

Measurements from conventional, digital and CT-derived cephalograms: a comparative study

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Objective: The purpose of this retrospective radiographic study was to determine the reliability and reproducibility of skeletal and dental measurements of lateral cephalograms created from a computerised tomography (CT) scan compared with conventional and digital lateral cephalograms.

Methods: CT and conventional lateral cephalograms of the same patients were obtained from university archives. The lateral cephalometric radiographs of 30 patients were manually traced. The radiographs were subsequently scanned and traced using Dolphin Imaging software version 11 (Dolphin Imaging, Chatsworth, CA, USA). The CT-created lateral cephalograms were also traced using the same software. Sixteen (10 angular and 6 linear) measurements were performed. Cephalometric measurements obtained from conventional, digital and CT-created cephalograms were statistically compared using repeated measures analysis of variance (ANOVA). Statistical significance was set at the $p < 0.05$ level of confidence.

Results: The intra-rater reliability test for each method showed high values ($r > 0.90$) except for mandibular length which had a correlation of 0.82 for the CT-created cephalogram. Five measurements (N-A-Pog, N-S, ANS-PNS, Co-ANS and Co-Gn) were found to be significantly different between the CT-created and conventional cephalograms and three measurements (SNB, ANB, and /1-MP) were found to be significantly different between the CT-created and digital cephalograms.

Conclusions: There are statistically-significant differences in measurements produced using a traditional manual analysis, a direct digital analysis or a 3D CT-derived cephalometric analysis of orthodontic patients. These differences are, on average, small but because of individual variation, may be of considerable clinical significance in some patients.

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Introduction

Cephalometry has been a valuable tool for clinical evaluation and research purposes in orthodontics. Two techniques may be used for cephalometric analysis; manual or computer aided. The manual technique involves landmark identification and a tracing performed on acetate paper, which is placed over the cephalometric radiograph. Difficulties with landmark identification¹⁻⁴ and measurement error are disadvantages.⁵ Computer-aided techniques also

require manual landmark identification using a mouse driven cursor on digital images. Software completes the analysis which reportedly reduces errors of tracing and measuring.⁶

Two-dimensional (2D) cephalograms have been used to interpret the three-dimensional (3D) craniofacial complex but suffer from limitations arising from distortion and the differential magnification of structures.⁷ Advances in imaging technology have made the 3D evaluation of the craniofacial structures

possible. While 3D analysis undergoes clinical validation,⁷ cephalometric analyses generated from 2D cephalograms are still used by many clinicians to determine the relationship of dentofacial structures.⁸⁻¹⁰

Computerised tomography (CT) makes comprehensive and accurate evaluation of dental and skeletal structures possible.¹¹ CT scans allow fast and precise acquisition of multiple thin slices to produce multiplanar 3D reconstructions which enhance the utility of CT as a diagnostic tool.¹¹ CT technology has become an acceptable, accurate and readily accessible aid in clinical practice to strengthen orthodontic diagnosis and treatment planning.¹¹

The purpose of this retrospective radiographic study was to determine the reliability and reproducibility of skeletal and dental measurements of lateral cephalograms created from CT scans compared with conventional and digital lateral cephalograms. The null hypothesis was that there were no differences in the comparative measurements generated using the three methods.

Materials and methods

Cephalograms were retrospectively gathered from the archives of the outpatient clinic of the Orthodontic Department, Al-Azhar University, Cairo, Egypt, of patients who had undergone spiral CT as a part of a previously conducted study.¹² The present study was approved by the Ethics Committee of the Faculty of Dental Medicine. The lateral cephalograms were taken with the same x-ray machine and a multi-planar spiral CT scanner (X vision EX, General Electric 'GE' Corporation Medical Systems Company, NY, USA) was used to obtain pretreatment CTs for all subjects. The patients' ages ranged from 8 to 15 years (mean 12.3 ± 1.9 years) and after applying the exclusion criteria, an original sample of 69 cephalograms was reduced to 30. Cephalometric records were excluded if the cephalogram showed gross asymmetry or that the patient was not properly positioned as shown by ear rod markers. In addition, records were excluded if landmarks could not be identified because of motion, resolution or lack of contrast; the cephalogram showed craniofacial deformity or excess soft tissues that could interfere with landmark location; or showed bilateral anatomical structures which did not allow accurate mid-sagittal superimpositions.

