

ACCURACY OF CONE BEAM-DERIVED LATERAL CEPHALOMETRIC RADIOGRAPHS

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ABSTRACT:

The aim of the present study is to compare the accuracy of linear measurements derived from conventional lateral cephalograms (CLC) versus cephalometric images derived from cone beam CT (CBLC).

The sample consisted of 10 edentulous dry skulls. Fifteen anatomical landmarks; of which 4 bilateral; were marked on each skull using metallic markers. The distances between these landmarks provided 8 linear measurements commonly used in lateral cephalometric analyses. The skulls were imaged using two techniques, lateral cephalometric radiograph and cone beam computed tomography. Using the OsiriX® computer program, 8 linear measurements were measured on the CLC and the CBLC. These measurements were compared with one's made directly on the skull.*

The results of this study showed that cephalometric measurement obtained from CBLC images are more representative to the anatomical truth.

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* Available at: <http://homepage.mac.com/rosset-antoine/osirix/Index2.html>

INTRODUCTION

Currently the cone beam computed tomography (CBCT) is gaining more popularity in orthodontics¹⁻⁷. One of the main concerns is the reliability and accuracy of the measurements taken from lateral cephalometric images derived from CBCT in comparison to the standard cephalometric and the golden (anatomical truth) measurement.

In the present study we compared direct linear measurements made on human dry skulls (anatomical truth) with that made on conventional lateral cephalograms (CLC) and cephalograms derived from 3D CBCT images (CBLC). The aim is to find out which technique (CLC or CBLC) is more representative to the anatomical truth.

MATERIAL AND METHODS

The sample consisted of 10 edentulous dry skulls. Hard acrylic was placed between maxilla and mandible to fix them together. Fifteen anatomical landmarks, of which 4 are bilateral, were marked on each skull using metallic markers. The distances between these landmarks provided 8 linear measurements commonly used in lateral cephalometric analysis.

The following linear measurements were taken from each skull:

N-ANS, N-A, Po-Or, ANS-PNS, N-Me, Go-Me, Ar-Go and Go-Pog.

To establish the true distances between the selected anatomic points, skull measurements were independently made by 2 observers 3 times using an electronic digital caliper. The mean of the 6 measurements was taken as the anatomic truth. The left and right measurements for the bilateral linear dimensions (Or-Po, Go-Pog, Go-Me and Go-Co) were averaged.

The skulls were imaged using two techniques, lateral cephalometric radiography and cone beam computed tomography.

1-Digital lateral cephalometric radiograph:

The setup for the conventional digital lateral cephalogram was adjusted with the source to mid-sagittal plane distance maintained at 150

cm and the detector was positioned 15 cm from the mid sagittal plane for all exposures. Exposure settings were 70kVp, 11mA and 1second exposure time* .

The skulls were stabilized in the cephalostat placed on nasion point and 2 ear rods in the external auditory meati and positioned with the Frankfort Horizontal Plane parallel to the floor, the sagittal plane perpendicular to the x-ray beam, and the left side closest to the detector. The central ray was directed at the right external auditory meatus.

Digital images were saved as JPG format and all the above 8 linear measurements were measured using OsiriX® computer program (Fig.1)

2-Cone beam computed tomography:

Images were acquired with the i-CAT® system*. Operated at 3 to 8 mA (pulse mode) and 120 kV with a high-frequency generator with fixed anode and 0.5 mm nominal focal spot size.

The anterior symphyseal region of the mandible of each skull was placed in the chin holder, vertical and horizontal lasers were used to position the skull. Each skull was oriented by adjusting the chin support until the midsagittal plane was perpendicular to the floor, and the horizontal laser reference coincided with the Frankfort horizontal plane.

Lateral scout images were made, and skull position was adjusted so that discrepancies between bilateral structures (e.g., posterior and inferior borders of the mandibular rami and zygomatic arches) were less than 5 mm. A single 360° rotation, 20-second scan, comprising 306 basis projections was made of each skull with 17.0 cm (diameter) x 13.2 cm (height) field of view. Control of acquisition parameters (mA, kVp) was automated. Primary reconstruction of the data are automatically performed after acquisition. Secondary reconstruction occurred in real time and provided contiguous color-correlated perpendicular axial, coronal, and sagittal 2D multi-planar reformatting (MPR) slices, with isotropic 0.4-mm. Three-dimensional reconstruction was used to create 2D simulated lateral skull projection images from the CBCT system (Fig 2).

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The linear measurements were made using the same software (OsiriX).

Statistics

The data was collected, tabulated and analyzed. A reproducibility index, called the Concordance correlation coefficient (CCC), introduced by Lin⁸ was used. It evaluates the agreement between 2 readings (from the same sample) by measuring the variation for the 45° line through the origin (the concordance line)^{8,9,10}.

Inter-observer error

The same measurements for all the three groups were measured by two different observer. Paired t test was done to measure the inter-observer error.

RESULTS

Comparison between the mean linear measurements of CLC, CBCL and direct (actual) measurements on the skull are presented in Table (1).

