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Comparison of the Accuracy of Hexagon Imaging Software versus Digital and Hand Tracings of Lateral Cephalograms

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Objectives The aim of this study was to evaluate the validity and reliability of a newly designed cephalometric analysis program (Hexagon software) in comparison with manual and digital (Dolphin software) tracings.

Methods Pre-treatment lateral cephalometric radiographs of 32 adult patients between 18 to 41 years (10 males and 22 females, mean age of 22.78 ± 5.17 years) were randomly chosen. For each radiograph, 10 angular and 6 linear measurements were calculated using three different methods (manual and digital using two different software programs). The cephalograms were manually traced using acetate paper, x-ray light box, 0.3 mm HB pencil, ruler, and protractor. For digital tracing, cephalograms were traced with Dolphin vertion-10 (USA) and Hexagon (Iran) software programs. All the analyses were performed by one operator 2 times with at least a four-week interval between the two tracings. The intra-class correlation coefficient (ICC) was used to evaluate the intra-examiner agreement, while the differences between the methods were analyzed using paired t-test, and ANOVA.

Results The intra-examiner repeatability of all measurements in all three tracing methods showed high agreement. Differences in measurements between the two software programs and hand tracing were not statistically significant for any of the cephalometric parameters (P>0.05).

Conclusion The results demonstrated that the accuracy of cephalometric tracing by the Hexagon software was similar to the Dolphin software, and the manual tracing technique.

Keywords Cephalometry; Image Processing; Computer-Assisted; Reproducibility of Results

Introduction

A lateral cephalogram is among the essential records for orthodontic patients. It is used for diagnosis, determination of treatment prognosis, treatment planning, and evaluation of treatment progress by comparing the pre-and post-treatment measurements. Also, it can be used in studies on the growth and development of the craniofacial complex.[1-5]

To properly study the different parts of the skull and know their relationship with each other, lateral cephalograms should be traced and analyzed. Cephalometric analysis is basically a measurement system designed to describe the relationships between various parts of the skeletal, dental, and soft tissue elements of the craniofacial complex. Anatomical landmarks on cephalometric radiographs are identified and connected to obtain linear and angular measurements to define these relationships. There are two methods of cephalometric tracings namely manual and computerized. Hand-tracing of conventional radiographic films has been the gold standard for cephalometric analysis for many years.[6-8] However, this method can be time-consuming and prone to errors (projection errors, landmark identification errors, and measurement errors).[4, 9-11]

Computerized tracing is another method of cephalometric analysis. This method has become more popular in orthodontic and orthognathic surgery offices during the recent decades after the advances in computer science combined with the advent of digital radiographs, and the emergence of cephalometric analysis software programs. In the computerized tracing technique, the anatomical landmarks are first digitized. The software program then calculates the cephalometric measurements after entering the location of the required landmarks. This process eliminates the measurement errors that may occur by manual tracing[5, 12-14], and it takes less time than manual tracing for cephalometric measurements.[4, 5, 9, 12] Moreover, it allows the user to perform multiple analyses simultaneously[12, 15-17], and allows digital archiving and facilitates the access to images without the problems of film distortion.[4, 5, 9, 12, 18]

In recent years, many software programs have evolved to perform cephalometric tracing and measurements with different types of analyses.[12, 15, 19] The majority of them have a number of characteristics that are not present in the manual tracing method. Most of these programs consist of both basic and advanced features. In use of the basic feature, the digital film is uploaded into the software and is then analyzed without any change in the image. The advanced feature has many functions ranging from changing the image properties (brightness, contrast, zoom, etc.) to automatic landmark identification.[20]

As new programs for computerized cephalometric analysis are launched continuously, their accuracy needs to be

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validated against the previously marketed software programs and against traditional hand tracing. Earlier studies have evaluated the accuracy of measurements in computer-aided versus manual cephalometric analyses.[4, 6, 10, 12, 15] However, the results of studies comparing the digitized methods of cephalometric tracing with the conventional methods have been contradictory and no clear consensus has reached regarding the preferred method. This may be due to the use of various cephalometric software programs and/or because of the differences in the method of obtaining digital images because the conversion of analogue film to digital format requires several additional steps that are not only time-consuming but may also result in magnification errors.[4, 11, 15, 21] Consequently, there is still a need to assess the accuracy of these newly emerging cephalometric software programs to allow the clinician to select the appropriate software program for routine use.

Hexagon is a new Iranian computerized cephalometric tracing program designed for use by orthodontists. It is a direct landmark digitization software which can be navigated by the mouse cursor. It can trace and analyze the direct digital cephalograms and also the scanned conventional cephalometric radiographs. This software includes all the important hard and soft tissue landmarks (Fig. 1).

