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Comparison of speed and precision of manual viz a viz computer assisted cephalometric measurements



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ABSTRACT

Objectives: The present study was undertaken for comparing measurements of various cephalometric parameters obtained by hand tracing method with those obtained by computerized software on direct digital lateral cephalograms and scanned lateral cephalograms so as to determine the validity of tracing methods and time required.

Methods: The study sample comprised of hard and soft copy of 100 digital lateral cephalometric radiographs from archives. The study sample was divided into three groups, Group A – comprised of hard copy of radiographs which were traced manually, Group B – comprised of direct digital images and Group C – comprised of scanned images. Both were traced using cephalometric software NemoCeph NX 2006. 18 cephalometric parameters were evaluated.

Result: 30 cephalograms were traced in each group. After ascertaining intra operator reliability rest of the cephalograms were traced. On comparing different groups, statistically significant differences were found for various parameters but the differences were not clinically significant.

Conclusion: The validity and reproducibility of various cephalometric parameters by manual tracing and software tracing of direct digital images and scanned images of lateral cephalogram were found to be highly correlated. In comparison to manual method, tracing using cephalometric software provides a significant time advantage.

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1. Introduction

The specialty of orthodontics began as a science of straightening of teeth. Since it became apparent that a beautiful face was the result of harmonious balance of its constituents the science of jaw proportions and measurements became integral to the specialty of orthodontics. The objective assessment of the same was possible due to the advent of cephalometrics, the origin of which can be traced to the 19th century.

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Hofrath[1] and Broadbent[2] independently devised the head holder to orient the head and face to predetermined standardized position and the cephalostat was inducted to the practice of orthodontics. Cephalometrics thus became the language in which the science of orthodontics began to be written.

Traditionally objective analysis of the lateral cephalograms was performed manually on acetate an overlay which is time consuming.[3] Storage of the data and its subsequent reproducibility is difficult and cumbersome.

Advancement in the field of computer sciences and technology has profoundly impacted the medical and dental profession. The computerized cephalometric system that emerged in early 1980's involved indirect method of conversion of hard copy of radiographic image to a digital format using digitizing tablet, camera or flatbed scanner.[4,5] The digital image was then analyzed using the Disc Operating System. This facilitated storage of data, ease of retrieval and transfers. This had limited capabilities of data analysis.

Robert Ricketts in collaboration with Rocky Mountain Orthodontics pioneered the development and advancement of computerized cephalometric systems.

Digital cephalometric radiography has the advantages of image transmission, manipulation, storage and teleradiology.[6] In-spite of numerous advantages its poor reproducibility when compared with conventional films has been reported by various researchers.[7,8] Some researchers have concluded that although there can be statistically significant difference with respect to reproducibility of cephalometric landmarks and measurements when conventional and digital cephalograms are compared, they might not be clinically significant.[9,10] Ozsoy[11] proposed that user-friendly and time-saving characteristics of computerized tracing makes this method inherently preferable to hand tracing of radiographs.

Due to lack of consensus on the preferred tracing method, keeping in view the cost effectiveness, time taken, accuracy and paucity of studies on the aforementioned issue the present cross-sectional study was undertaken for comparing measurements of various cephalometric parameters obtained by hand tracing method with those obtained by computerized software on direct digital and scanned lateral cephalograms so as to determine the validity of tracing methods and time required.

2. Material and methods

The study sample comprised of hard and soft copy of 100 digital lateral cephalograms from archives. Gender, type of occlusion and skeletal pattern were not taken into consideration in the study design. Cephalograms used were recorded by Panaromic System Model ADVAPX cephalostat machine. Inclusion criteria were radiographs without any artifacts that could interfere with locating anatomical points, permanent dentition and absence of significant craniofacial deformity or

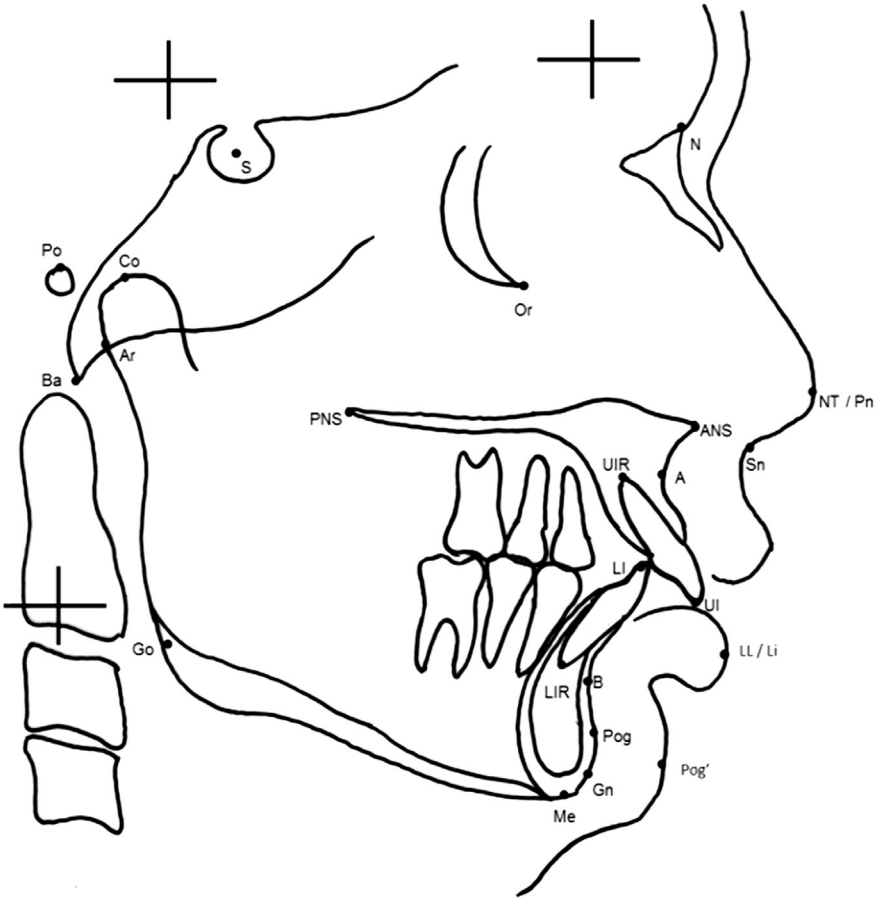


Fig. 1 – Landmarks traced for Group A.