A- Direct measurements on the skull versus CLC

The Concordance Correlation Coefficient revealed poor agreement for N-A, N-Me, Po-Or, Go-Ar, Go-Me and ANS-PNS measurements while N-ANS and Go-Pog showed fair and excellent agreement respectively. (Table: 2)

B- Direct measurements on the skull versus lateral cephalogram derived from CBCL

The Concordance Correlation Coefficient revealed excellent agreement for N-ANS, N-A and ANS-PNS, fair agreement for Po-Or and Go-Ar and poor agreement for Go-Me, Go-Pog and N-Me (Table 2).

Inter-observer error:

Paired t-test did not reveal any significant difference between the two observers measurements in all the groups (Table 3,4 &5).

Table (1): Mean of the linear measurements for LC, CBCT and direct skull measurements.

Measurement	Skull	LC	CBCT
N-A	61.825	68.229	62.156
N-Me	109.952	119.134	110.843
N-ANS	57.947	62.87	57.414
Po-Or	84.614	100.372	83.86
Ar-Go	32.071	33.466	31.997
Go-Me	93.243	92.131	81.046
Go-Pog	89.409	89.531	80.415
ANS-PNS	52.463	59.404	52.246

Table (2): Descriptive statistic for comparison between the CLC, CBLC and direct skull measurements.

Measurements	Test	LC	CBCT
N-A	CCC	0.026***	0.839*
N – Me	CCC	-0.006***	0.314***
N-ANS	CCC	0.466**	0.786*
Po-Or	CCC	-0.044***	0.730**
Ar-Go	CCC	0.129***	0.636**
GO-Me	CCC	0.251***	0.004***
Go-Pog	CCC	0.834*	0.046***
ANS-PNS	CCC	0.095***	0.836*

CCC = Concordance Correlation Coefficient:

*= $p > 0.75$ = Excellent agreement

**= $0.4 > p < 0.75$ = Fair agreement

***= $p < 0.4$ = Poor agreement

Table 3: Paired t-test measuring difference between 2 observer's measurements in the skull group.

	Mean ± SD		"t" value	Prob.
	Observer 1	Observer 2		
N-A	61.83 ± 0.33	61.45 ± 0.41	1.573	0.150 NS
N-Me	109.95 ± 0.35	110.23 ± 0.40	1.304	0.225 NS
N-ANS	57.95 ± 1.44	57.85 ± 1.41	0.588	0.570 NS
Po-Or	84.61 ± 0.51	84.62 ± 0.51	0.060	0.954 NS
Ar-Go	32.07 ± 0.24	32.25 ± 0.24	0.266	0.826 NS
Go-Me	93.24 ± 0.16	92.82 ± 0.21	0.419	0.685 NS
Go-Pog	89.41 ± 0.56	89.31 ± 0.60	0.846	0.420 NS
ANS-PNS	52.46 ± 0.40	52.57 ± 0.53	0.354	0.731 NS

Table 4: Paired t-test measuring difference between 2 observer's measurements in the CLC group.

	Mean ± SD		"t" value	Prob.
	Observer 1	Observer 2		
N-A	68.23 ± 0.57	67.93 ± 0.67	1.963	0.081 NS
N-Me	119.13 ± 0.54	118.88 ± 0.68	1.091	0.304 NS
N-ANS	62.87 ± 1.36	62.89 ± 1.35	0.176	0.864 NS
Po-Or	100.37 ± 2.47	100.25 ± 2.49	0.419	0.685 NS
Ar-Go	33.47 ± 0.33	33.42 ± 0.38	0.442	0.669 NS
Go-Me	92.13 ± 0.56	92.03 ± 0.70	0.487	0.638 NS
Go-Pog	89.53 ± 0.90	89.48 ± 1.02	0.250	0.808 NS
ANS-PNS	59.40 ± 0.92	59.68 ± 1.32	0.455	0.660 NS

Table 4: Paired t-test measuring difference between 2 observer's measurements in the CBLC group.

	Mean ± SD		"t" value	Prob.
	Observer 1	Observer 2		
N-A	62.16 ± 0.30	62.17 ± 0.40	0.063	0.951 NS
N-Me	110.84 ± 0.31	111.28 ± 0.44	1.820	0.102 NS
N-ANS	57.41 ± 1.16	57.24 ± 1.14	0.673	0.518 NS
Po-Or	83.86 ± 0.60	83.92 ± 0.58	0.209	0.840 NS
Ar-Go	32.00 ± 0.47	31.61 ± 0.52	1.402	0.195 NS
Go-Me	81.05 ± 1.22	80.72 ± 1.27	1.498	0.168 NS
Go-Pog	80.42 ± 1.07	80.37 ± 1.11	0.509	0.623 NS
ANS-PNS	52.25 ± 0.48	53.71 ± 1.00	1.409	0.192 NS

