An evaluation of the reproducibility of landmark identification in traditional versus computer-assisted digital cephalometric analysis system

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Abstract

Objective: To determine the reliability of Computer Assisted Digital Cephalometric Analysis System (CADCAS) in terms of landmark identification on the values of cephalometric measurements in comparison with those obtained from original radiographs. **Materials and Methods:** The study material consisted of Twenty five lateral cephalograms selected randomly, 16 cephalometric points together with 10 angular and 5 linear cephalometric measurements. The landmarks were manually picked on the tracing & the measurements of X &Y axis done with reference grid. The same tracing was digitized & image loaded in the software (ViewBox 3.1.1) was checked for the magnification (metal ruler) & distortion. The second part of the study compared manual and the CADCAS since the landmarks were manually digitized on screen as against the manually picked ones on the tracing paper. The x and y-coordinates for 16 landmarks were measured, mean and standard deviation calculated, linear and angular measurements compared. **Statistical Analysis:** A paired t-test was done to calculate the statistical significance of the differences. Intraclass reliability coefficient (signifying reproducibility) of the variable was recorded. The observations were tabulated and analysis was done using the paired t test at a P value <0.05. **Results:** Out of 47 variables looked for, 21 showed statistical significance. Direct digitization onscreen (CADCAS) was the quickest and least tedious method. CADCAS was unreliable with linear measurements involving bilateral structures such as Gonion & Articulare. **Conclusions:** Both the methods are equally reliable and reproducible. The intra- class reliability coefficient of all variables differed only slightly, which is not clinically significant.

Key words: Cephalometrics, computer-assisted digital cephalometric analysis system, digitization

INTRODUCTION

Cephalometrics is an important tool in orthodontic diagnosis, treatment planning, evaluation of treatment results and prediction of growth. The traditional cephalometric analysis was performed by tracing radiographic landmarks on acetate overlays and using these landmarks to measure the desired linear and angular values. This traditional hand-tracing process can be time-consuming and the linear, and angular cephalometric measurements obtained manually with a ruler and protractor may be prone to error.[1] The major sources of error in cephalometric analysis include radiographic film magnification, tracing, measuring, recording, and landmarks identification.[1-5]

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Previous studies revealed that inconsistency in landmark identification is an important source of error in conventional cephalometry. This error is specific to each landmark and affected by experience and training of the observers.[1-3,5]

Rapid advances in computer science have led to its wide application in cephalometry. The computer-aided cephalometric analysis is faster in data acquisition and analysis than conventional methods.[6-10] Several cephalometric programs have been developed to computer-aided cephalometric analysis by digitizing the landmarks.

However, digitizing may introduce errors such as head film movement and improper sequencing of digitized points. To take advantage of image processing and computer-based filling system that can integrate patient's records and images, the original cephalometric radiographic films may be transformed into a digital format by a scanner or video camera. A radiographic system for taking direct-digital lateral cephalograms at reduced radiation dose is presently available.[11] Consequently, many commercially available or customized programs have been developed to conduct cephalometric analyses directly on the screen-displayed digital image.[12-14] Such application could substantially reduce the potential errors in the use of digitizing pads and totally eliminate the need of hardcopies of digitally born images for conventional cephalometric analysis. Digital cephalometry also has the benefits of image storage transmission and processing.[15]

Great efforts have been made to develop systems for automatic computerized identification of cephalometric landmarks.[16,17] However, automated systems are at present unable to compete with manual identification in terms of accuracy of landmark position. The landmarks lying on poorly defined structures are difficult to automatically identify due to poor signal-to-noise ratio.[14]

Earlier studies revealed that the computer-aided cephalometric analysis does not introduce more measurements error than tracing, as long as landmarks are identified manually.[18] Therefore, manually identifying landmarks on screen-displayed digital images for cephalometric analysis may still be the better strategy.