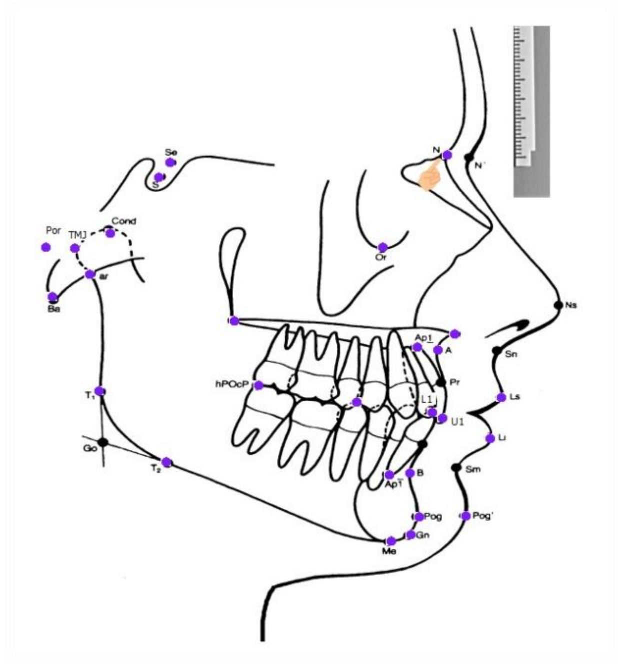


Figure 1- Important hard and soft tissue landmarks used in Hexagon Software

General reference planes include the cranial base plane, the Frankfurt plane, the maxillary plane, the mandibular plane, and the occlusal plane. Among the cephalometric analyses that can be carried out by this program are analyses of Downs, Steiner, Harvold, Jaraback, Wits, A.M. Schwarz, McNamara, and Tweed. Also, the cephalometric soft tissue analysis includes the nasolabial angle, E-Line, and S-Line.

In comparison with the manual technique, the advantages of this cephalometric analysis software include:

a) Ability to adjust magnification, density, contrast, and image quality, and this, in turn, will help in identifying landmarks efficiently and accurately.
b) Calculating the cephalometric measurements automatically after entering the locations of all the required landmarks. This will help eliminate the measurement errors that may occur by the manual tracing, and saves time.
c) Providing a variety of analysis options with faster analysis. This will aid in facilitating diagnosis, treatment planning, and evaluation of treatment outcome.
d) Allowing digital archiving of the information with quick access to them.

Also, this new program has some additional benefits compared with the Dolphin software program which include:

a) Low cost
b) Providing the auto-correction of the SN-FH angle validity if its value is less or more than the normal range. Also, all the angles related to the SN plane will be corrected automatically in this situation.
c) The ability to measure both the anatomical and functional occlusal plane according to the clinician's need. This is important because the Wits measurement depends on the functional occlusal plane rather than the anatomical plane.
d) The ability to measure the Se-N plane, in addition to its ability to calculate the S-N plane, which is important in Schwarz analysis.

As a result, this new software can be a cost-effective and user-friendly tool with a variety of options that meet the needs of contemporary clinical practice as well as areas of research. There is no published data on the accuracy and reproducibility of cephalometric analysis using this new software in the literature. Therefore, the aim of this study was to evaluate the reliability and validity of cephalometric angular and linear measurements obtained from computerized tracing of direct digital radiographs using a new software program (Hexagon imaging software) in comparison with two other methods, Dolphin imaging software (version 10) and hand-tracing of digital radiographic printouts.

Methods and Materials

The protocol of this study was approved by the ethics committee of the School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

The sample size calculation was based on 5% alpha significance level and 10% beta to achieve 90% study power to detect a difference of 2 mm or 2 degrees with a maximum standard deviation of 3.35 for the cephalometric measurements between the methods. Thus, at least 30 samples were required. Therefore, we used 32 radiographs in this study.

The study was conducted on adult patients (10 males, 22 females) with various malocclusions that needed orthodontic treatment. The patients were between 18-41 years (mean age=22.78±5.17 years). Thirty-two pre-treatment lateral cephalograms were randomly collected from the archives of the Orthodontics Department of Dental School, Shahid Beheshti University of Medical Sciences, Tehran, Iran. All radiographs were taken in a standardized manner by using the same direct digital cephalometer (SOREDEX, CRANEX D 2012, Finland) with the recommended settings for a single exposure (85 kVp, 10 mA, 5 s).

In the process of acquiring X-ray film, the patient was positioned in the cephalostat using adjustable bilateral ear rods placed within each auditory meatus while the patient was standing and the nose clamp was fixed at the root of the nose to support the superior part of the face. The mid-sagittal plane of the patient was parallel to the film plane while the x-ray beam was perpendicular to the mid-sagittal plane of the patient, which was also perpendicular to the film plane. The patient's Frankfort plane was oriented parallel to the floor with teeth in centric occlusion and the lips in repose. The selection criteria for the lateral cephalograms were as follows:

1. Radiographs had to be of good quality with no artifacts to prevent interference with the identification of anatomical landmarks.
2. The age of patients should be 18 years or older.
3. Patients had to have no craniofacial or asymmetrical defects.
4. Patients had to have full permanent dentition, except 3rd molars, and without any impaction and/or supernumerary teeth to prevent their effect on root apex identification.
5. Patients had no dental implant or prosthesis.
6. There was no restriction for gender or malocclusion type of patients.

All radiographs were traced with three different methods of manual, Dolphin software (USA), and Hexagon software (Iran) by the same examiner in a dark room. The midpoint of bilateral structures was chosen to make a single structure or landmark. Regardless of the tracing method, no more than 6 radiographs were traced at a time to minimize errors due to the operator's fatigue.

For the manual tracing, a digital film imager (Sony UP-DF 550 Film Station-Japan) was used to produce hard copies from digital films. The 32 digital radiographic printouts were traced manually on a viewing box by one well-trained examiner using acetate papers (0.003-inch thick x 8 inch x 10 inch, O_2 Ortho Organizers, Inc., USA), with a 0.3 mm HB mechanical pencil, a millimeter ruler, and a cephalometric protractor. Furthermore, the procedure of tracing and landmark identification was performed by the stepwise tracing technique. (Fig 2) After completion of tracing, all the required linear and angular measurements were made.