asymmetry. Stained/discolored radiographs, deciduous/mixed dentition and lateral cephalograms of syndromic patients were excluded from the study.

The research protocol was approved by the Institutional Ethical Committee. The study sample was divided into three groups i.e. ***Group A – Manual tracing*** comprised of hard copy of radiographs which were traced manually, ***Group B – Direct digital tracing*** comprised of soft copy of radiographs (direct digital image). ***Group C – Scanned digital tracing*** comprised of soft copy of radiographs which were obtained by scanning the printed copies of radiographs by using Epson Perfection V700 Photo, Long Beach, CA scanner. Radiographs of Group B and C were traced using cephalometric software NemoCeph NX 2006 Version 6.0 (Nemotec Software SRL, Madrid, Spain).

2.1. *Group A – Manual tracing*

Cephalograms in Group A were traced manually using the standard technique. The armamentarium comprised of hard copy of 100 lateral cephalometric radiographs which were printed after resizing to 1:1 magnification using a 2400 dots per inch (dpi) color laser printer (Magicolor 5450; Konica Minolta, Osaka, Japan), light box, acetate sheets measuring 8 × 12 inch and 0.003 inch thickness, fine felt tipped black pen sharp 3H drawing pencil, protractor, scale of size 1 feet, sharpener and eraser.

A total of 23 landmarks were traced (Fig. 1, Table 1) from which 18 cephalometric parameters were evaluated (Fig. 2, Table 2). Bilateral structures were averaged to make a single structure or landmark.

Time taken for tracing was recorded from taping of the cephalogram till recording of the last measurement with the help of a digital stopwatch.

2.2. *Group B – Digital tracing*

Cephalograms in Group B were traced using cephalometric software NemoCeph NX 2006. The armamentarium comprised of soft copy of 100 lateral cephalometric radiographs, cephalometric software and Dell Inspiron 1464 laptop. The specifications of the laptop were Processor – Intel Core i3, RAM 4 GB, storage capacity 500 GB.

The direct digital image of radiographs was originally available in DICOM (Digital Imaging and Communications in Medicine) format. NemoCeph NX 2006, is not compatible with DICOM files, hence the images were converted to JPEG and saved at a resolution, 300 dpi, 2000 × 2510 pixels and 8 bit grayscale using Adobe Photoshop CS (Adobe Systems, San Jose, California, USA). Images were imported to cephalometric

Table 1 – Landmarks used Group A.

Landmark	Definition
Skeletal	
N	Most anterior point of frontonasal suture in the median plane.
S	Midpoint of the hypophyseal fossa.
A	Deepest midline point in the curved bony outline from the base to the alveolar process of maxilla.
ANS	Tip of the bony anterior nasal spine in the median plane.
PNS	Intersection of the continuation of anterior wall of the pterygopalatine fossa and floor of the nose.
Ba	Lowest point on the anterior margin of the foramen magnum in the median plane.
Co	Superior most point on the head of the condyle.
Ar	Point of intersection of the posterior margin of ascending ramus and the outer margin of the cranial base.
B	Most posterior point in the outer contour of mandibular alveolar process in the median plane.
Pog	Most anterior point of the bony chin in the median plane.
Gn	Most anteroinferior point of the bony chin.
Me	Most inferior point of the bony chin.
Go	Most posterior and inferior point on outline of mandibular angle.
Or	Lowermost point of the orbit.
Po	Uppermost point of the external auditory meatus.
Dental	
UI	Tip of the incisal edge of the most anterior maxillary central incisor.
UIR	Root apex of the most anterior maxillary central incisor.
LI	Tip of the incisal edge of the most anterior mandibular central incisor.
LIR	Root apex of the most anterior mandibular central incisor.
Soft tissue	
Pog'	Most anterior point on the soft tissue chin in the mid saggital plane.
LL/Li	Most anterior point on lower lip.
NT/Pn	Most anterior point on the nose.
Sn	Point at which the columella (nasal septum) merges with the upper lip in the mid saggital plane.

