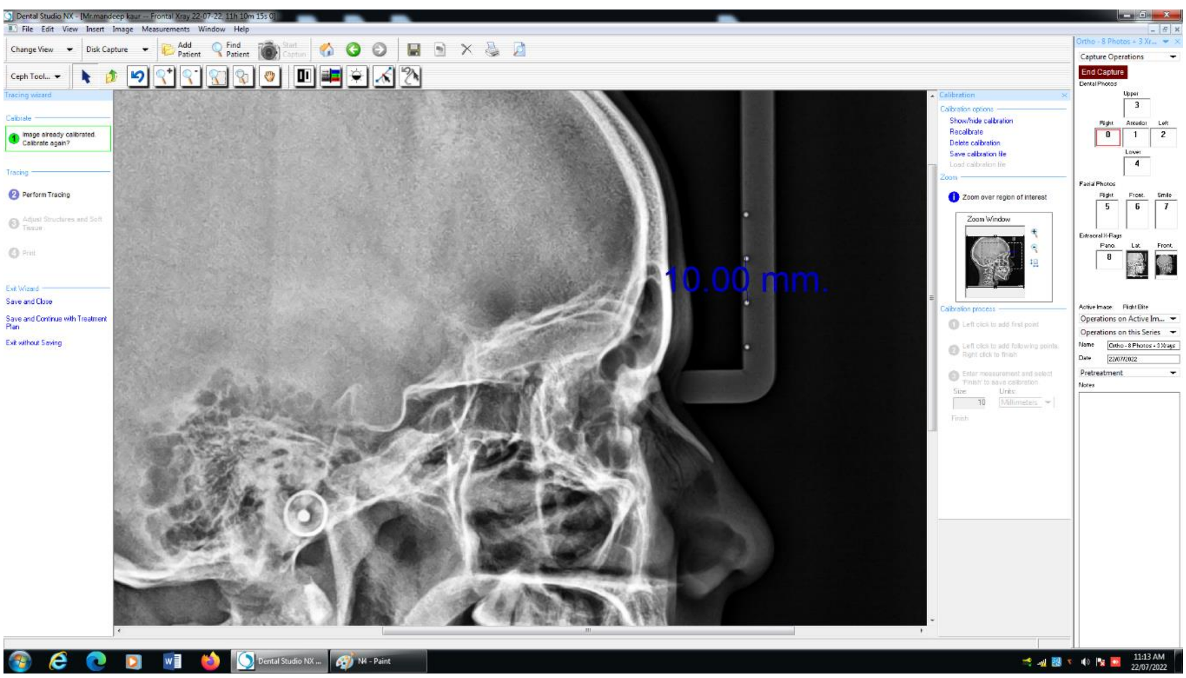

Figure 1. Calibration tool for calibrating the digital image

measurements by manual tracing and from digitized images on the monitor using the Nemoceph software. These 10 landmarks were used to calculate the 11 variables. A single operator performed all the measurements using both methods to reduce operator variability.

For manual tracing, Landmark identification was performed on a view box using matte acetate paper and a 0.3 mm [4H] graphite pencil under dim light conditions. The measurements were made using a cephalometric protractor for angular measurements and a millimeter ruler for linear measurements to the nearest 0.5 mm. The position of the identified landmarks was recorded in the X and Y coordinates format. The origin of X and Y coordinates were oriented with the Y-axis constructed vertically along the wire fixed to the cephalostat, and the X-axis was drawn perpendicular to the Y-axis.

For digital tracing (Fig. 2), Landmark identification was performed on a high-resolution monitor displaying images with a mouse-controlled cursor connected with the computerized imaging and cephalometric analysis (Nemoceph). After recording a landmark with the mouse, a dot on the monitor–displayed image indicated its position in the form of X and Y coordinates.

The various cephalometric landmarks (Fig. 3) used in the study were as follows:

Point A: Deepest point of the curve of the maxilla, between the anterior nasal spine (ANS) and the dental alveolus

Anterior Nasal Spine (ANS): The tip of the anterior nasal spine

Point B: Most posterior point in the concavity along the anterior border of the symphysis

Basion (Ba): Most inferior posterior point of the occipital bone at the anterior margin of the occipital foramen

Gonion (Go): The most convex point where the posterior and inferior curves of the ramus meet

Menton (Me): Most inferior point of the symphysis

Nasion (Na): Intersection of the internasal suture with the nasofrontal suture in the midsagittal plane