For digital tracing, direct digital films were used. All the radiographs were converted to JPEG digital files and saved in a computer. The digital tracing of 32 radiographic images was performed in each software program by using two separate computers, both having the same specifications (Dell computer, Core i7, USA) and monitors (1280×1024-pixel monitor, Samsung, Korea). The cephalometric digital image was captured using the software and displayed on the monitor. After that, the image was standardized by calibration of the actual size of each image in millimeters depending on the known distance (10 mm) between two fixed points of the software calibration ruler on the screen, and then identification of cephalometric landmarks was implemented manually on a digital image using a mouse-driven cursor. After completing the required cephalometric landmark identification, all the angular and linear measurements were calculated by the software automatically and then stored in the software imaging archive. (Figs 3, 4)

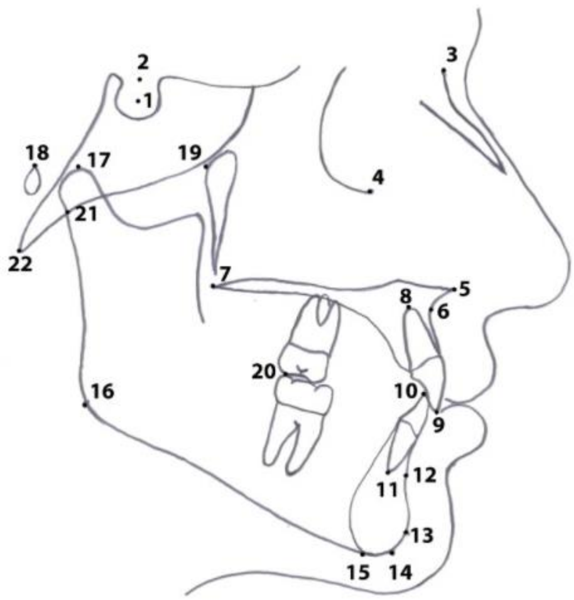
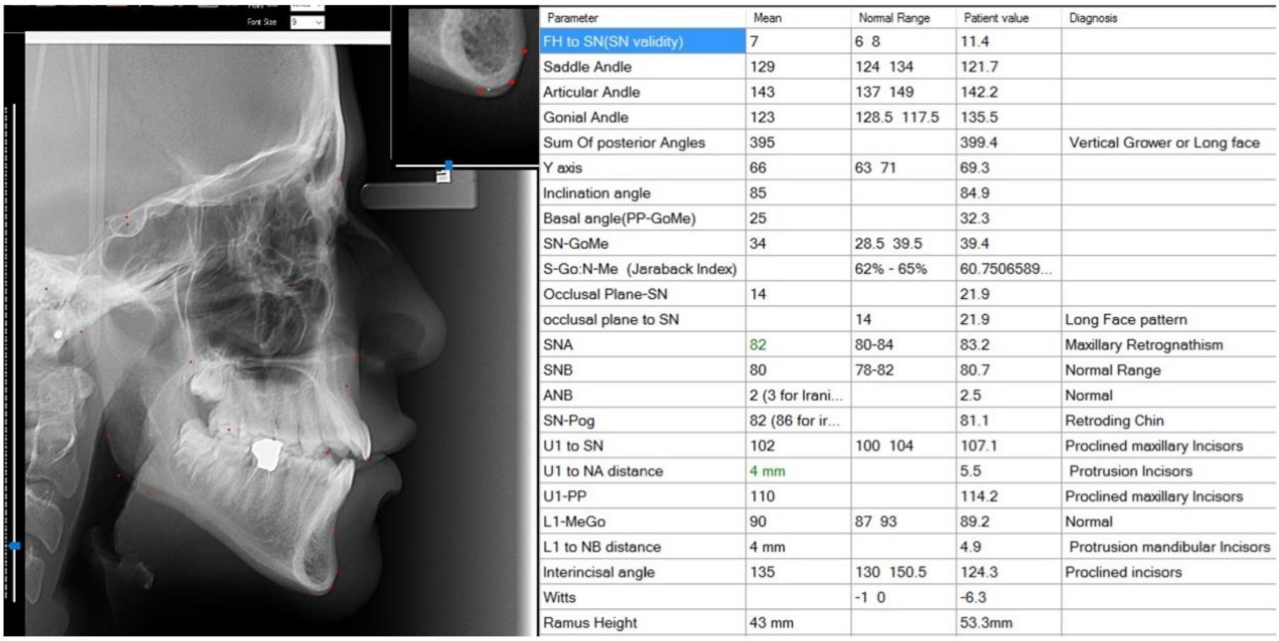


Figure 2- Picture of landmarks identification by the Manual Tracing

1. Sella(S); 2. Sella entrance(Se); 3. Nasion (N); 4. Orbitale(Or); 5. Anterior nasal spine (ANS); 6. Point A(A); 7. Posterior nasal spine (PNS); 8. Apex of upper central incisor(Ap\1) 9. Incisor superius (Is); 10. Incisor inferius (Ii); 11. Apex of lower central incisor(Ap/1); 12. Point B(B); 13. Pogonion (Pog); 14. Gnathion (Gn); 15. Menton (Me); 16. Gonion (Go); 17. Condylion(Co); 18. Porion(Po); 19. Pterygomaxillare fissure(Pt); 20. Posterior point of the occlusal plane(PPOcP); 21. Articulare(Ar); 22. Basion(Ba)