All cephalograms were taken with subjects positioned in the cephalostat with the sagittal plane perpendicular

to the path of the x-rays, Frankfort plane parallel to the floor, the teeth in centric occlusion and the lips lightly together. The conventional and digital tracings as well as all the measurements were performed by one investigator (AG). The manual tracing was performed on fine grain 0.003 inch transparent acetate papers using a 0.3 mm lead pencil. The tracing process was conducted in a darkened room using a screen-viewing box. The selected landmarks were traced with bilateral structures averaged to make a single structure or landmark. All measurements were carried out manually and entered into an Excel spreadsheet (Microsoft, Seattle, WA, USA) for statistical evaluation.

The radiographs were subsequently scanned (Epson Perfection V700 Photo, Long Beach, CA, USA) with an accompanying Dolphin ruler (100 mm) into a JPEG digital format at 300 dpi resolution and an eight-bit grey scale. Once captured, software calibration of the actual size of the image in millimeters was based on a

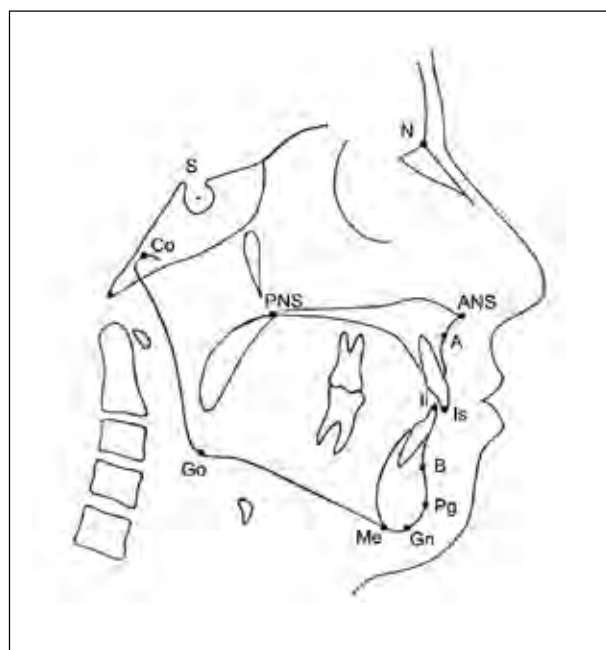


Figure 1. Cephalometric reference points and landmarks.

S: Sella
N: Nasion
ANS: Anterior nasal spine
PNS: Posterior nasal spine
Point-A (subnasal)
Is: Incisor superior
Ii: Incisor inferior
Point-B (supramental)
Pg: Pogonion
Gn: Gnathion
Me: Menton
Go: Gonion
Co: Condylion

Table I. Definition of cephalometric skeletal and dental measurements used in the study.

Skeletal angular measurements (degrees)	
SNA	Anteroposterior position of the maxilla relative to the anterior cranial base
SNB	Anteroposterior position of the mandible relative to the anterior cranial base
ANB	The difference between SNA and SNB angles, and defines the relationship, in the sagittal plane of the maxillary and mandibular bases
Angle of convexity	The angle formed by the intersection of the N-A-point to A-point – pogonion. It reveals the convexity (or concavity) of the skeletal profile
SN-MP	The angle formed between the SN plane and the mandibular plane
SN-PP	The angle formed between the SN plane and the Palatal plane
PP-MP	The angle formed between the palatal plane and the mandibular plane
Gonial angle	The angle between mandibular plane and ramal plane
Dental angular measurements (degrees):	
Upper incisor to SN (I /-SN)	The angle formed between the long axis of upper central incisor and the anterior cranial base (SN plane)
Lower incisor to mandibulare plane (I /-MP)	The angle formed between long axis of lower central incisor and the mandibular plane
Skeletal linear measurements (mm):	
Anterior cranial base(N-S)	The linear distance from sella turcica and most anterior point of the frontonasal suture
Mandibular body length (Go-Gn)	Linear distance from gonion and gnathion
Maxillary length (ANS-PNS)	Linear distance from ANS to PNS
Co-ANS	The linear distance from condylion (Co) to anterior nasal spine. It represents the effective midfacial length
Co-Gn	The linear distance from condylion (Co) to the gnathion (Gn). It represents the effective mandibular length
LAFH(ANS-Me)	The lower anterior facial height, linear distance from ANS to Menton