However, for digital imaging to offer significant advantages in cephalometry, the images must yield as much information as is available on conventional radiographic film. The main question is whether landmarks identification in digital images is comparable to that performed on original radiographic films.

The aim of this study, therefore, was to determine the reliability of computer-assisted digital cephalometric analysis system (CADCAS) in terms of landmark identification of the values of cephalometric measurements in comparison with those obtained from original radiographs.

MATERIALS AND METHODS

The study material consisted of twenty-five lateral Cephalograms selected randomly.

Criteria for case selection

- X-rays of good quality to permit identification of landmarks.
- Absence of unerupted or partially erupted teeth that would have hindered landmark identification.
- Subjects selected were nongrowers to reduce changes in image density due to growth (>16 years of age).

The 16 cephalometric points were used in the study, together with 10 angular and 5 linear cephalometric measurements [Figures 1-3].

ANALYSIS OF LATERAL CEPHALOGRAMS

Lateral cephalograms of 25 subjects under standardized conditions were taken. All the cephalograms were taken using a single machine (Planmeca Proline PM-2002) with an anode to midsubject distance of 5 feet. The tube voltage was 70 kvp, current 12 mA and exposure time was 1.8 s.

Each radiograph was calibrated for the X-axis and Y-axis (coordinates) drawing two lines with marker, perpendicular to each other with their intersection representing the (0,0) axes. These two lines were drawn such that they did not hinder any landmark identification. The area under these lines was selected for the study. These lines were used as a reference grid for digitizing the radiograph and measuring the horizontal and vertical distances of the recorded cephalometric landmarks and facilitate comparison of methods. The abscissa was sufficiently above and the ordinate sufficiently far to the left to ensure that all measurements recorded were positive. In addition, these lines were utilized by the software (ViewBox 3.1.1) program (dHAL software, Demetrios. J. Halozonetis, Kifissia, Greece) to recalibrate the change in the image size.

Methods

Landmark identification using tracing paper followed by measurement with ruler and protractor

Tracing was carried out in a darkened room using an

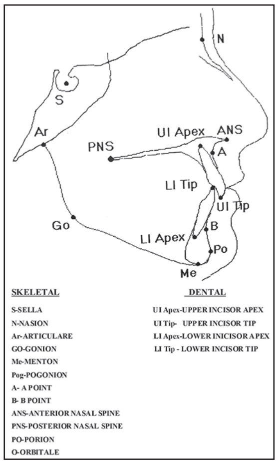

Figure 1: Cephalometric landmarks

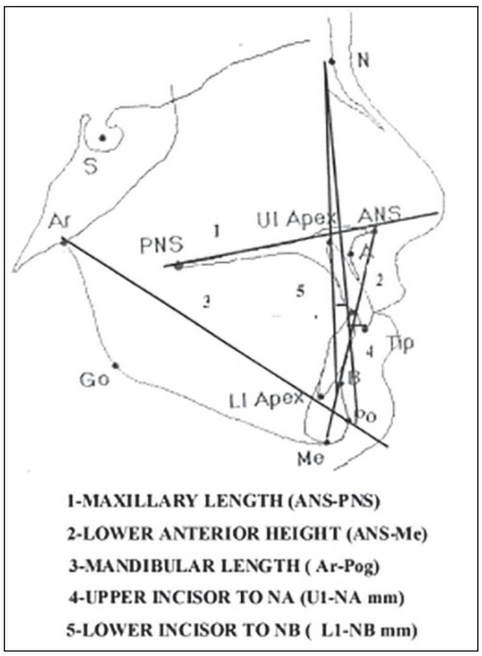

Figure 3: Cephalometric angles

illuminated viewing screen with a black surround to reduce extraneous light. Each radiograph was firmly secured to the surface of a viewing box and a sheet of fine grade, acetate tracing paper fixed to the x-ray. Using 2HB pencil landmarks were identified by a single point in structures and double images, the midpoint was chosen by construction. No more than 10 radiographs were traced in any one session to prevent operator fatigue, and the same radiograph was not retraced within week, to avoid the risk of memorization of landmarks. For hand measurements, the tracings were secured, and the relative reference grid was reproduced from the radiograph to the tracing sheet and then the X and Y coordinates for each landmark was recorded. Linear and angular measurements were done after drawing planes and angles required for it [Figure 4].