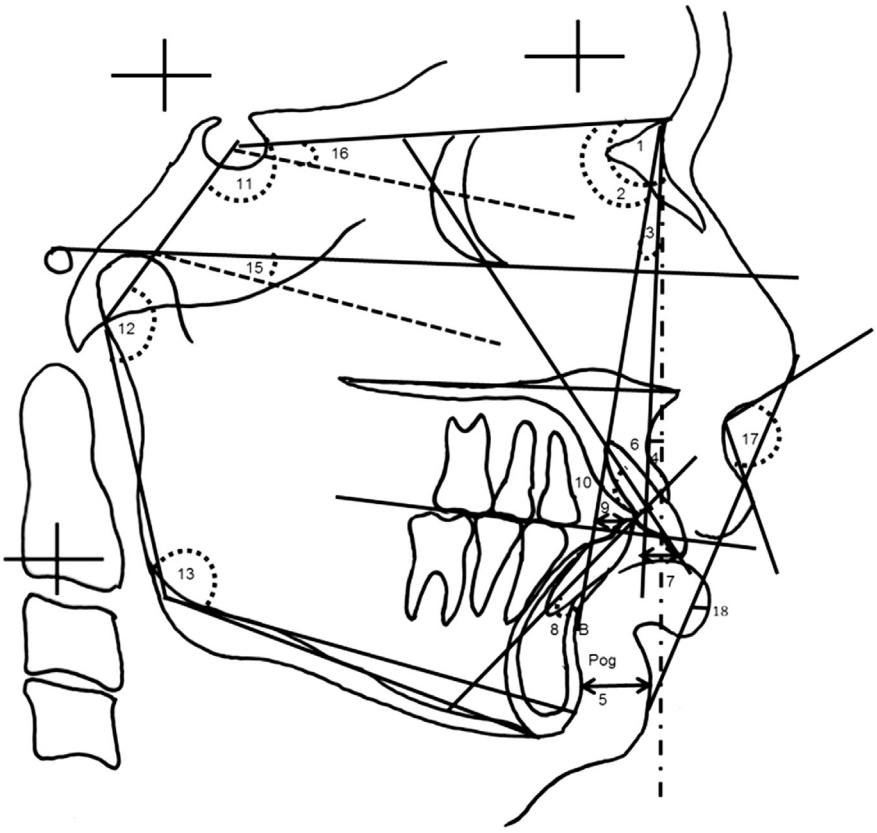


Fig. 2 – Cephalometric parameters evaluated.

software and landmarks were digitized following which measurements were generated automatically. Prior to digitization of landmarks, all images were calibrated. The software does not readily permit the outline tracing therefore a line of best fit was used. Image enhancements were used as needed to identify individual landmarks. 41 landmarks were traced manually with the help of a mouse driven cursor on flat screen monitor of laptop with display resolution of 1366 × 768 pixels (Fig. 3, Tables 1 and 3). In Group B all the landmarks enlisted in the software need to be located before any cephalometric parameter could be evaluated. From these landmarks 18 cephalometric parameters were evaluated (Table 2).

Time taken for tracing was recorded from importing the image to the software till recording of the measurement with the help of a digital stopwatch.

2.3. *Group C – Scanned tracing*

Cephalograms in Group C were traced using cephalometric software NemoCeph NX 2006. The armamentarium comprised of scanned soft copy of 100 lateral cephalometric radiographs, cephalometric software, Dell laptop and Epson Perfection scanner.

The printed copies of selected radiographs were scanned and saved in JPEG format at a resolution, 300 dpi, 2000 × 2510 pixels and 8 bit grayscale using Adobe Photoshop CS. Protocol for tracing was similar to the one used in Group B.

Time taken for tracing was recorded from scanning of the radiograph till recording of the measurement with the help of a digital stopwatch.

All the composite tracings were performed by single individual. Thirty cephalograms in all the three groups were traced twice after a gap of a week to ascertain intra operator reliability. After ascertaining intra operator reliability remaining cephalograms were traced and data was compiled.

Every day no more than 10 radiographs were traced regardless of the method used in order to avoid operator fatigue.

2.4. *Statistical analysis*

The collected data with respect to all the three study groups was compiled in MS Excel Worksheet. Data was analyzed with the SPSS version 17 and MS Excel Worksheet.

Intra operator reliability and systematic error i.e. differences in measurements among methods investigated was evaluated by Bland Altman statistical inference procedure. The level of statistical significance was set at $p < 0.05$.

All the three tracing methods were compared together with intra class co-relation co-efficient statistical inference procedure. The level of statistical significance was set at intra class co-relation co-efficient > 0.75.

Time required for tracing in different groups was compared using Friedman's test.

Table 2 – Cephalometric parameters evaluated.

S No	Cephalometric parameter	Definition
Skeltal		
	SNA	The inferior posterior angle formed by the intersection of lines SN and NA.
	SNB	The inferior posterior angle formed by the intersection of lines SN and NB.
	ANB	Angle formed by the intersection of lines NA and NB.
	N perp – A	Perpendicular distance from point A to a line perpendicular to the FH plane from point N.
	N perp – Pog	Perpendicular distance from pogonion to a line perpendicular to the FH plane from point N.
Dental		
	U1 – NA (°)	Angle formed by intersection of the long axis of most prominent maxillary central incisor to the plane between points N and A.
	U1 – NA (mm)	Perpendicular distance from the tip of most prominent maxillary central incisor to the plane between points N and A.
	L1 - NB (°)	Angle formed by intersection of the long axis of most prominent mandibular central incisor to the plane between points N and B.
	L1 – NB (mm)	Perpendicular distance from the tip of most prominent mandibular central incisor to the plane between points N and B.
	U1 - L1(°)	Angle formed by intersection of long axis of most prominent maxillary central incisor and long axis of most prominent mandibular central incisor.
Growth Pattern		
	Saddle angle	Angle formed by nasion - sella and sella – articulare planes.
	Articulare angle	Angle formed by sella - articulare and articulare – gonion planes.
	Gonial angle	Angle formed by articulare - gonion and gonion – menton planes.
	Sum	Sum of saddle, articulare & gonial angles.
	FMA	Angle formed between Go-Me plane and Frankfort horizontal planes.
	Go-Gn to Sn	Angle formed between Go-Gn plane and sella nasion planes.
Soft tissue		
	Nasolabial angle	Angle formed by columella, subnasale, and the most prominent point of the upper lip.
	Li – E line	Perpendicular distance between E line and Lower lip anterior / Labrale Inferius.