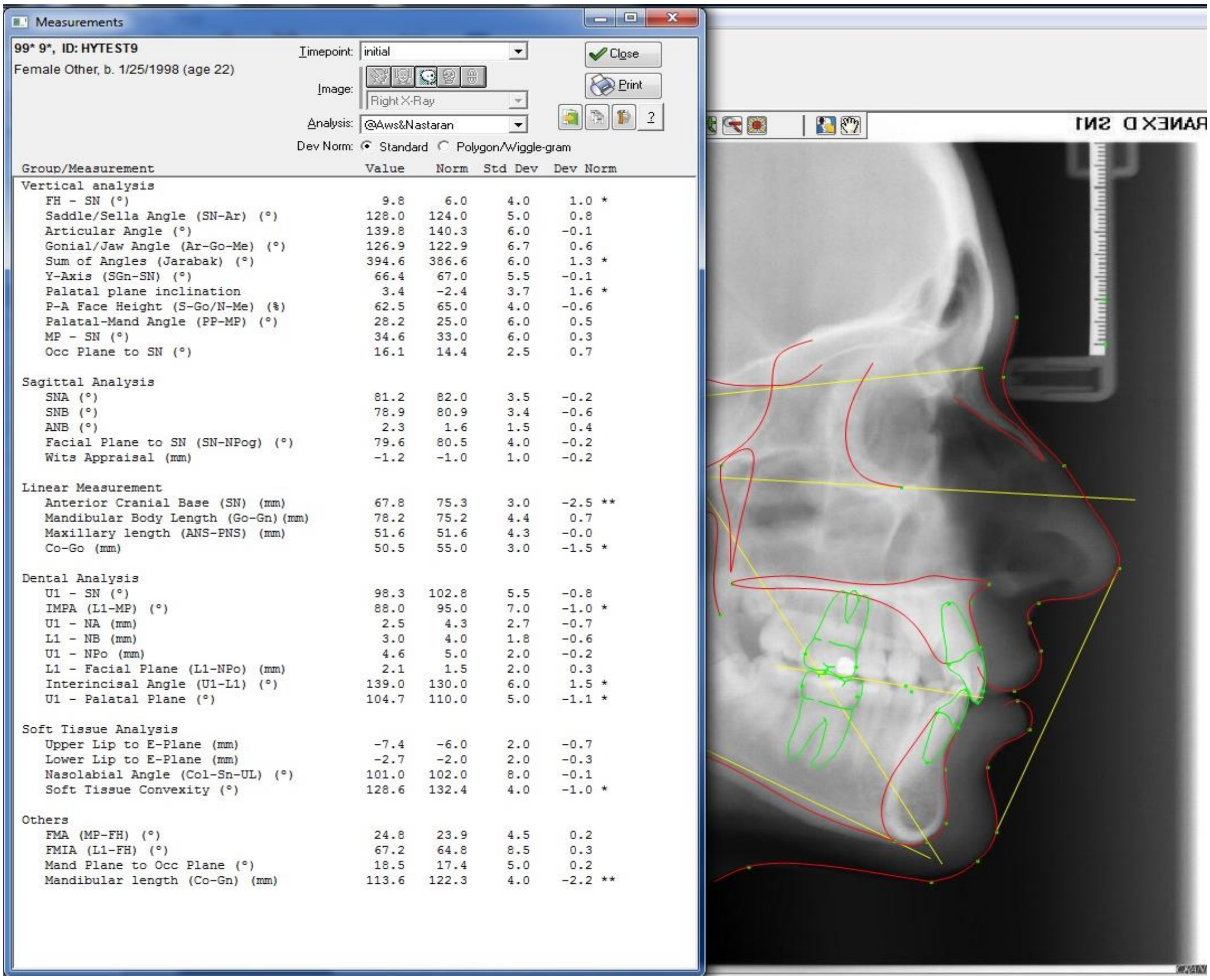
To investigate the reliability (intra-examiner error) and reproducibility of the manual and digital methods, all 32 radiographs were retraced manually and digitally by the same operator, to minimize variability of the measurements, after at least a four-week interval between the first and second analysis. Sixteen parameters (10 angular and 6 linear measurements) were used in this study (Table 1).

Data were analyzed with SPSS version 21.0 (SPSS Inc., IL, USA). The mean and standard deviation of the differences in the linear and angular measurements between the three methods and between the first (T1) and second (T2) measurements for each method were calculated. To evaluate the intra-examiner error, the intraclass correlation coefficient (ICC) was used. The agreement measures were as follows: values less than 0.5= poor, values between 0.5 and 0.75= moderate, values between 0.75 and 0.9= good, and values greater than 0.90= excellent.[22] The differences between the three methods were analyzed by paired t-test and ANOVA with one within-factor variable which was the measurement method. Statistical significance was set at P≤0.05.



Parameter	Mean	Normal Range	Patient value	Diagnosis
FH to SN(SN validity)	7	6 8	11.4	
Saddle Andle	129	124 134	121.7	
Articular Andle	143	137 149	142.2	
Gonial Andle	123	128.5 117.5	135.5	
Sum Of posterior Angles	395		399.4	Vertical Grower or Long face
Y axis	66	63 71	69.3	
Inclination angle	85		84.9	
Basal angle(PP-GoMe)	25		32.3	
SN-GoMe	34	28.5 39.5	39.4	
S-Go:N-Me (Jaraback Index)		62% - 65%	60.7506589...	
Occlusal Plane-SN	14		21.9	
occlusal plane to SN		14	21.9	Long Face pattern
SNA	82	80-84	83.2	Maxillary Retrognathism
SNB	80	78-82	80.7	Normal Range
ANB	2 (3 for Irani...		2.5	Normal
SN-Pog	82 (86 for ir...		81.1	Retroding Chin
U1 to SN	102	100 104	107.1	Proclined maxillary Incisors
U1 to NA distance	4 mm		5.5	Protrusion Incisors
U1-PP	110		114.2	Proclined maxillary Incisors
L1-MeGo	90	87 93	89.2	Normal
L1 to NB distance	4 mm		4.9	Protrusion mandibular Incisors
Interincisal angle	135	130 150.5	124.3	Proclined incisors
Witts		-1 0	-6.3	
Ramus Height	43 mm		53.3mm	