S, Sella; N, Nasion; ANS, anterior nasal spine; PNS, posterior nasal spine; MP, mandibular plane; PP, palatal plane; Go, gonion; Gn, gnathion; Co, condylion; Me, menton; LAFH, lower anterior facial height

known distance between 2 points on the screen ruler. The digital tracing was performed using Dolphin Imaging software version 11 (Dolphin Imaging, Chatsworth, CA, USA). Landmark identification was carried out manually on the digital images using a mouse-driven cursor and data was stored in the Dolphin Imaging archive.

Patient CT scans were obtained at 120 kV and 20 mA (low dose), with a scanning time of 2 sec/section and voxel size 0.49. The machine's perpendicular light beams were used to standardise head position in all three planes. The scans were taken with the patients in the supine position with the palatal plane

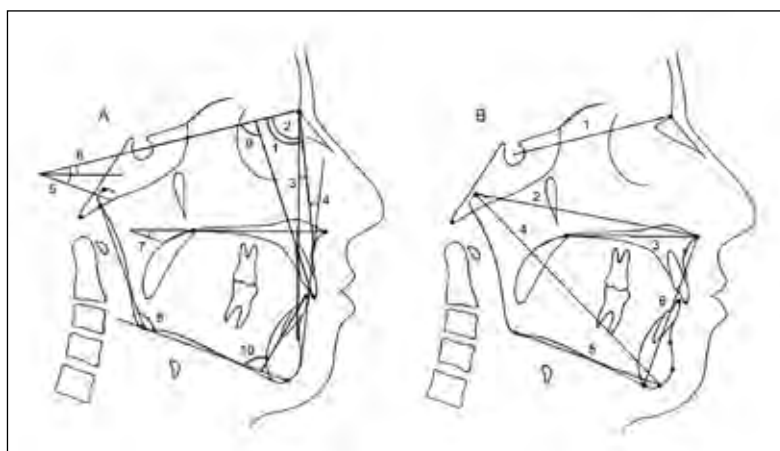
perpendicular to the floor. Each subject was positioned so that the longitudinal light beam passed through the center of glabella and the philtrum, and the transverse light beam passed through the lateral canthi of the eyes. Processing of the DICOM (digital imaging and communications in medicine) images, the creation of the lateral cephalograms with 100 mm bar (ruler), and the tracing and digitisation of cephalograms were carried out using Dolphin Imaging software.

Thirteen landmarks were defined on each cephalogram (Figure 1) and 16 selected skeletal and dental parameters were measured (Table I and Figure

Table II. Mean differences, standard deviation (SD) and intra-examiner reliability expressed as Pearson's correlation coefficient for repeated measurements of conventional, digital cephalograms and computed tomography.