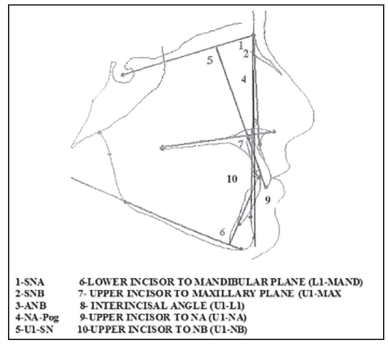

Figure 2: Cephalometric planes

Landmark identification using tracing paper followed by digitization

Following point identification on the tracing sheets with the reference grid marked on it, the tracing was scanned using an *Astra Umax-1220U* flatbed scanner. The optical resolution of the charged coupled device (CCD) on this scanner was 300 dpi (dot per inch). Each cephalometric point marked on the tracing paper was subsequently digitized using a crosswire mouse cursor and recorded by clicking a mouse button.

From these digitized points, the computer software (ViewBox 3.1.1) calculated the X and Y coordinate (in relation to the Cartesian axes) and then the software calculated the linear and angular measurements automatically [Figure 5].

Landmark identification using computerized recording of scanned images (computer-assisted digital cephalometric analysis system method)

The lateral skull radiographs were scanned using an *Astra Umax 1220U* flatbed scanner fitted with a transparency hood. The optical resolution of the CCD on this scanner was 300 dpi (dots per inch). Images were scanned and digitized using 'ViewBox 3.1.1' Cephanalysis and Surgical planning software for Windows developed by Dr. Halazonetis, dhal software limited, Greece.

Images were captured at the resolution of 300 dpi using grayscale palette and a magnification of 0%. As the final image is determined by scanning resolution and magnification factor, these two settings were kept constant for this study. It took approximately 10 s to scan each radiograph at this resolution. The images were stored as Joint Photographic Expert Group (JPEG) format, and each requiring 450 kb of disk space.

Radiographic images were subsequently opened using "ViewBox 3.1.1" software and digitized on 15 inch color monitor at a screen resolution of 800 × 600 pixels. The digitizing window is approximately 9 inches wide and 8 inches high on a 15 inch monitor.

The landmarks were located using a cross-wire mouse cursor and recorded by clicking a mouse button. The X and Y coordinates of these points were subsequently used to calculate various angular and linear measurements used in the study [Figure 6]. For each landmark, placement differences between original radiographs and their digitized counterparts assessed by the values of X and Y coordinates produced by the software. The X coordinate and Y coordinate were further analyzed to evaluate the pattern of recording differences in horizontal and vertical directions.

To verify the manual measurements of traditional cephalometric analysis, the value of each item was compared with the corresponding measurements from the digital counterpart (CADCAS). All the differences between the two sets of data were calculated and compared [Tables 1-3].