Figure 3- Picture of digital analysis by the Hexagon Software



Group/Measurement	Value	Norm	Std Dev	Dev Norm
Vertical analysis				
FH - SN (°)	9.8	6.0	4.0	1.0 *
Saddle/Sella Angle (SN-Ar) (°)	128.0	124.0	5.0	0.8
Articular Angle (°)	139.8	140.3	6.0	-0.1
Gonial/Jaw Angle (Ar-Go-Me) (°)	126.9	122.9	6.7	0.6
Sum of Angles (Jarabak) (°)	394.6	386.6	6.0	1.3 *
Y-Axis (SGn-SN) (°)	66.4	67.0	5.5	-0.1
Palatal plane inclination	3.4	-2.4	3.7	1.6 *
P-A Face Height (S-Go/N-Me) (%)	62.5	65.0	4.0	-0.6
Palatal-Mand Angle (PP-MP) (°)	28.2	25.0	6.0	0.5
MP - SN (°)	34.6	33.0	6.0	0.3
Occ Plane to SN (°)	16.1	14.4	2.5	0.7
Sagittal Analysis				
SNA (°)	81.2	82.0	3.5	-0.2
SNB (°)	78.9	80.9	3.4	-0.6
ANB (°)	2.3	1.6	1.5	0.4
Facial Plane to SN (SN-NPog) (°)	79.6	80.5	4.0	-0.2
Wits Appraisal (mm)	-1.2	-1.0	1.0	-0.2
Linear Measurement				
Anterior Cranial Base (SN) (mm)	67.8	75.3	3.0	-2.5 **
Mandibular Body Length (Go-Gn)(mm)	78.2	75.2	4.4	0.7
Maxillary length (ANS-PNS) (mm)	51.6	51.6	4.3	-0.0
Co-Go (mm)	50.5	55.0	3.0	-1.5 *
Dental Analysis				
U1 - SN (°)	98.3	102.8	5.5	-0.8
IMPA (L1-MP) (°)	88.0	95.0	7.0	-1.0 *
U1 - NA (mm)	2.5	4.3	2.7	-0.7
L1 - NB (mm)	3.0	4.0	1.8	-0.6
U1 - NPo (mm)	4.6	5.0	2.0	-0.2
L1 - Facial Plane (L1-NPo) (mm)	2.1	1.5	2.0	0.3
Interincisal Angle (U1-L1) (°)	139.0	130.0	6.0	1.5 *
U1 - Palatal Plane (°)	104.7	110.0	5.0	-1.1 *
Soft Tissue Analysis				
Upper Lip to E-Plane (mm)	-7.4	-6.0	2.0	-0.7
Lower Lip to E-Plane (mm)	-2.7	-2.0	2.0	-0.3
Nasolabial Angle (Col-Sn-UL) (°)	101.0	102.0	8.0	-0.1
Soft Tissue Convexity (°)	128.6	132.4	4.0	-1.0 *
Others				
FMA (MP-FH) (°)	24.8	23.9	4.5	0.2
FMIA (L1-FH) (°)	67.2	64.8	8.5	0.3
Mand Plane to Occ Plane (°)	18.5	17.4	5.0	0.2
Mandibular length (Co-Gn) (mm)	113.6	122.3	4.0	-2.2 **

Figure 4- Picture of digital analysis by the Dolphin Software

Table 1- Cephalometric measurements used in this study

NO.	Cephalometric measurements	Definition
1	FH-SN Angle	Angle between the S-N plane and the Frankfurt horizontal plane.
2	Y-Axis Angle	Angle between the S-N plane and the S-Gn plane. Angle between the anterior cranial base (S-N) and the most anteroinferior point of the bony chin (Gn) in the center of the sella.
3	Occlusal p.-SN Angle	Angle between the anterior cranial base (S-N) and the Occlusal plane.
4	SNA Angle	Angle between the S-N plane and the N-A plane. Anteroposterior position of the maxilla in relation to the anterior cranial base (S-N).
5	SNB Angle	Angle between the S-N plane and the N-B plane. Anteroposterior position of the mandible in relation to the anterior cranial base (S-N)
6	ANB Angle	Angle between the A-N plane and the N-B plane. Anteroposterior relation of the maxilla and mandible to each other in respect to the Nasion.
7	SN-NPog Angle	Angle between the S-N plane and the N-Pog. Anteroposterior relationship of the Pogonion to the anterior cranial base.
8	U1-SN Angle	Angle between the anterior cranial base (S-N) and the long axis of the upper central incisor.
9	IMPA Angle	Angle between the mandibular plane (Go-Me) and the longitudinal axis of the lower central incisor.
10	U1-PP Angle	Angle between the longitudinal axis of the upper central incisor and the palatal plane.
11	S-N Distance	The linear distance from the Sella turcica point to the Nasion point. It represents the length of the anterior cranial base.
12	Go-Gn Distance	The linear distance from the Gonion point to the Gnathion point. It represents the mandibular length.
13	ANS-PNS Distance	Linear distance from the anterior nasal spine point to the posterior nasal spine point. It represents the length of maxilla.
14	Wits Appraisal	Relation of the maxilla and mandible to each other. Linear distance between points A and B parallel to the occlusal plane.
15	U1-NA Distance	Distance of the incisal edge of the upper central incisor to the N-A line.
16	L1-NB Distance	Distance of the incisal edge of the lower central incisor to the N-B line.