Pogonion (Pog): Most anterior point on the mid-sagittal symphysis

Porion (Po): Highest point of the ear canal; most superior point of the external auditory meatus

Sella (S): Center of the pituitary fossa of the sphenoid bone

The various angular measurements under consideration in the study were the SNA, SNB, ANB, IMPA, and the upper central incisor to the SN, and facial angle. The various linear measurements under consideration in the study were as follows:

Mandibular length (Co to Gn)

Midfacial length (Co to Point A)

Maxillomandibular difference

Lower anterior facial height (ANS to Me)

Lower incisor to point A

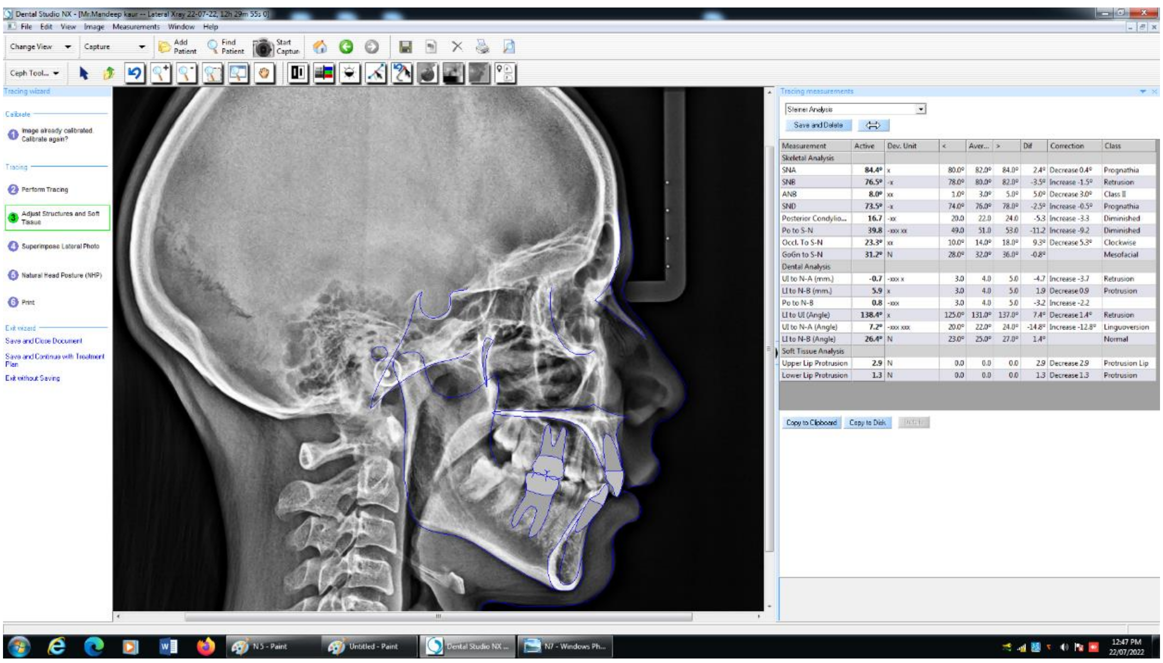

Figure 2. Tracing done using Nemoceph software

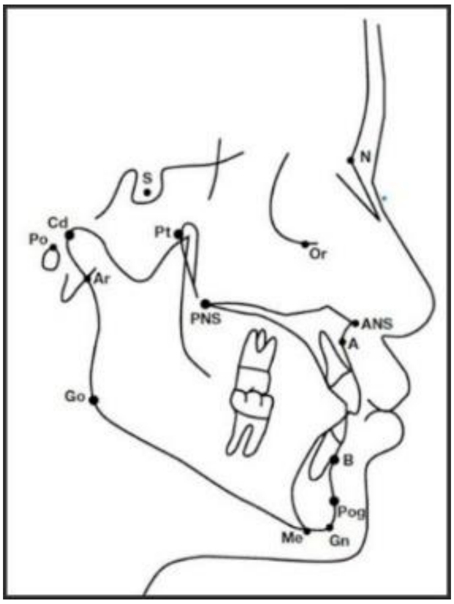

Figure 3. Various cephalometric landmarks used in the study

Data Analysis

For data analysis, cephalograms of one subject were chosen at random. The conventional and digital cephalograms were traced ten times on separate days to verify the validity and reliabilty of angular and linear measurements. The landmark identification error was estimated by comparing the coefficient of variation of the readings obtained by the digital and analog methods. After that, all the cephalograms were traced by both digital and conventional methods.