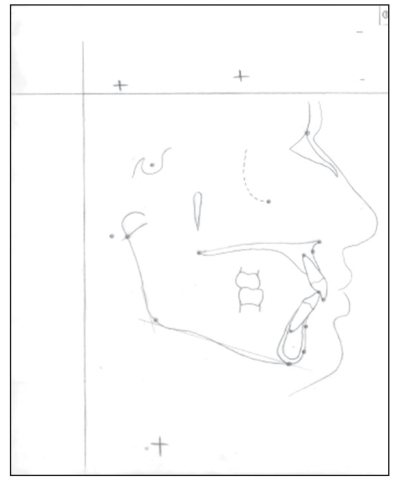

Figure 4: Manual tracing

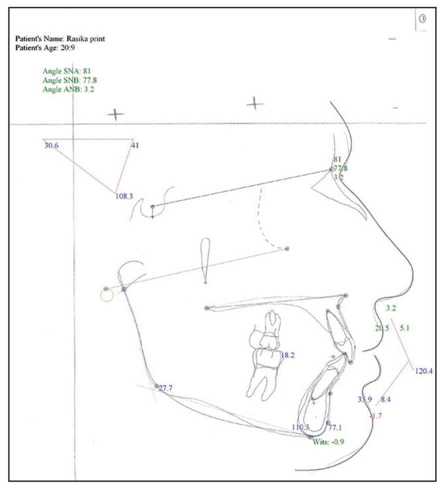

Figure 5: Digitized tracing

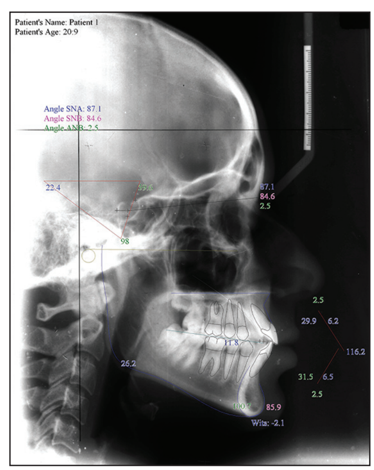

Figure 6: Computer-assisted digital cephalometric analysis system tracing

RESULTS AND DISCUSSION

Baumrind and Frantz[2] stated that some cephalometric landmarks can be located with more precision than others, depending on the radiographic complex of the region. The distribution of errors for many landmarks is systematic and follows a typical pattern (non-circular envelop) making the landmarks more reliable in either horizontal or vertical plane depending on the topographic orientation on the anatomic structures along which they are defined.

Ongkosuwito *et al.*[19] demonstrated that the image quality of a cephalogram scanned at resolution of 300 dpi is sufficient for clinical comparison to original analogue cephalometrics.

In this study, the disagreement between measurements from the traditional naked-eye method and with CADCAS could be explained partly by inherent factor in the traditional method. In measuring a tracing by a ruler and protractor, assumptions have to be made in an attempt to record the exact positions of the dotted landmarks and the pencil line, which themselves have a width.

The study consisted of 16 landmarks that were measured in X and Y coordinates. *Sella* was located well manually both in X axis and Y axis compared to CADCAS, as it showed less mean deviation. The reliability of *Articulare* point in digital image was not as good as in the original radiograph in Y axis. *Menton* ranks high in order of reproducibility in vertical direction. *Pogonion* can be located more precisely with both the methods in X axis, but in Y axis, the reliability of its location is questionable. *Gonion* The manual method was found a little better to CADCAS since the gonion point used was a constructed point. Point A was reliably located in X axis in both the methods. However, significant differences were produced in the Y axis. Since point A is marked as the anterior surface of maxilla, it is difficult to locate in Y axis than X axis. ANS was more reproducible vertically than horizontally. This could be because the radiographic images of the bone in this region tends to