3. Results

3.1. *Intra operator reliability (Table 4)*

Among parameters evaluated statistically significant difference was found in SNB ($p = 0.00$), N perp – A ($p = 0.03$), U1-NA (mm) ($p = 0.00$), Saddle angle ($p = 0.01$), Articulare angle ($p = 0.00$), Gonial angle ($p = 0.00$), FMA ($p = 0.01$) and GoGn –SN ($p = 0.01$) in Group A, SNA ($p = 0.03$), ANB ($p = 0.01$), L1-NB (mm) ($p = 0.00$), Saddle angle ($p = 0.00$), Sum of saddle-articulare – gonial angles ($p = 0.00$) and FMA ($p = 0.00$) in Group B, N perp – A ($p = 0.04$), U1-NA (mm) ($p = 0.02$), Articulare angle ($p = 0.02$), FMA ($p = 0.03$) and Nasolabial angle ($p = 0.00$) in Group C.

3.2. *Systematic error between Group A–Group B, Group B–Group C and Group C–Group A (Table 5)*

Among parameters evaluated statistically significant difference was found in SNA ($p = 0.00$), SNB ($p = 0.00$), N perp – Pog ($p = 0.00$), U1-NA (mm) ($p = 0.00$), L1–NB (mm) ($p = 0.00$), Saddle angle ($p = 0.00$), Articulare angle ($p = 0.00$), Gonial angle ($p = 0.01$), Sum ($p = 0.00$), FMA ($p = 0.00$) and Go-Gn to Sn ($p = 0.00$) and and Nasolabial angle ($p = 0.03$) on comparing Group A with Group B, in SNA ($p = 0.00$), SNB ($p = 0.00$), Saddle angle ($p = 0.01$), Articulare angle ($p = 0.00$), Sum ($p = 0.00$) and FMA ($p = 0.00$), Nasolabial angle ($p = 0.00$) and Li – E line ($p = 0.00$) on comparing Group B with Group C and in SNA ($p = 0.00$), SNB ($p = 0.00$), N perp – Pog ($p = 0.00$), U1 – NA (°) ($p = 0.02$), U1 – NA (mm) ($p = 0.00$), L1–NB (mm) ($p = 0.00$), Saddle angle ($p = 0.00$), Articulare angle ($p = 0.00$), Gonial angle ($p = 0.00$), Sum ($p = 0.00$), FMA ($p = 0.00$), Go-Gn to Sn ($p = 0.02$), Nasolabial angle ($p = 0.00$) and Li – E line ($p = 0.00$) on comparing Group C with Group A.

3.3. *Systematic error among study Group A, Group B and Group C*

The intra class co-relation co-efficient for all the cephalometric parameters evaluated was greater than 0.9. (Table 6, Fig. 4)

3.4. *Comparison of time required*

Mean time taken in Group A, Group B and Group C was 15.5 min, 6.9 min and 7.2 min respectively. Mean rank for Group A, Group B and Group C were 3, 1.13 and 1.88 respectively. (Table 7)

4. Discussion

Lateral cephalograms are used for diagnosis, growth prediction and assessment of treatment outcome. Precise results can be achieved by minimizing the errors involved in

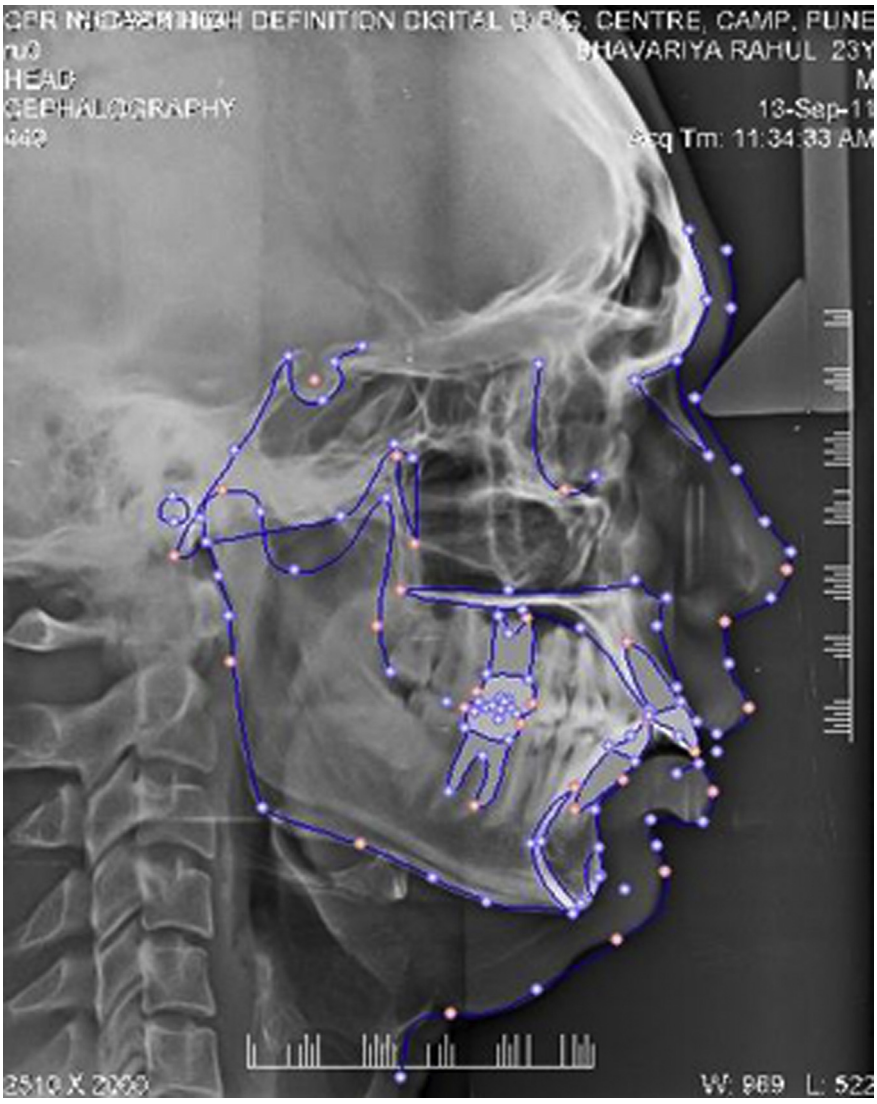


Fig. 3 – Landmarks traced for Group B and C.