Measurements	Conventional cephalogram		Digital cephalogram		Computed tomography scanogram	
	Difference (Mean $\pm$ SD)	r	Difference (Mean $\pm$ SD)	r	Difference (Mean $\pm$ SD)	r
Angular (degrees)						
SNA	-0.03 $\pm$ 0.7	0.98	0.6 $\pm$ 1.6	0.93	0.1 $\pm$ 1.2	0.95
SNB	-0.4 $\pm$ 1.2	0.94	0.1 $\pm$ 0.9	0.97	0.4 $\pm$ 1.4	0.93
ANB	0.4 $\pm$ 1.4	0.92	0.5 $\pm$ 1.3	0.91	0.4 $\pm$ 1.5	0.88
Angle of convexity (N-A-Pog)	-0.04 $\pm$ 0.7	0.99	-0.0007 $\pm$ 1.1	0.99	0.3 $\pm$ 0.9	0.99
SN-MP	-0.2 $\pm$ 0.8	0.99	0.07 $\pm$ 0.5	0.99	0.5 $\pm$ 2.1	0.95
SN-PP	0.7 $\pm$ 0.9	0.98	-0.6 $\pm$ 1.3	0.96	0.2 $\pm$ 1.3	0.95
PP-MP	-0.3 $\pm$ 0.8	0.99	0.01 $\pm$ 0.4	0.99	0.3 $\pm$ 1.9	0.95
Gonial angle	-0.1 $\pm$ 0.7	0.99	0.007 $\pm$ 0.4	0.99	0.3 $\pm$ 1.8	0.96
1/-SN	-0.2 $\pm$ 0.9	0.99	-0.1 $\pm$ 0.9	0.99	0.2 $\pm$ 1.3	0.98
/1-MP	0.4 $\pm$ 1.3	0.99	-0.2 $\pm$ 0.8	0.99	0.7 $\pm$ 1.7	0.97
Linear (mm)						
N-S	0.3 $\pm$ 0.9	0.97	-0.1 $\pm$ 0.7	0.98	0.6 $\pm$ 1.4	0.95
Go-Gn	-1.3 $\pm$ 1.6	0.94	1.7 $\pm$ 1.9	0.94	0.3 $\pm$ 3.6	0.82
ANS-PNS	0.6 $\pm$ 2.5	0.82	-1 $\pm$ 2.1	0.91	0.5 $\pm$ 1.4	0.94
Co-ANS	1.3 $\pm$ 1.5	0.96	-0.8 $\pm$ 1.3	0.96	0.6 $\pm$ 1.5	0.93
Co-Gn	0.6 $\pm$ 1.2	0.98	-0.7 $\pm$ 1.0	0.99	0.2 $\pm$ 1.4	0.98
IAFH	0.1 $\pm$ 0.7	0.99	-0.4 $\pm$ 1.3	0.98	0.5 $\pm$ 1.3	0.98

r (Pearson's correlation coefficient): $r > 0.8$ = strong; $0.5 \leq r \leq 0.8$ = moderate; $r < 0.5$ = weak

**Figure 2.** Cephalometric measurements.

A. Skeletal and dental angular measurements: 1, SNA; 2, SNB; 3, ANB; 4, angle of convexity; 5, SN-MP; 6, SN-PP; 7, PP-MP; 8, gonial angle; 9, 1/-SN; 10, /1-MP

B. Skeletal linear measurements: 1, N-S; 2, Co-ANS; 3, ANS-PNS; 4, Co-Gn; 5, Go-Gn; 6, ANS-Me

2). All 30 radiographs were retraced manually and digitally (scanned cephalograms and CT created cephalograms) within a six-week interval to assess examiner reliability (intra-examiner error) and the reproducibility of the manual and digital methods. The scanned images and constructed images were analysed together to avoid introducing additional errors in scanning and orientation. Linear and angular parameters were measured to the nearest 0.1 mm and 0.1 degree respectively.

All statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS), 16.0 (SPSS Inc, Chicago, IL, USA). Shapiro-Wilks normality test and Levene's variance homogeneity test were applied to the data. Because data were found to be normally distributed and there was homogeneity of variance between the groups, the statistical evaluations were performed using parametric tests. The results of the comparison between the angular and linear measurements of the conventional, digital and CT techniques were calculated by repeated measures analysis of variance (one-way ANOVA) and Tukey Honestly Significant Difference (HSD) test. Statistical significance was tested at alpha level of 0.05.