Statistical analysis

Statistical analysis was applied to check the reliability of parameters assessed through the two methods and the mean, standard deviation, and the coefficients of variation were calculated for each parameter and each imaging modality.

For all the variables, the test of normality (Shapiro-Wilk's test) was conducted to identify the distribution of each variable. The variables with significant value (p-value <0.05) in the Shapiro-Wilk's test were considered as non-normally distributed and the ones with insignificant p-value were considered as normally distributed.

Descriptive analysis in both groups of conventional and digital methods were presented as the mean with standard deviation (for normal distribution), and the median with interquartile range (IQR) were calculated for non-normally distributed variables as a measure of central tendency. The range was presented for both distributions.

Along with the descriptive analysis, analytical tests were used to compare the mean differences for the same parameters between the digital and conventional method. For this, the Wilcoxon signed rank test was used where distribution was non-normal for at least one of the comparing variables.

Where normal distribution was detected for both the variables, the repeated sample t-test was used to identify if the mean difference was significant.

All the descriptive and analytical statistical calculations were done using the SPSS software version 23.0.

3. Results

For digital tracing, the coefficients of variation were less than 1, suggesting a high degree of reliability. The results showed a high coefficient of variation for the manual tracing for the Porion, Basion, Sella, Point B, and Gonion landmarks.

For the angular measurements, except for the nasolabial angle, all other values showed lower coefficients of variation for the digital method than for the conventional method. Table 1 shows the coefficients of variation of angular measurements for both conventional and digital methods. For the linear measurements, all the measurements under consideration showed much higher coefficients of variation in the conventional mode than the digital mode, implying that the digital mode is more reliable. Table 2 shows the coefficients of variation of linear measurements for both conventional and digital methods.

Table 1. Comparative values for Coefficient of Variation of Angular Measurements for Digital and Conventional Method

PARAMETERS	Digital	Conventional
	CV	CV
SNA	0.61	0.61
SNB	0.61	1.31
ANB	0.48	3.1
Facial angle	0.63	2.19
IMPA	0.54	0.95
Nasolabial angle	2.5*	1.22
FH-GoMe	2.48	7.6
SN-GoGn	2.57	4.8

*CV - coefficient of variation

The facial angle varied between 79° to 102° in the conventional method (Table 3), while the same varied between 78.9° to 94.0° (Table 4) in the digital method, which was found to be not significantly different (p-value: 0.462) (Table 5).

Table 2. Comparative values for Coefficient of Variation of Linear Mesurements for Conventional and Digital Methods		
Parameters	**Digital**	**Conventional**
	CV	**CV**
ANS-Me	0.57	2.8
Co-A	0.83	1.84
Co-Gn	0.49	0.81
N-Me	0.5	1.64
L1-Apo	0.04	1.8

*CV - coefficient of variation

The distance between L1 to NB varied between 1 to 10 mm in the conventional method (Table 3), though the range was wider in the digital method, ranging between 0 and 12.6 mm (Table 4), and the mean distance between L1 to NB from the two methods were significantly different (p-value=0.001) (Table 5).

Out of the 29 parameters, the mean difference of sixteen parameters was calculated to be statistically significant (Table 5). Additionally, when we calculated the range for all the parameters, the variability of outcome measures reduced considerably for several variables. In some instances, the variation remained nearly the same and for a very few variables it increased. In the case of U1-NA (°) the value was 24° (12°-36°) in the conventional method (Table 3), which increased to 39.9° (8.4°-48.3°) in the digital method (Table 4). In contrast to this, the value for Occl-SN was 27°, with a range of 3-30° for the conventional method (Table 3). However, for the digital method, the value decreased to 7.9°, where it ranged between 19.0° and 26.9° (Table 4). The variation in GoGn-SN did not change much in both methods, with the value in the conventional method being 26° (13-39°) (Table 3) versus the value in the conventional method being 27.5° (12.2-39.7°) (Table 4). Therefore, statistical significance of the 16 parameters (Table 5) showed that the digital method of cephalometric tracing can be relied upon for reliability.