cephalometry. Cephalometric errors are broadly categorized into acquisition, identification and technical measurement errors. Acquisition errors are made during cephalogram exposure or during computer processing. Identification errors are associated with landmark recognition which is mainly affected by observer experience, landmark definition and the quality of the image. Technical measurement errors are induced by measuring device or technique.

Digital cephalometry is an amalgamation of traditional cephalometry, computer science and digital technology. The progress in computer technology in orthodontics has not only resulted in ease of image archiving, manipulation and transmission but has also raised questions on the validity as well as the reproducibility of digital cephalometrics.[6]

In the present study manual tracing was done on the hard-copy printouts of the digital radiographs. Though distortion occurs when hard-copy printouts of digital cephalograms are obtained but studies have shown it to be clinically insignificant.[12] Proposed advantage of using digital cephalogram over analogue is that it eliminates processing error.

Bruntz et al[12] found vertical enlargement and horizontal reduction when analogue film was converted to digital format using a scanner. In the present study tracings on scanned images were compared with the tracings done by manual method and tracings of direct digital images using cephalometric software in order to determine if scanning is a reliable method of digitization.

In the present study, calibration errors were minimized as manual tracing was done on the hard-copy printouts of the digital radiographs printed at 1:1 magnification. Scanning of radiographs was done using the same scanner and computer and prior to digital tracing, images were calibrated using the software.

Cephalogram images were converted to JPEG format. Studies have shown that the loss of detail that occurs when an

Table 3 – Landmarks used in Group B and C.

Landmark	Definition
Skeletal	
Pm	Point midway between B and Pogonion.
Ag	Superior most point in the posterior part of inferior border of mandibular body.
Ks	Medial most point in the inferior part of posterior border of ramus.
Dental	
A6	Upper first molar, most distal surface.
A6M	Upper first molar, most mesial surface.
B6	Lower first molar, most distal surface.
B6M	Lower first molar, most mesial surface.
OA	Midpoint in the incisor overbite in occlusion.
OB	Most distal point of contact between the most posterior molars in occlusion.
Soft tissue	
Gn'	Most antero inferior point on the soft tissue chin in the mid saggital plane.
C	Deepest point formed by the submandibular area and the neck.
Me'	Most inferior point on the soft tissue chin in the mid saggital plane.
ILS/Ils	The point of greatest concavity in the midline between labrale inferius and soft tissue pogonion.
UL/Ls	Most anterior point on upper lip.
Sts	The lowermost point on the vermillion of upper lip.
SLS/Sls	The point of greatest concavity in the midline between subnasal & labrale superior.
N'	The point of greatest concavity in the midline between the forehead and the nose.
G	The most prominent anterior point in the mid saggital plane of forehead.

image is compressed into JPEG format does not significantly affect the diagnostic quality of the image when standard compression settings are used.[13,14]

In the present study quality parameters used were 300 dpi and 8 bit grayscale as (a) studies have shown that image quality of cephalogram in standard resolution (300 dpi) is comparable with high resolution (600 dpi) (b) Magnification leads to lack of clarity of image and scanning at 300 dpi prevented this problem.[15,16] Main drawback of using such high resolution radiographs is increase in the file size. It has been found that atleast 7-bit grayscale is mandatory because fewer gray shades may lead to unreliable decisions on reproducibility of measurements.[17]

For comparison of method of measurements with a standard method Bland and Altman[18] proposed calculation of the mean difference between two methods of measurement, 95% limits of agreement i.e. the mean difference +/− (1.96SD) and plotting the differences "Y" axis versus the mean of the two readings "X" axis. Zero bias line, 95% upper (0 + 1.96 SD) and 95% lower (0−1.96 SD) are also overlaid on the same scatter plot.

Bland–Altman plot discourages researchers from the misuse of applications of the correlation coefficient between two measurements as a measure of validity. Shortcoming with the correlation coefficient is that the two measures might be highly correlated, yet there could be substantial differences in the two measurements across their range of values.[18] Luiz et al[19] mentioned that Altman-Bland approach is the preferred statistical tool to evaluate agreement between two measurements.

In the present study, angular and linear cephalometric measurements have been evaluated over landmark identification because measurements provide data for treatment planning and also because the differences in landmark location used in combination to generate measurements might cancel each other out or increase the magnitude of the discrepancy.[10,15]

In the present study statistically significant difference was found in few parameters on comparing Group A with Group B, Group B with Group C and Group C with Group A (Table 5). Baumrind et al[20] have proposed that clinical significance should be determined by taking into account the standard deviation of normal value of each parameter evaluated. According to Chen et al[12] measurement differences of less than 2 units (mm or degree) are generally within 1 standard deviation of normal values in cephalometric analysis. Gregston et al[21] mentioned that in a clinical situation reproducibility that is within 2 ° or 2 mm will probably not make a difference in treatment. Since the difference of the mean observed between measurements was very small/negligible, therefore it was concluded that the readings made by the operator were highly reliable for all the parameters evaluated.