Results

Method error:
The method error (the intra-examiner error) for the three methods is shown in Table 2. The mean and SD of differences, and ICC for each of the 16 measurements with the conventional and digital methods were calculated. The ICC values were found to be above 0.90 for all parameters. The highest magnitude of the difference in means between the first (T1) and second (T2) tracings was - 0.003 mm or 0.003° for manual tracing (MT), - 0.006 mm or 0.006° for Dolphin tracing (DT), and 0.003 mm and 0.003° for Hexagon tracing (HT).

Table 2- Intra-examiner reliability of manual, Dolphin, and Hexagon tracing methods (operator error)

Parameters	MT (T1-T2) Mean Difference	ICC	DT (T1-T2) Mean Difference	ICC	HT (T1-T2) Mean Difference	ICC
	Mean ± SD		Mean ± SD		Mean ± SD	
FH-SN °	0.003 ± 0.373	0.993[a]	0.003 ± 0.418	0.992[a]	0.000 ± 0.526	0.987[a]
Y-axis °	-0.003 ± 0.505	0.990[a]	-0.003 ± 0.408	0.993[a]	-0.003 ± 0.480	0.990[a]
Occl.p-SN °	-0.003 ± 0.472	0.993[a]	-0.003 ± 0.613	0.988[a]	-0.003 ± 0.547	0.990[a]
SNA °	0.000 ± 0.455	0.985[a]	-0.003 ± 0.329	0.992[a]	-0.003 ± 0.501	0.982[a]
SNB °	0.003 ± 0.529	0.982[a]	0.000 ± 0.499	0.984[a]	-0.003 ± 0.546	0.982[a]
ANB °	-0.003 ± 0.444	0.981[a]	-0.003 ± 0.495	0.977[a]	0.000 ± 0.558	0.971[a]
SN-NPog °	-0.003 ± 0.550	0.984[a]	0.003 ± 0.357	0.994[a]	-0.003 ± 0.707	0.974[a]
U1-SN °	0.003 ± 0.406	0.998[a]	0.000 ± 0.299	0.999[a]	-0.003 ± 0.871	0.990[a]
IMPA °	-0.003 ± 0.515	0.998[a]	0.006 ± 0.332	0.999[a]	0.003 ± 0.619	0.997[a]
U1-PP °	-0.003 ± 0.470	0.997[a]	-0.003 ± 0.327	0.999[a]	-0.003 ± 0.802	0.992[a]
S-N (mm)	-0.003 ± 0.515	0.991[a]	0.003 ± 0.530	0.991[a]	0.003 ± 0.525	0.991[a]
Go-Gn (mm)	-0.003 ± 0.710	0.994[a]	-0.006 ± 0.653	0.995[a]	0.003 ± 0.637	0.995[a]
ANS-PNS (mm)	0.000 ± 0.449	0.989[a]	-0.003 ± 0.501	0.986[a]	0.003 ± 0.628	0.979[a]
Wits (mm)	-0.003 ± 0.443	0.992[a]	0.003 ± 0.340	0.995[a]	0.000 ± 0.531	0.989[a]
U1-NA (mm)	-0.003 ± 0.565	0.960[a]	-0.006 ± 0.635	0.952[a]	-0.003 ± 0.745	0.927[a]
L1-NB (mm)	-0.003 ± 0.577	0.975[a]	-0.003 ± 0.458	0.984[a]	0.000 ± 0.723	0.961[a]

MT= Manual tracing; DT= Dolphin tracing; HT= Hexagon tracing; T1= First tracing; T2= Second tracing; SD: Standard deviation

Table 3- Differences in cephalometric measurements between each software and the manual tracing and between the two software programs

Parameters	Mean Difference (MT-DT)		P-value	Mean Difference (MT-HT)		P-value	Mean Difference (DT-HT)		P-value
	Mean	SD		Mean	SD		Mean	SD	
FH-SN °	-0.003	0.263	0.947	0.000	0.359	1.000	0.003	0.442	0.968
Y-axis °	-0.003	0.232	0.940	0.000	0.262	1.000	0.003	0.304	0.954
Occl.p-SN °	0.003	0.176	0.921	0.000	0.181	1.000	-0.003	0.285	0.951
SNA °	0.000	0.238	1.000	-0.003	0.331	0.958	-0.003	0.432	0.968
SNB °	0.003	0.229	.939	0.000	0.375	1.000	-0.003	0.480	0.971
ANB °	-0.003	0.245	0.943	-0.003	0.394	0.965	0.000	0.468	1.000
SN-NPog °	-0.003	0.392	0.964	-0.003	0.480	0.971	0.000	0.638	1.000
U1-SN °	-0.003	0.241	0.942	-0.003	0.471	0.970	0.000	0.475	1.000
IMPA °	-0.006	0.253	0.890	-0.003	0.324	0.957	0.003	0.381	0.963
U1-PP °	-0.003	0.331	0.958	0.000	0.485	1.000	0.003	0.617	0.977
S-N (mm)	-0.003	0.276	0.949	-0.003	0.289	0.952	0.000	0.265	1.000
Go-Gn (mm)	0.003	0.382	0.963	0.003	0.359	0.961	0.000	0.413	1.000
ANS-PNS (mm)	0.003	0.286	0.951	-0.003	0.336	0.958	-0.006	0.490	0.943
Wits (mm)	-0.003	0.276	0.949	-0.003	0.365	0.962	0.000	0.382	1.000
U1-NA (mm)	0.000	0.333	1.000	-0.003	0.334	0.958	-0.003	0.414	0.966
L1-NB (mm)	0.003	0.287	0.951	0.003	0.292	0.952	0.000	0.321	1.000

MT= Manual tracing; DT= Dolphin tracing; HT= Hexagon tracing; SD: Standard deviation

Between-group comparisons:
The comparison of each method against the other and the comparison of the three methods with each other are shown in Tables III, and IV, respectively. The results were as follows:

- No significant differences between MT and DT methods were observed in any measurement (P>0.05) with the highest magnitude of the difference in means between the measurements of the two methods to be 0.003 mm or - 0.006°.
- The differences between MT and HT methods were not statistically significant in any of the angular or linear measurements (P > 0.05) with the highest magnitude of the difference in means between the measurements of the two methods to be 0.003 mm or - 0.003°.
- No significant differences between DT and HT methods were observed in any measurement (P > 0.05) with the highest magnitude of the difference in means between the measurements of the two methods to be - 0.006 mm or 0.003°.
- ANOVA showed no statistically significant differences (P > 0.05) in the calculated angular and linear measurements among the three groups.