Table 3. Descriptive analysis of the conventional method

Component	**Significance level (Shapiro-Wilk's test)**	**Range**	**Mean (±standard deviation)**	**Median (inter quartile range)**
Facial Angle	0.007	23 (79-102)	-	87.67 (4)
Convexity	0.008	14 (0-14)	-	5 (5)
Mandibular plane angle	0.005	25 (12-37)	-	23.12 (6)
A-B plane angle	0.089	12 (0-12)	4.75 (±2.62)	-
U1-NA	0.022	12 (0-12)	-	6.16 (2)
U1-L1	0.003	47 (112-159	-	129.01 (10)
L1 -Occl	<0.001	73 (10-83	-	64 (12)
IMPA	0.381	31 (82-113)	96.06 (±5.81)	-
SNA	0.045	17 (75-92)	-	83.00 (4)
SNB	0.006	17 (72-89)	-	80.52 (3)
ANB	0.001	6 (0-6)	-	2.81 (1.9)
Occl-SN	<0.001	27 (3-30)	-	12 (4)
GoGn-SN	0.007	26 (13-39)	-	25.16 (5)
U1-NA (mm)	0.006	12 (1-13)	-	5 (2)
U1-NA (°)	0.102	24 (12-36)	25.06 (±5.54)	-
L1-NB (mm)	<0.001	9 (1-10)	-	3.89 (3)
L1-NB (°)	0.102	27 (11-38)	24.88 (±5.55)	-
FMA	0.012	24 (12-36)	-	22.92 (5)
FMIA	0.027	36 (46-82)	-	61.35 (6)
IMPA	0.002	43 (70-113	-	95.88 (9)
Na to perpendicular PtA	0.002	10 (0-10)	-	3.17 (2.5)
Nasolabial angle	0.131	58 (70-128)	100.59 (±10.61)	-
Co-PtA	<0.001	41 (83-124)	-	94.81(8)
Co-Gn	0.025	45 (89-134)	-	117.92 (9)
Difference between Co-Pt A and Co-Gn	0.418	22 (15-37)	25.15 (±4.88)	-
ANS-Me	0.024	19 (56-75)	-	64.53 (3)
Mandibular Plane	0.018	24 (12-36)	-	22.94 (6)
Pog-N perpendicular	<0.001	23 (0-23)	-	7.35 (5)

U1-PtA	0.038	10 (0-10)	-	4.15 (2)

P value less than 0.05 is statistically significant

Table 4. Descriptive analysis of the digital method

Component	Significance level (Shapiro-Wilk's test)	Range	Mean (±standard deviation)	Median (inter quartile range)
Facial Angle	0.257	15.1 (78.9-94.0)	87.39 (±3.03)	-
Convexity	0.626	22.3 (-7.2 – 15.1)	3.08 (±4.86)	-
Mandibular plane angle	0.011	23.5 (9.8-33.3)	-	19.46 (4.5)
A-B plane	0.223	11.4 (-0.4 – 11.0)	4.95 (±2.53)	-
U1-NA	0.002	16.8 (0-16.8)	-	6.36 (2.6)
U1-L1	0.465	56.2 (96.8-153.0)	123.55 (±9.77)	-
L1 -Occl	0.154	31.8 (-0.9 – 30.9)	12.86 (±6.74)	-
IMPA	0.237	25.8 (87.3-113.1)	100.87 (±5.82)	-
SNA	0.274	16.4 (74.2-90.6)	83.16 (±3.12)	-
SNB	0.125	16.9 (71.7-88.6)	80.46 (±2.96)	-
ANB	0.108	8.8 (-0.9 – 7.9)	2.66 (±1.93)	-
Occl-SN	0.238	7.9 (19.0-26.9)	23.23 (±1.39)	-
GoGn-SN	0.040	27.5 (12.2-39.7)	-	25.60 (5.0)
U1-NA (mm)	0.006	16.3 (-1.9 – 14.4)	-	5.19 (3.0)
U1-NA (°)	0.016	39.9 (8.4-48.3)	-	27.20 (6.4)
L1-NB (mm)	0.016	12.6 (0-12.6)	-	4.84 (2.7)
L1-NB (°)	0.283	38.0 (4.3-42.3)	26.18 (±6.87)	-
FMA	<0.001	99.7 (13.0-112.7)	-	23.70(4.9)
FMIA	0.053	32.3 (42.0-74.3)	59.60 (±7.07)	-
IMPA	0.237	25.8 (87.3-113.1)	100.87 (±5.82)	-
Na to perpendicular	0.246	14.1 (-7.6 – 6.5)	-1.07 (±2.98)	-
Nasolabial angle	0.721	53.5 (72.7-126.2)	102.71 (±11.01)	-
Co-PtA	0.073	26.1 (72.8-98.9)	84.08 (±4.73)	-
Co-Gn	0.260	27.1 (97.7-124.8)	110.12 (±6.32)	-
Difference between Co-Pt A and Co-Gn	0.172	17.1 (19.4-36.5)	26.04 (±3.70)	-
ANS-Me	0.055	18.4 (53.6-72.0)	61.12 (± 4.37)	-
Mandibular Plane	0.102	22.5 (12.7-35.2)	21.93 (±4.59)	-
Pog-N perpendicular	0.141	26.1 (-18.7 –7.4)	-4.76 (±5.31)	-
1-PtA	0.028	14.3 (-1.5 – 12.8)		4.80 (3.1)