Manual method and Digital method are highly reliable for all cephalometric parameters evaluated as intra class co-relation co-efficient for all the variables was greater than 0.9 (Table 6).

Macrì and Wenzel[8] proposed that even though digital images can be enhanced, this would only increase reproducibility and not precision. Same was observed in the present study as image enhancement features of software were used while tracing radiographs of Group B and Group C. On comparing their results to those of Group A no significant differences were found.

Table 4 – Ascertaining intra operator reliability.

Variable	Group A					Group B					Group C				
	Mean (SD)		p value	95% CI for mean(diff)		Mean (SD)		p value	95% CI for mean(diff)		Mean (SD)		p value	95% CI for mean(diff)	
SNA	−0.17	0.65	0.17	−0.41	0.08	−0.1	0.25	0.03	−0.19	−0.01	0.01	0.22	0.8	−0.07	0.09
SNB	−0.3	0.47	0	−0.47	−0.13	0.01	0.38	0.85	−0.13	0.16	0.06	0.31	0.32	−0.06	0.17
ANB	0.1	0.71	0.45	−0.17	0.37	−0.14	0.28	0.01	−0.24	−0.04	−0.01	0.18	0.69	−0.08	0.05
N perp – A	−0.37	0.85	0.03	−0.68	−0.05	−0.07	0.34	0.3	−0.19	0.06	−0.1	0.25	0.04	−0.19	0
N perp – Pog	−0.27	1.14	0.21	−0.69	0.16	0.05	0.43	0.5	−0.11	0.21	0.01	0.39	0.93	−0.14	0.15
U1 – NA (°)	−0.37	1.16	0.09	−0.8	0.07	0.01	0.34	0.92	−0.12	0.13	−0.02	0.36	0.73	−0.16	0.11
U1 – NA (mm)	0.43	0.77	0	0.14	0.72	0.09	0.26	0.08	−0.01	0.19	−0.13	0.31	0.02	−0.25	−0.02
L1 – NB (°)	0.23	1.7	0.46	−0.4	0.87	0.1	0.29	0.08	−0.01	0.21	−0.09	0.3	0.1	−0.2	0.02
L1 – NB (mm)	−0.07	0.52	0.49	−0.26	0.13	0.21	0.27	0	0.11	0.31	0.08	0.33	0.21	−0.05	0.2
U1 – L1(°)	0.27	1.51	0.34	−0.3	0.83	0.05	0.44	0.54	−0.12	0.22	0.09	0.32	0.12	−0.03	0.21
Saddle angle	0.4	0.77	0.01	0.11	0.69	0.34	0.48	0	0.16	0.51	0.01	0.49	0.88	−0.17	0.2
Articulare angle	−0.77	0.94	0	−1.12	−0.42	0.04	0.9	0.81	−0.3	0.38	0.39	0.84	0.02	0.08	0.7
Gonial angle	0.67	0.96	0	0.31	1.02	0.07	0.65	0.56	−0.17	0.31	−0.12	0.4	0.12	−0.27	0.03
Sum	0.27	0.94	0.13	−0.09	0.62	0.48	0.69	0	0.22	0.74	0.34	1.08	0.1	−0.07	0.74
FMA	0.47	0.86	0.01	0.15	0.79	0.32	0.55	0	0.12	0.53	0.25	0.6	0.03	0.02	0.47
Go-Gn to Sn	0.33	0.66	0.01	0.09	0.58	0.09	0.7	0.47	−0.17	0.35	0	0.8	0.98	−0.3	0.29
Nasolabial angle	−0.07	1.41	0.8	−0.59	0.46	−0.13	0.41	0.09	−0.28	0.02	−0.66	0.89	0	−0.99	−0.33
Li – E line	−0.17	0.46	0.06	−0.34	0.01	0.02	0.39	0.78	−0.13	0.17	−0.12	0.93	0.5	−0.46	0.23

Table 5 – Ascertaining systematic errors between groups.