Table 1: Comparison of Manual & CADCAS

Measurement X-AXIS	Manual Mean (x1)	Manual STDEV1	CADCAS Mean (x2)	CADCAS STDEV2	Mean diffrence (X1-X2)	Stdev diff. STDD (Sd)	Standard error (S.E) Sd/n	*T* value Mean/S.E	*P* value
SKELETAL									
Sella (S)	34.8	5.133	35.144	5.152	0.344	0.576	0.1152	3.34	**
Nasion (N)	108.12	6.628	108.048	6.811	0.072	0.96	0.192	0.375	NS
Articulare (Ar)	17.52	2.77	17.5	2.634	0.02	1.04	0.208	0.0962	NS
Gonion (Go)	27.76	4.841	27.22	4.834	0.54	1.82	0.364	1.48	NS
Menton (Me)	96.72	6.314	96.88	6.396	0.16	1.07	0.214	0.748	NS
Pogonion (Pog)	104.12	6.366	103.78	6.139	0.34	1	0.2	1.68	NS
A-Point	105.96	5.578	105.756	5.001	0.204	2.27	0.454	1.33	NS
B-Point	102.2	5.816	102.02	5.766	0.18	0.683	0.1366	1.32	NS
ANS	110.24	5.332	108.28	5.057	1.96	1.43	0.286	6.98	**
PNS	54.4	4.573	54.536	4.561	0.136	1.23	0.246	0.554	NS
Porion (Po)	13.4	2.081	13.592	2.116	0.192	0.445	0.089	2.16	**
Orbitale (O)	90.8	4.881	89.836	4.952	0.964	1.52	0.304	3.24	**
DENTAL									
UIE	111.68	5.728	111.216	5.189	0.464	2.42	0.484	0.958	NS
UIA	100.64	5.559	100.968	5.987	0.328	2.08	0.416	0.788	NS
LIE	108.28	5.556	108.236	5.532	0.044	0.81	0.162	0.271	NS
LIA	96.76	5.509	96.164	5.081	0.596	1.77	0.354	1.73	NS
Y-AXIS									
SKELETAL									
Sella (S)	36.6	5.041	37.044	5.178	0.444	0.463	0.0926	4.8	**
Nasion (N)	28.52	6.41	28.908	6.493	0.988	2.29	0.458	0.848	NS
Articulare (Ar)	69.4	4.133	70.188	4.339	0.788	1.23	0.246	3.16	**
Gonion (Go)	119.6	5.845	120.404	6.654	0.804	2.98	0.596	1.4	NS
Menton (Me)	146.16	8.209	146.392	8.396	0.232	0.823	0.164	1.41	NS
Pogonion (Pog)	139.44	8.036	137.412	7.736	2.028	1.48	0.296	6.87	**
A-Point	86.36	6.473	87.224	6.074	0.864	1.28	0.256	3.38	**
B-Point	126.04	7.179	128.836	8.019	2.796	2.18	0.436	5.85	**
ANS	81.84	6.121	82.296	6.034	0.456	0.826	0.165	2.76	**
PNS	81.6	4.272	81.712	4.383	0.112	0.942	0.188	0.594	NS
Porion (Po)	67.52	1.004	67.74	1.083	0.22	0.614	0.122	1.79	NS
Orbitale (O)	58.88	5.479	59.78	5.699	0.9	1.21	0.242	3.71	**
DENTAL									
UIE	109.72	6.997	108.95	9.316	0.77	20.4	4.08	1.26	NS
UIA	86.76	5.939	87.156	6.222	0.396	4.51	0.902	0.439	NS
LIE	106.84	6.668	106.856	6.736	0.016	0.551	0.1102	0.145	NS
LIA	126.12	6.186	126.7	6.77	0.58	3.38	0.676	0.325	NS

NS – Non-significant; *$p < 0.05$; **$p < 0.001$

fade out when followed horizontally, but the general line of nasal floor gives a useful indication of the situation of this landmark.

In this study, all the dental landmarks (UIE, UIA, LIE and LIA) were located quite well. When compared to CADCAS, neither variable had statistical significance. Due to radiopacity and definite sharp bends (in contrast to contour or curve) of the dental landmark, the localization is more consistent.

In this study, there was significant difference in the values of linear and angular measurements, which could be attributed to the difference in the localization of landmarks and measurement errors as seen in study of Sayinsu *et al*.[4] Since the first part of the study revealed significant differences in the landmark identification, this will consequently affect the linear and angular measurements.

Angular measurements: Seventy percent of the variables had mean differences between methods that were statistically significant. The greatest differences were found for the measurements involving Sella, A-point and Incisor position. The items with relatively larger measurement differences and a wide range of variations were angular measurements reflecting the axis of upper and lower incisal edges (U1-SN, L1-MAND, U1-MAX, U1-NA).