Results

Intra-examiner reliability of repeated measurements, the mean differences, standard deviations and correlation coefficients (r) for each of the 16 measurements of conventional, digital and computed tomography techniques are presented in Table II. The greatest difference between the first and second tracings within each technique was 1.3 mm and 0.7 degrees (Co-ANS, SN-PP) for the conventional, 1.7 mm and 0.6 degrees (Go-Gn, SNA) for the digital and 0.6 mm and 0.7 degrees (N-S, /I-MP) for the CT techniques, respectively. The correlation coefficients (r) of all measurements for the three methods were above 0.90 (strong correlation) except for maxillary length which had a correlation of 0.82 for the conventional cephalogram, ANB angle ($r = 0.88$) and mandibular length ($r = 0.82$) for the CT. Overall, reliability was good and intra-examiner error was small.

The results of the statistical analysis are summarised in Table III. Significant differences between the three techniques were observed for nearly all of the angular and linear measurements. Only two out of the ten angular measurements [SN-MP ($p = 0.112$)

and I/-SN ($p = 0.084$)], and only one out of six linear measurements [LAFH ($p = 0.290$)] showed no statistically significant difference between the groups.

Discussion

The present study compared the reliability and reproducibility of cephalometric measurements on CT-created cephalograms with conventional and digital lateral cephalograms. According to Richardson¹³ and Sandler,¹⁴ manual tracing methods compare favourably with the results obtained from digitised radiographs. Gravely and Benzies¹⁵ reported that, if landmark identification was performed manually, measurement errors were no different from those produced via digital means. In the current study, statistically significant differences were found between manual and computer-aided techniques. These results matched those of Chen et al.¹⁶ who showed significant differences for all measurements derived from conventional radiographs and digitised cephalograms. Although statistically significant differences were found between the measurements performed on conventional and digital cephalograms, Baumrind et al. suggested that the clinical significance should be evaluated based on the standard deviations.¹⁷ The small differences in the averages generated from the three sets of measurements might be of little clinical significance but, because of large standard deviations, differences for individual patients may be of considerable importance.

The diagnostic value of cephalometric analysis has been shown to be associated with accurate and reproducible landmark identification.^{18,19} However, this is also believed to be the main source of analysis error.²⁰⁻²² The variability of the patient's hard and soft tissues, radiographic quality and the experience of the clinician, affects the accurate identification of landmarks.²³ While Chen et al.¹⁶ expected digitised image processing would assist landmark identification on poorly defined structures, Macri and Wenzel reported that landmark reliability in lower quality digitised radiographs was not shown to improve with digital processing.²⁴

The quality of a digital image relies on the number of pixels and gray levels. The reliability of landmark identification on a digital cephalogram with a pixel size of 0.003 mm has been shown to be better than a landmark identified on an original radiograph.²⁵ In

Table III. Mean, standard deviation (SD) and the significant differences between conventional, digital cephalograms and computed tomography as expressed by *p* value.

Measurements	Conventional cephalogram	Digital cephalogram	Computed tomography scanogram	<i>p</i> value	Multiple comparison		
	Mean ± SD	Mean ± SD	Mean ± SD		Digital/manual	CT/manual	CT/digital
Angular (degrees)							
SNA	78.3 ± 3.3	79.3 ± 3.6	78.8 ± 3.9	0.001*	0.000	0.428	0.153
SNB	76.2 ± 3.6	77.4 ± 3.6	76.0 ± 3.8	0.001*	0.000	1.000	0.007
ANB	2.1 ± 3.4	1.9 ± 3.2	2.8 ± 2.6	0.023*	1.000	0.135	0.043
Angle of convexity (N-A-Pog)	4.1 ± 6.0	4.5 ± 6.3	4.9 ± 6.3	0.007*	0.020	0.014	0.747
SN-MP	41.8 ± 6.5	42.4 ± 6.3	42.6 ± 6.9	0.112			
SN-PP	8.3 ± 3.9	7.4 ± 3.8	7.9 ± 4.3	0.021*	0.000	0.615	0.471
PP-MP	34.6 ± 6.6	35.7 ± 6.5	35.6 ± 5.8	0.038*	0.000	0.167	1.000
Gonial angle	131.6 ± 6.3	132.5 ± 7.0	131.5 ± 6.4	0.048*	0.009	1.000	0.150
1/-SN	103.9 ± 7.4	104.5 ± 7.0	103.7 ± 7.4	0.084			
/1-MP	84.7 ± 7.8	84.1 ± 7.9	85.8 ± 7.5	0.001*	0.140	0.390	0.002
Linear (mm)							
N-S	70.3 ± 4.3	70.1 ± 4.5	69.3 ± 4.6	0.002*	1.000	0.011	0.052
Go-Gn	77.7 ± 4.5	80.0 ± 4.8	78.5 ± 5.9	0.001*	0.000	0.376	0.090
ANS-PNS	50.9 ± 3.6	49.8 ± 4.0	48.6 ± 4.5	0.000*	0.033	0.001	0.134
Co-ANS	87.9 ± 4.8	85.0 ± 4.7	85.0 ± 4.2	0.000*	0.000	0.000	1.000
Co-Gn	118.8 ± 6.8	116.5 ± 7.3	117.1 ± 7.6	0.000*	0.000	0.001	0.777
IAFH	74.1 ± 7.5	74.0 ± 7.1	74.6 ± 7.0	0.290			