Variable	Group A & Group B					Group B & Group C					Group C & Group A				
	Mean	SD	p value	95% CI for mean(diff)		Mean	SD	p value	95% CI for mean(diff)		Mean	SD	p value	95% CI for mean(diff)	
SNA	−0.27	0.54	0	−0.38	−0.17	−0.23	0.63	0	−0.35	−0.1	−0.55	1.06	0	−0.76	−0.34
SNB	−0.33	0.68	0	−0.46	−0.19	−0.21	0.55	0	−0.32	−0.1	−0.54	0.86	0	−0.71	−0.36
ANB	0.01	0.55	0.86	−0.1	0.12	−0.01	0.23	0.61	−0.06	0.03	0.02	0.49	0.71	−0.08	0.12
N perp – A	0.13	0.9	0.15	−0.05	0.31	−0.08	0.43	0.07	−0.16	0.01	0.04	0.98	0.66	−0.15	0.24
N perp – Pog	−0.42	1.01	0	−0.62	−0.22	0.14	0.69	0.05	0	0.27	−0.33	0.95	0	−0.52	−0.14
U1 – NA (°)	−0.12	0.69	0.08	−0.26	0.01	−0.07	0.47	0.13	−0.17	0.02	−0.18	0.75	0.02	−0.32	−0.03
U1 – NA (mm)	0.53	0.49	0	0.43	0.63	−0.11	0.61	0.08	−0.23	0.01	0.4	0.75	0	0.25	0.55
L1 – NB (°)	−0.1	0.66	0.14	−0.23	0.03	0.01	0.46	0.84	−0.08	0.1	−0.08	0.75	0.3	−0.23	0.07
L1 – NB (mm)	0.64	0.74	0	0.49	0.79	0	0.46	0.91	−0.1	0.09	0.64	0.81	0	0.47	0.8
U1 – L1(°)	0.17	2.7	0.52	−0.36	0.71	0.08	0.57	0.18	−0.04	0.19	0.25	2.73	0.36	−0.29	0.79
Saddle angle	0.87	1.03	0	0.67	1.08	0.23	0.81	0.01	0.07	0.39	1.39	1.54	0	1.09	1.7
Articulare angle	0.43	1.06	0	0.22	0.64	0.5	0.99	0	0.3	0.69	0.82	1.59	0	0.51	1.14
Gonial angle	−0.41	1.45	0.01	−0.69	−0.12	−0.11	0.77	0.15	−0.26	0.04	−0.69	1.8	0	−1.04	−0.33
Sum	1.35	2.02	0	0.95	1.75	0.72	1.26	0	0.47	0.96	1.91	1.9	0	1.53	2.28
FMA	−0.81	1.08	0	−1.03	−0.6	0.32	0.82	0	0.15	0.48	−0.5	1.33	0	−0.76	−0.23
Go-Gn to Sn	−0.76	1.97	0	−1.16	−0.37	0.2	1.28	0.12	−0.05	0.45	−0.56	2.35	0.02	−1.03	−0.1
Nasolabial angle	−0.53	2.49	0.03	−1.03	−0.04	−0.97	1.38	0	−1.25	−0.7	−1.41	2.71	0	−1.94	−0.87
Li – E line	0.01	0.75	0.87	−0.14	0.16	−0.41	0.8	0	−0.56	−0.25	−0.39	1.01	0	−0.59	−0.19

Table 6 – Ascertaining systematic error among Group A, Group B & Group C.

Parameter		Intraclass correlation	95% Confidence interval	
			Lower bound	Upper bound
SNA	Single measures	0.960	0.945	0.972
	Average measures	0.986	0.981	0.990
SNB	Single measures	0.977	0.968	0.984
	Average measures	0.992	0.989	0.995
ANB	Single measures	0.989	0.985	0.992
	Average measures	0.996	0.995	0.997
N perp – A	Single measures	0.959	0.943	0.971
	Average measures	0.986	0.980	0.990
N perp – Pog	Single measures	0.984	0.978	0.989
	Average measures	0.995	0.993	0.996
U1 – NA (°)	Single measures	0.998	0.997	0.998
	Average measures	0.999	0.999	0.999
U1 – NA (mm)	Single measures	0.974	0.965	0.982
	Average measures	0.991	0.988	0.994
L1 – NB (°)	Single measures	0.998	0.997	0.998
	Average measures	0.999	0.999	0.999
L1 – NB (mm)	Single measures	0.977	0.968	0.984
	Average measures	0.992	0.989	0.995
U1 – L1(°)	Single measures	0.990	0.986	0.993
	Average measures	0.997	0.995	0.998
Saddle angle	Single measures	0.959	0.944	0.971
	Average measures	0.986	0.981	0.990
Articulare angle	Single measures	0.941	0.919	0.958
	Average measures	0.980	0.972	0.986
Gonial angle	Single measures	0.969	0.958	0.978
	Average measures	0.990	0.985	0.993
Sum	Single measures	0.949	0.930	0.964
	Average measures	0.982	0.975	0.988
FMA	Single measures	0.981	0.973	0.986
	Average measures	0.994	0.991	0.995
Go-Gn to Sn	Single measures	0.960	0.944	0.971
	Average measures	0.986	0.981	0.990
Nasolabial angle	Single measures	0.980	0.972	0.986
	Average measures	0.993	0.990	0.995
Li – E line	Single measures	0.972	0.961	0.980
	Average measures	0.991	0.987	0.993

On evaluation of intra examiner reliability statistically significant difference was found in some of the parameters evaluated (Table 4). Since the difference of mean observed between original and repeat measurements was very small/negligible, therefore it was concluded that the readings made by the operator were highly reliable for all the parameters evaluated.

Various researchers have found difficulties in locating landmarks. Sekiguchi and Savara[22] indicated that nasion may be difficult to identify when the nasofrontal suture is not accurately visualized. Chen et al[7] found difficulty in locating gonion due to poorly defined anatomical outline. In the present study operator did not find difficulty in landmark

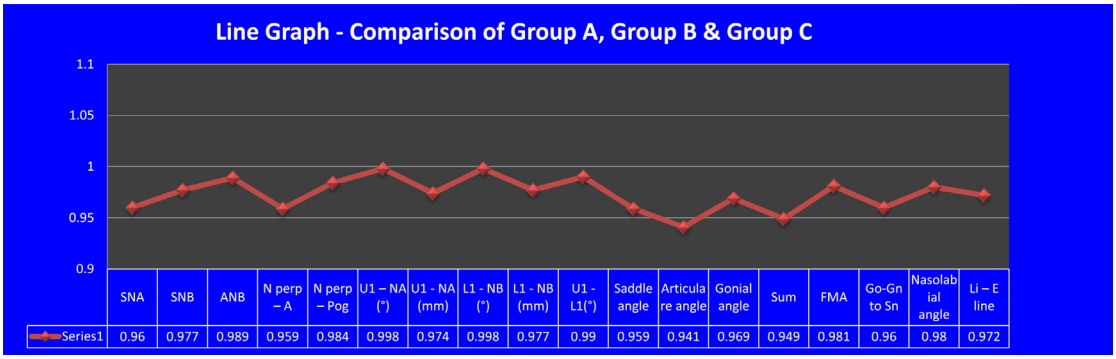


Fig. 4 – Comparison of Group A, Group B & Group C.