P value less than 0.05 is statistically significant

Table 5. Comparison between the conventional and digital method

Component	Difference in mean	Wilcoxon Signed Rank Test		Paired sample t-test	
		Test statistics	Level of Significance	Test statistics	Level of Significance
Facial Angle	0.28	787.50	0.462	-	-
Convexity	2.19	450.50	0.001	-	-
Man plane	3.67	217.50	<0.001	-	-
A-B plane	0.21	-	-	-0.632	0.530
U1-NA	0.20	889.00	0.795	-	-
U1-L1	5.46	190.50	<0.001	-	-
L1 -Occl	44.92	1.00	<0.001	-	-
IMPA	4.81	-	-	-7.578	<0.001
SNA	0.27	754.50	0.434	-	-
SNB	0.06	883.00	0.988	-	-
ANB	0.16	698.50	0.309	-	-
Occl-SN	10.68	1761.00	<0.001	-	-
GoGn-SN	0.44	938.00	0.689	-	-
U1-NA (mm)	0.72	504.50	0.093	-	-
U1-NA (°)	2.14	1257.50	0.005	-	-
L1-NB (mm)	0.95	1331.00	0.001	-	-
L1-NB (°)	1.30	-	-	-1.810	0.076
FMA	0.85	702.00	0.167	-	-
FMIA	1.75	567.50	0.017	-	-
IMPA	4.99	1651.00	<0.001	-	-
Na1 to PtA	4.24	135.50	<0.001	-	-
Nasolabial angle	2.11	-	-	-1.188	0.240

Co-PtA	10.73	5.00	<0.001	-	-
Co-Gn	7.80	150.00	<0.001	-	-
Difference between Co-Pt A and Co-Gn	0.89			-1.611	0.113
ANS-Me	3.41	206.00	<0.001	-	-
Mandibular Plane	1.01	624.50	0.049	-	-
Pog-N	12.10	15.00	<0.001	-	-
U1-PtA	0.58	968.00	0.097	-	-

P value less than 0.05 is statistically significant

4. Discussion

Lateral cephalogram is a two-dimensional method of diagnosis in orthodontics. The accurate identification of landmarks and accurate linear and angular measurements are a requisite for satisfactory diagnosis and treatment planning. Studies conducted so far comparing the different tracing modalities have given ambiguous results (3,4,5,6). Sandler(3) showed that direct digitization of the radiographs proved to be the most reproducible, particularly with angular measurements, although statistically significant differences were rarely found. Geelen et al. (4) demonstrated a statistically significant difference between the reproducibility of film, hardcopy, and monitor-displayed images in 11 of the 21 landmarks, stating that there was no unequivocal trend that one modality was always the best.

Gregston et al. (5) compared the reliability and dispersion of 10 angular and five linear cephalometric parameters by the manual method and using software, and concluded that the reliability of each method was considered clinically acceptable. The statistically significant differences in the means of numerous parameters did not appear to be clinically meaningful. In a similar study, Santoro et al. (6) showed greater variability in the digital cephalometric measurements but concluded that digital cephalometric software can be reliably chosen as a routine diagnostic tool. Other studies tested the reproducibility of measurements (8,9,10,11) of a single landmark as identifying landmarks are the primary source of error.

The present study analyzed the reproducibility and validity of linear and angular parameters via the analog and digital methods by evaluating 10 landmarks, and the six linear measurements and five angular measurements by the conventional and digital methods. The results for digital tracing showed the coefficients of variation to be less than 1, which suggested a high degree of reliability. For most manually traced images, the landmarks with high coefficients of variation were Porion, Basion, Sella, Point B, and Gonion. The coefficients of variation of all the landmarks under consideration in the study were invariably higher in the conventional method as compared to the digital method, which is again supported by Scott et al. (12), who stated that landmark identification using digital images had more landmarks that proved to be precise in both X- and Y-dimensions than the conventional film-based landmark identification method.