Table 2: Comparison of Manual and CADCAS

Measurement	Manual Mean (x1)	Manual STDEV1	CADCAS Mean (x2)	CADCAS STDEV2	Mean diff. (x1-x2)	Stdev diff. STDD (Sd)	Standard error (S.E)Sd/n	*T* value Mean/S.E	*P* value
LINEAR									
ANS-PNS	56.36	1.912	53.8232	1.941	2.5368	2.13	0.504	5.92	***
Ar-Pog	112.24	5.524	111	6.1611	1.24	1.28	0.256	4.7	***
ANS-Me	65.92	4.526	65.442	4.556	0.478	0.772	0.154	3.1	**
U1-NA	6.28	2.424	6.292	2.282	0.012	1.71	0.342	0.035	NS
L1-NB	5.04	1.989	4.876	2.233	0.164	0.857	0.171	0.957	NS
ANGULAR									
SNA	82.36	3.225	81.516	3.52	0.844	1.96	0.392	2.15	*
SNB	80.56	2.945	80.272	3.327	0.288	1.06	0.212	2.31	*
ANB	1.92	1.579	1.928	1.281	0.008	1.18	0.236	0.033	NS
NA-Pog	3.36	2.464	1.788	1.451	1.735	2.23	0.446	2.63	*
U1-SN	110.16	6.7	108	6.364	2.16	2.52	0.504	4.66	***
L1-MAND	98.68	5.632	100.748	5.803	2.068	3.15	0.63	3.28	**
U1-MAX	116.6	5.766	114.448	6.023	2.152	3.16	0.632	3.41	**
1-1 ANGLE	123.6	7.863	123.768	7.222	0.168	5.16	1.032	0.163	NS
U1-NA	28.08	6.04	26.608	6.049	1.472	2.8	0.56	2.63	*
L1-NB	27.16	5.145	27.892	5.143	0.732	2.23	0.446	1.64	NS

NS – Non-significant; $*P < 0.05$; $**P < 0.01$; $***P < 0.001$

The reliability (coefficient) table shows that there was not much of a difference in the reproducibility of landmarks in each of the methods. This means that both the methods are equally reliable and reproducible to some extent. The intra-class reliability coefficient of all the variables between two methods differed only slightly, which is not significant.

The CADCAS method was found to be slightly better for cephalometrics performed on digital compared with traditional method as also seen in others studies of Celik *et al*.,[6] Yu *et al*.,[7] Albarakati *et al*.,[8] Tsorovas and Karsten.[9]

Geelan *et al*.[20] and Chen *et al*.[1] who used a flatbed scanner for digitizing also agreed that digital cephalometrics could produce better results using digital pictures of 150 dpi, 8 bits. On the other hand, all authors using a video camera to digitize cephalogram Oliver,[13] Macri and Wenzel,[21] Nimkarn and Miles[22] found poor results for their digital technique compared with their conventional radiographs using digital pictures with an unknown format and lower quality parameters 65 dpi, 8 bits and average original quality Oliver,[6] 51 dpi unknown grayscale Macri and Wenzel[21] or unknown parameters Nimkarn and Miles.[22] In the present study, pictures in standard resolution (300 dpi) and 8 bit grayscale were used. This was necessary because magnification should still be possible without pixelising when using an average screen resolution of 115 dpi. Grayscale is also important since the identification of landmarks is most often an evaluation of gray shades. The use of at least 7-bit grayscale is mandatory because fever gray shades may lead to unreliable decisions on the reproducibility of measurements (Ongkosuwito *et al*.).[19]

The comparison technique must also be taken into consideration since it could affect the grayscale or number off pixels. In the present study, a 'lossy' compression techniques (JPEG) was used. The JPEG format has been shown to have no effect on diagnostic accuracy in the field of thoracic imaging (MacMahon *et al*.,[23] Goldberg *et al*.[24]).