Table 7 – Comparison of time required.

Variable	N	Mean rank	Mean	Std. deviation	Minimum	Maximum	Percentiles			Friedman test
							25th	50th (Median)	75th	
Manual	100	3.00	930.05	16.515	899	999	919.00	929.50	939.00	Chi-Square = 179.471032745592
Digital	100	1.13	411.93	39.376	357	482	372.50	400.00	449.00	Df = 2
Scanned	100	1.88	430.53	39.516	357	495	399.75	430.00	467.50	Asymp. Sig.(p value) < (0.001)

identification as intra examiner reliability was high in all the study groups.

Comparison of time required among study groups had statistically significant difference (Table 7). Manual tracing time was approx double the time required for tracing by using cephalometric software.

4.1. *Limitations of the study*

- More soft tissue parameters need to be evaluated.
- Time taken was not categorized into time required for landmark location, tracing and making measurements.
- Reliability of NemoCeph NX 2006 software for predicting growth and surgical treatment outcome needs further study with a larger sample size and more number of operators.

5. Conclusions

Following conclusions were drawn from the present study:-

1. On comparing manual tracing and NemoCeph NX 2006 software tracing of direct digital images and scanned images of lateral cephalogram, statistically significant differences were found which were not clinically significant.
2. The validity and reproducibility of various cephalometric parameters by different tracing methods was found to be highly correlated.
3. In comparison to manual method, tracing using software provides a significant time advantage.

Conflicts of interest

All authors have none to declare.

REFERENCES

1. Hofrath H. DieBedeutung der Rontgenfern und Abstandsaufnahmefur die Diagnostik der Kieferanomalien. *Fortschr Orthod*. 1931;1:231–258.
2. Broadbent BH. A new x-ray technique and its application to orthodontics. *Angle Orthod*. 1931;1:45–66.
3. Chen SK, Chen YJ, Yao CCJ, Chang HF. Enhanced speed and precision of measurement in a computer-assisted digital cephalometric analysis system. *Angle Orthod*. 2004;74:501–507.
4. Jackson PH, Dickson GC, Birnie DJ. Digital image processing of cephalometric radiographs: a preliminary report. *Br J Orthod*. 1985;12:122–132.
5. Cohen AM, Linney AD. A low cost system for computed-based cephalometric analysis. *Br J Orthod*. 1986;13:105–118.
6. Forsyth DB, Shaw WC, Richmond S. Digital imaging of cephalometric radiography, part 1: advantages and limitations of digital imaging. *Angle Orthod*. 1996;66:37–42.
7. Chen YJ, Chen SK, Chang HF, Chen KC. Comparison of landmark identification in traditional versus computer-aided digital cephalometry. *Angle Orthod*. 2000;70:387–392.
8. Macri V, Wenzel A. Reliability of landmark recording on film and digital lateral cephalograms. *Eur J Orthod*. 1993;15:137–148.
9. Chen YJ, Chen SK, Yao JCC, Chang HF. The effects of differences in landmark identification on the cephalometric measurements in traditional versus digital cephalometry. *Angle Orthod*. 2004;74:155–161.
10. Santoro M, Jarjoura K, Cangialosi TJ. Accuracy of digital and analogue cephalometric measurements assessed with the sandwich technique. *Am J Orthod Dentofacial Orthop*. 2006;129:345–351.
11. Ozsoy OP, Gokcelik A, Memikoglu TUT. Differences in cephalometric measurements: a comparison of digital versus hand-tracing methods. *Eur J Orthod*. 2009;31:254–259.
12. Bruntz LQ, Palomo JM, Baden S, Hans MG. A comparison of scanned lateral cephalograms with corresponding original radiographs. *Am J Orthod Dentofacial Orthop*. 2006;130:340–348.
13. MacMahon H, Doi K, Sanada S. Data compression: effect on diagnostic accuracy in digital chest radiography. *Radiology*. 1991;178:175–179.
14. Goldberg MA, Pivovarov M, Mayo-Smith WW, et al. Application of wavelet compression to digital radiographs. *AJR Am J Roentgenol*. 1994;163:463–468.
15. Ongkosuwito EM, Katsaros C, Hof MAV, Bodegom JC, Jagtman AMK. The reproducibility of cephalometric measurements: a comparison of analogue and digital methods. *Eur J Orthod*. 2002;24:655–665.
16. Sayinsu K, Isik F, Trakyali G, Arun T. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. *Eur J Orthod*. 2007;29:105–108.
17. Thijssen M. *Bepaling en bewaking van de beeldkwaliteit in de radiodiagnostiek [Definition and control of image quality in radiographic diagnostics]* [PhD Thesis]. Netherlands: Universiteitsdrukkerij KUN; 1993.
18. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1:307–310.
19. Luiz RR, Costa AJL, Kale PL, Werneck GL. Assessment of agreement of a quantitative variable: a new graphical approach. *J Clin Epidemiol*. 2003;56:963–967.
20. Baumrind S, Frantz RC. The reliability of headfilm measurements–2. Conventional angular and linear measurements. *Am J Ortho*. 1971;60:505–517.
21. Gregston MD, Kula T, Hardman P, Glaros A, Kula K. A comparison of conventional and digital radiographic methods and cephalometric analysis software: I. Hard tissue. *Semin Orthod*. 2004;10:204–211.
22. Sekiguchi T, Savara BS. Variability of cephalometrc landmarks used for face growth studies. *Am J Orthod*. 1972;61:603–618.