Table 4- Comparison of cephalometric measurements among the three methods (intergroup comparisons)

Parameters	Manual Teaching (MT)		Dolphin Tracing (DT)		Hexagon Tracing (HT)		F-value	P-value	Anova Test
	Mean	SD	Mean	SD	Mean	SD			
FH-SN °	9.3469	3.24077	9.3500	3.34191	9.3469	3.30503	0.002	0.998	NS
Y-axis °	66.7500	3.57636	66.7531	3.46466	66.7500	3.49627	0.003	0.997	NS
Occl.p-SN °	15.3438	3.85720	15.3406	3.87905	15.3438	3.78979	0.004	0.996	NS
SNA °	82.9406	2.59911	82.9406	2.59327	82.9438	2.59614	0.002	0.998	NS
SNB °	79.7500	2.75622	79.7469	2.79908	79.7500	2.88858	0.001	0.988	NS
ANB °	3.1906	2.25165	3.1938	2.26772	3.1938	2.35330	0.001	0.992	NS
SN-NPog °	80.4063	3.10680	80.4094	3.14185	80.4094	2.98646	0.001	0.996	NS
U1-SN °	106.8469	6.10600	106.8500	6.11545	106.8500	6.03180	0.001	0.992	NS
IMPA °	93.8094	7.33636	93.8156	7.34083	93.8125	7.41967	0.006	0.994	NS
U1-PP °	112.6531	6.00220	112.6563	5.94637	112.6531	6.10314	0.001	0.994	NS
S-N (mm)	68.5313	3.78873	68.5344	3.88235	68.5344	3.89040	0.003	0.997	NS
Go-Gn (mm)	77.8500	6.48751	77.8469	6.62683	77.8469	6.50131	0.001	0.999	NS
ANS-PNS (mm)	51.1250	2.95100	51.1219	2.86049	51.1281	2.99260	0.004	0.980	NS
Wits (mm)	-1.4656	3.46881	-1.4625	3.47709	-1.4625	3.55126	0.002	0.998	NS
U1-NA (mm)	5.2531	1.89532	5.2531	1.88423	5.2563	1.91276	0.002	0.998	NS
L1-NB (mm)	6.1875	2.51367	6.1844	2.55193	6.1844	2.53022	0.002	0.998	NS

MT= Manual tracing; DT= Dolphin tracing; HT= Hexagon tracing; SD: Standard deviation

Discussion

Cephalometric analyses mainly determine the sagittal and vertical aspects of the facial morphology, and they depend on cephalometric films to study the relationship between the hard and soft tissue landmarks. They can be used to detect facial developmental abnormalities before the treatment, in the middle of treatment to assess the level of progress, or at the end of treatment to make sure the treatment goals have been met. Therefore, the accuracy is important in determining the anatomical points, and in calculating the linear and angular measurements.

Accuracy is a crucial aspect of every scientific measurement, and any technology used in the diagnosis of a disease or disorder, such as malocclusion, requires high reliability and reproducibility. Reliability is the extent to which measurements can be replicated (the degree of consistency of a measure). A test will be reliable if it gives the same repeated result under the same conditions. Reproducibility means that a result obtained by an experiment or observational study should be achieved again with a high degree of agreement when the study is replicated with the same methodology by different researchers. Therefore, the reproducibility of measurements is a basic requisite for determining the accuracy of any analytical method. In orthodontic clinical cases, an accuracy that is within 2° for angular measurements or 2 mm for linear measurements is clinically acceptable.[23-25] Several researchers have conducted investigations on the accuracy of both manual and computer-aided cephalometric measurements. Initial studies mainly focused on testing the identification and reproducibility of cephalometric landmarks. [9, 26-28] Recent studies aimed to compare the measurement results rather than the landmark position[4, 10-12, 15] mostly because the reproducibility analysis of lines and angles is more challenging (as related to multiple sources of error) than landmarks studies.[13, 15, 21, 29]

Cephalometrics analysis is a prerequisite in diagnosing a malocclusion and analyzing the treatment outcome. Advances in computer technology have led to an increase in the use of digital systems, whether in radiology or in tracing and analyzing cephalometric radiographs. This, in turn, resulted in the emergence of many programs dedicated to tracing and analyzing the cephalograms with different methods or techniques. It is expected that the use of computers in diagnosis and treatment planning will reduce the occurrence of operator errors due to fatigue and provide a standardized, fast, and effective evaluation with high reproducibility.[4] Regardless of the type of method used (manual, mechanical, or digital), it must be accurate and exhibit a high rate of reproducibility in both tracing and analysis to ensure minimal errors. The present study evaluated the reliability and reproducibility of some commonly used cephalometric measurements made with two different computer programs (Dolphin and Hexagon software programs) on direct digital films in comparison with measurements made by the manual tracing method on printouts of digital films.