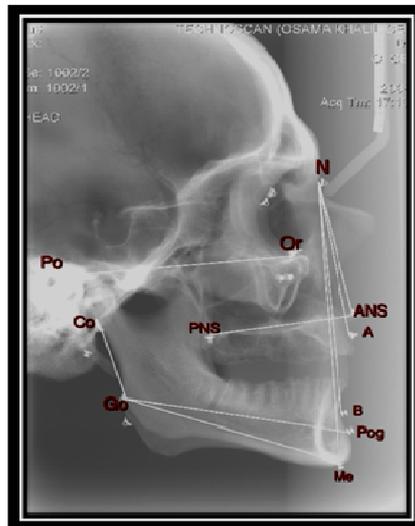


Figure (2): Traced digital lateral cephalogram of the skull

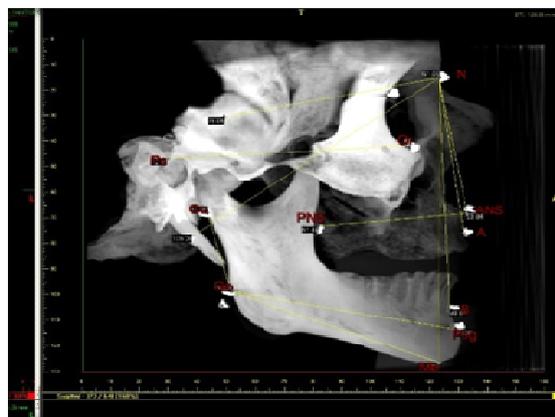


Figure (2): Traced Lateral cephalogram of the skull from three-dimensional cone beam computed tomography scans

DISCUSSION

Because assessment of anatomic landmarks in 3D is still under development, the transition from the 2D to the 3D analysis could be achieved by using CBCT synthesized cephalograms^{4,7}.

In order to evaluate the reliability and accuracy the CLC and CBLC techniques were compared to the anatomical truth (Direct skull measurements). Previous study applied similar technique but reevaluated soft tissue measurements¹¹.

The standardization of the skulls position in CBCT machines was done by vertical and horizontal laser beams, C-band around the forehead along with the scout image in which the x-ray beam was parallel to the occlusal plane.

In this study, OsiriX software was utilized for 3D reconstruction of CBCT cuts. Moreover, linear measurements of all lateral cephalometric tracings were calculated using the same software. Such software was proved useful in the display and analysis of large sets of three-dimensional medical images.

In order to eliminate identification errors, all cephalometric landmarks (N, A, ANS, B, Pog, Me, Or, PNS, Go, Ar and Po) were previously localized by metallic markers on the skull. Similar approach was described by Kusnoto B et al¹² and Adams GL et al¹³ who have used radiopaque markers on skeletal landmarks as targets for both physical and radiographic measurements. By applying direct physical measurements to these known and marked sites, the actual anatomical distances could be established as a gold standard with which the conventional lateral cephalograms and those obtained from CBCT images could be compared to determine their accuracy.

In the conventional lateral cephalometric image, the skulls were positioned visually in the cephalostat with the Frankfort plane parallel to the floor. On the other hand, skull positioning in the CBCT machine was done using laser level indicators. In addition, digital scout images were acquired to establish minimal bilateral discrepancy before final CBCT acquisition¹⁴.

Linear measurements obtained from conventional lateral cephalograms and those obtained from CBCT images were compared with those made directly on the skull. The results showed that cephalograms obtained from CBCT images were accurate for most of measurements and the conventional lateral cephalograms had the least

accuracy. Lateral cephalogram were accurate for ANS-PNS measurement. These results coincide with those of Moshiri F et al¹⁴. The only difference was that their measurements showed good agreement regarding N-Me, whereas in our study it showed fair agreement. Their conventional lateral cephalograms measurements also showed the least accuracy; but they were accurate for Po-Or and N-ANS.

This difference might be because of errors of projection present in the conventional cephalograms, and therefore the identification of landmarks of bilateral structures (eg, the mandibular line) presents some inaccuracy¹⁵.

On the other hand, the CBCT data sets can provide undistorted 3D morphology, making it possible to identify craniofacial structures more naturally.

In contrast to conventional cephalograms, the errors due to malposition of the patient during image acquisition could be corrected in CBCT data sets by iterative adjustment. The innate 3D characteristics of the CBCT data set allow for the generation of virtually an infinite number of reformatted images¹⁶ and orthogonal cephalograms (parallel x-rays). In addition, it is possible to represent the right and left parts of the skull separately, avoiding superimposition of the bilateral structures; the position of the teeth in the 2 sides can be determined, and all non-pertinent structures can be virtually excised¹⁷.

The results of this study are similar to that of Adams GL et al¹³ who found that cephalometric evaluation of radiographic images taken in the conventional 2D system often renders both inaccurate and imprecise measurements. In contrast, the relatively new 3D Cephalometric system (Sculptor) provides a much more precise evaluation of linear measures and only slightly inaccurate measures that are underestimated by about 1.0 mm.

CONCLUSION

- Cephalometric views derived from CBCT are accurate representative to the anatomical truth.

- Linear cephalometric measurements derived from CBCT do not coincide with the same measurements on the regular cephalometric x-ray.
- Caution should be taken when applying norms derived from regular lateral cephalometric on cephalometric derived from CBCT.

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