The mean difference of the 16 parameters was discovered to be statistically significant from each other. On calculating the range for all the parameters, there was a considerable reduction in the variability of outcome measures for several variables, emphasizing on the reliability of the digital method for cephalometric tracing and calculating the linear and angular measurements.

The present study eliminated interoperator error by using the ability of one operator to perform basic cephalometric measurements both digitally and manually. All radiographs under consideration in the study were taken on one machine, and great care was taken to position all patients in the same natural head position in both the digital and analog methods for quality control.

Chen (13,14) et al. demonstrated the accuracy of landmark identification in computer-aided digital cephalometry. Compared to traditional cephalometry, the differences were generally under 1 mm except for points Or, Me, PNS. Thus, Me is a more reliable cephalometric landmark in the digital method as compared to the traditional method, as demonstrated in the present study, where there is higher coefficients of variation in the conventional method as compared to the digital method along both axes. According to the present study, point A and S are more accurate vertically, and similar results have been observed in the study of Trpkova et al. (15).

In the present study, Pog is the only cephalometric landmark with a more significant coefficient of variation in the digital method along the Y-axis than the conventional method. This could be explained by the landmark lying on the curved surface. This is further supported by Broch (16) and Stabrun et al. (17), who also stated the inaccuracies in identifying Pog as the landmark lies on the curved surface. Of the angular measurements under investigation in the present study, the nasolabial angle, mandibular plane angle (according to the Downs analysis and Steiner analysis) have shown the most significant variation in the conventional method compared to the digital method. The nasolabial angle was the only parameter that demonstrated low levels of reproducibility. This finding aligns with Sayinsuet et al. (18), Kublashviliet et al. (19), and Baumrind et al. (20, 21). Different reference planes may be constructed during conventional hand tracing to identify the innermost point of a curve; therefore, measurements of the nasolabial angle, which is constructed on a curve, may show significant variation.

A higher amount of error depicted by the angular measurements, as shown by a higher coefficient of variation, can be explained because angular measurements are formed by joining specific planes that are formed by joining separate cephalometric landmarks. Therefore, errors in landmark identification lead to errors amplifying when angular measurements are considered. This is similar in the case with linear parameters, where the coefficients of variation were invariably higher in the conventional method than in the digital method. Thus, more errors are incorporated when one uses the conventional image capture and tracing method than the digital method of image acquisition and tracing done using cephalometric software. Similar findings have been suggested by Oliver (22). However, few studies (23, 24) have resulted in opposite findings, where a more significant random error was associated with angular and linear measurements recorded on the digital images than on the conventional radiographs. In addition, there was a systematic error producing a statistically significant difference in the majority of angular and linear measurements between the digital images and conventional radiographs.

Compared to conventional cephalograms, the digital images recorded simultaneously show more reproducible measurements due to the better soft tissue visualization. The reliability of the digital method and inaccuracies of the conventional method were further explained by Chen et al. (15, 16), who stated that overlapping structures create a blurred image, making the identification inaccurate as well as the acetate overlay leading to obscured visualization of the landmarks (3).

The findings in the present investigation indicate that digital cephalometrics may be a better method for some measurements. The digital technique also has the following advantages: no need for a dark room for tracing, chemicals, or physical space for storage. There is reduced radiation exposure, improved landmark identification through image enhancement techniques, faster cephalometric data acquisition, with efficient storage and archiving. The other advantages of digital imaging include the possibility of teleradiology and ability to duplicate radiographs easily at lesser expenses.

However, it has some disadvantages. The digital pictures that originate from poor-quality analog cephalometric radiographs often give an even poorer image. This is important because poor-quality digital cephalometric radiographs influence the identification of landmarks. There are also differences between the various digital techniques. One need to buy the digital softwares to do the digital analysis and the person needs to be well trained.

The advantages of the study is that the digital method can be routinely used for cephalometric measurements for the above stated parameters while the disadvantage is that only 29 parameters were assessed while more could have been tested for the reproducibility.

Conclusion

The descriptive analysis clearly showed that the variation of the values measured was reduced for most of the parameters in the digital method than the conventional method. Though in few cases such as FMA, the conventional method produced more concise results than the digital method, which was applicable for a limited number of parameters. Hence, we can conclude that the results produced from the digital method are more precise and reliable than the conventional method.

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