Measurements are subject to errors depending on cephalometric radiographs. Radiographic errors fall into two main categories of systematic and random. Systematic error implies a bias in the recording and measuring system to produce measurements predictably different from the actual values. Systematic error includes such factors as the geometric magnification of the radiographic image and distortion due to differential magnification between different planes. Both magnification and distortion can be calculated from the geometry of the apparatus, and can also be measured by the use of standard scales in the field of view.[30, 31] When two series of radiographs are measured by different operators who have different concepts of a particular landmark, there will again be a systematic error.[32] Random error largely arises through uncertainty in the visual identification of radiographic landmarks. In this way, lack of resolution prevents accurate landmark identification, and this can occur either through unsharpness of the image or lack of contrast.[30-32] Random error can also arise as a result of variations in the positioning of the patient in the cephalostat.[32]

Recently, the use of digital cephalometrics in orthodontic clinics has become more widespread, and direct transfer of images to a computer database is now possible. A digital image has many advantages with regard to image enhancement such as adjustment of contrast, brightness, and enlargement or reduction.[17, 33-35] Thus, to eliminate the errors due to magnification, the present study relied on digital radiographs (with standardized and high-quality lateral cephalograms) rather than scanned images. Using direct digital cephalograms can completely eliminate the need for scanning conventional radiographic films which not only can introduce magnification errors but also require an additional time-consuming step.[4, 11, 15, 21] Also, the use of digital cephalometric film can eliminate any error that might have occurred during film processing. Both Dolphin and Hexagon software programs allow for image enhancement through adjustments of magnification, contrast, and brightness. Furthermore, both software programs feature a digital tool to correct landmark position after initial digitization. Any procedure that helps improve landmark identification is beneficial because the identification of point location remains the main source of error in cephalometry.[4, 6, 12, 15, 26]

In the present study, identification of landmarks for digital tracings was carried out manually on digital images using a mouse-driven cursor, and the measurements were determined automatically by the software. In addition to the use of direct digital x-ray films, hard-copy printouts of digital radiographs were also used in this study to carry out the measurements by hand tracing. Although slight enlargements have been reported in printed films of digital cephalograms, it has been shown that differences are minimal and have been regarded as clinically acceptable.[8]

Landmark identification is greatly affected by operator experience, which might be as important as the tracing method itself. Since standardization is important in comparative studies and the inter-examiner error has been reported to be greater than the intra-examiner error,[11, 21, 24, 36, 37] all the cephalometric measurements in this study were carried out by one well-experienced examiner to minimize errors. The intra-operator error in both angular and linear measurements was assessed on manual and digital tracings of radiographs by determining the reliability with a test-retest method. Error analysis of the manual tracing and digital tracings (by Dolphin software, and Hexagon software) showed a high correlation in duplicated measurements by the three methods. All the results of the ICC test for the repeated measurements within each technique were higher than 0.90 (strong correlation). This means that the operator had no difficulty in correctly reproducing measurements on digital film printouts and on monitor-displayed images, and the landmarks were easily identifiable. The results indicated that the reliability of duplicated measurements by the manual method appeared to be similar to the two digital methods, where a high correlation was observed between the repeated measures in digital and manual tracings. These results provided an indication of excellent intra-examiner reliability for all three methods. The results agree well with previous studies that have shown high reliability of measurements.[7, 11, 15, 16, 19]

Dinkova and Ivanova in their study on 34 profile X-rays examined the results of manual and digital measurements by two different software programs (3Txer 2.6.0. Inc. and OrthoDental). They found no statistically significant difference in the obtained results between the used methods.[12] Erkan et al. examined 30 lateral cephalograms. The authors compared the results obtained by four different digital programs (Dolphin, Vistadent, Nemoceph, and Quick Ceph 2000) with the manual method. The results showed no statistically significant difference in any of the measured values.[36] Paixão et al, in their study on 50 lateral cephalograms scrutinized the values measured by the digital technique (Dolphin Imaging 11.0) versus the manual method. The results showed no statistically significant difference in any of the assessed measurements.[19]

In our study, comparison between the methods (MT versus DT, MT versus HT, and DT versus HT) displayed no statistically significant differences (P>0.05) for the 16 cephalometric measurements. The findings showed high reproducibility in the cephalometric measurements with the Hexagon software versus the Dolphin software, and with the Hexagon software versus the manual tracing. Also, high reproducibility of the measurements was observed between the Dolphin software and the manual tracing.

Regarding the comparison of the three methods with each other (Table 4), ANOVA was used to assess the difference between the means of the cephalometric measurements recorded with the three tracing techniques. The results showed no statistically significant differences (P>0.05) in the calculated angular and linear cephalometric measurements among the three methods. The present finding was similar to the results of Dinkova and Ivanova[12], Erkan et al.[36] and Paixão et al.[19] and also compatible with other reported results.[16, 38, 39] The results of the current study showed excellent reproducibility of the three methods. Also, we found that the cephalometric tracing and analysis by the two digital methods were faster than the conventional hand-tracing method, and this was consistent with other studies.[4, 5, 12, 13, 37]

Based on statistical analyses in this study, the results of all the assessed variables in the current study indicated that the reproducibility of cephalometric tracings recorded by the manual and digital (by Dolphin and Hexagon programs) techniques was high. The lack of statistical significance of the differences in measurements between both computerized methods, and the hand tracing technique indicated that the tested software (Hexagon software program) can be reliably used in orthodontic diagnosis.

Conclusion

The results demonstrated that the accuracy of cephalometric tracing by the Hexagon software was similar to the Dolphin software, and the manual tracing techniques. Therefore, this new software can be used routinely in clinical practice as well as for research purposes.

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Conflict of Interest

No Conflict of Interest Declared ■

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