*Significant at *p* < 0.05

the present study, the image resolution was set at 300 dpi with 8 bit grey levels for improved visualisation, even though the software manufacturer recommended a resolution of 150 dpi. Using high resolution, good quality radiographs with the assistance of software manipulation, clear visualisation of anatomic structures and the accuracy of landmark identification may approximate those obtained using quality CT cephalograms. The present study determined that the fewest number of differences were found between the CT-synthesised cephalograms and the digital cephalograms which was attributed to the high quality of the images.

According to Cevdanes et al., landmarks like condylion, porion and gonion have greater margins for error.²⁶ Superimposition of middle ear and temporal fossa structures make the identification of anatomical porion difficult⁷ and Chen et al.²⁷ showed significant variability in the localisation of gonion. Bruntz et al.²⁸ confirmed the unreliability of landmarks like porion, articulare, posterior nasal spine and the upper molar while Sekiguchi and Savara²⁹ stated that nasion was difficult to identify if the naso-frontal suture was obscure. This might explain the statistically significant differences found in measurements which involved nasion, gonion, posterior nasal spine and condylion in the present study. However, 1/SN and

SN-MP measurements, which include nasion, did not statistically vary between the three methods.

It has been considered that 3D CT cephalometry is highly accurate and reliable.^{30,31} According to the results of the present study, cephalometric measurements performed on CT-created cephalograms may be assumed to be comparable with conventional and digitised cephalograms. However, greater differences were found between the conventional and digital cephalometric measurement methods.

The threshold for a clinically meaningful difference was suggested as ± 2 mm or ± 2 degrees.^{32,33} Olmez et al.³⁴ compared direct skull measurements with 3D computer-assisted measurements and showed good reliability of the computer-assisted measurements. However, greater differences were found in comparing direct skull measurements with cephalometric measurements. These differences were attributed to divergence of the x-ray beam and related magnification.³⁴ Structures at any distance from the central x-ray beam were magnified but structures farther from the film were magnified more.³⁴

The three-dimensional representation of structures is diagnostically important in the craniofacial area. Moreover, resorption, hyperplastic growth, displacement, shape anomalies of condyles and morphological differences between left and right sides may be detected with CT scans.⁷ These capabilities make the CT a valuable diagnostic tool but as new 3D techniques emerge, there is a need for reliable 3D normative data.⁷ Weighing the advantages and disadvantages of CT acquisition, radiation exposure and cost still restrain routine use in orthodontics.

Conclusions

From the results of this study, the following conclusions may be drawn:

1. Statistically-significant differences in measurements were identified when comparing traditional manual analysis, direct digital analysis or 3D CT-derived cephalometric analysis of orthodontic patients.
2. These differences may be small but, because of individual variation, may be of considerable clinical significance in selected patients.
3. The relevance of these differences will vary according to the aims and objectives set by assessing clinicians.

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