In any study, comparing methods of cephalometric measurements, in addition to reproducibility it is important to consider the ease and speed at which measurements can be obtained. In this study, the use of hand measurements from tracing was by far the most tedious and time-consuming. Measurements of radiographs took much longer than when digitization was carried out. In addition to this inconvenience, they are the disadvantages of errors that occurred in misreading the measuring instruments and possible errors in transcribing the data to the computer.

Direct digitization onscreen (CADCAS) was the quickest and least tedious method. A session involving the measurements of 10 radiographs took over twice as long when tracings were constructed prior to digitization. In large cephalometric studies, a method that is reproducible and eliminates the fatigue of tracing and data transcribing errors is of real advantage.

The digital technique also has the advantages as it does not require physical space for storage. It should be borne in mind, however that digital pictures that originate from

Table 3: Showing value of correlation coefficient applied to each possible pair of measurement variable

X-AXIS	Manual (M)	CADCAS ©	Reproducibity
SKELETAL			
Sella (S)	0.994	0.998	C
Nasion (N)	0.998	0.982	M
Articulare (Ar)	0.886	0.973	C
Gonion (Go)	0.949	0.87	M
Menton (Me)	0.973	0.993	C
Pogonion (Pog)	0.996	0.994	M
A-Point	0.992	0.983	M
B-Point	0.991	0.994	C
ANS	0.976	0.968	M
PNS	0.976	0.986	C
Pornion (Po)	0.928	0.973	C
Orbltale (O)	0.981	0.959	M
DENTAL			
UIE	0.995	0.86	M
UIA	0.988	0.987	M
LIE	0.995	0.996	C
LIA	0.942	0.961	C
Y-AXIS			
SKELETAL			
Sella (S)	0.993	0.997	C
Nasion (N)	0.991	0.986	M
Articulare (Ar)	0.988	0.968	M
Gonion (Go)	0.98	0.94	M
Menton (Me)	0.997	0.999	C
Pogonion (Pog)	0.93	0.988	C
A-Point	0.985	0.985	M=C
B-Point	0.99	0.99	M=C
ANS	0.988	0.991	C
PNS	0.983	0.987	C
Pornion (Po)	0.842	0.869	C
Orbltale (O)	0.975	0.993	C
DENTAL			C
UIE	0.997	0.998	
UIA	0.985	0.993	C
LIE	0.997	0.998	C
LIA	0.978	0.986	C
LINEAR			
ANS-PNS	0.936	0.773	M
Ar-Pog	0.984	0.984	M=C
ANS-Me	0.994	0.978	M
U1-NA	0.477	0.837	C
L1-NB	0.883	0.991	C
ANGULAR			
SNA	0.969	0.917	M
SNB	0.913	0.957	C
ANB	0.775	0.743	C
NA-Pog	0.838	0.879	C
U1-SN	0.986	0.972	M
L1-MAND	0.9	0.896	M
U1-MAX	0.957	0.933	M
1-1 ANGLE	0.924	0.157	M
U1-NA	0.94	0.827	M
L1-NB	0.844	0.923	C

*1.00 indicates measurements were identical; Reliability of more than 0.75 is considered good to excellent. Superiority of method indicates by M-Manual and C-CADCAS.

poor quality analogue cephalometric radiographs often give a poorer image. This is important because poor quality (digital) cephalometric radiographs influence the identification of landmarks.

The traditional cephalometric technique may not be a "gold standard" but it is justifiably a standard with which the CADCAS technique can be compared. A statistically significant finding is not always clinically significant.

CONCLUSION

From the analysis and discussion of results following conclusions were drawn from this study.

1. There is an appreciable amount of error in taking cephalometric measurement from radiographs whichever method is chosen.
2. Some cephalometric landmarks can be located with greater accuracy than others.
3. Each anatomical landmark exhibits its characteristic dispersion of errors in both Cartesian coordinate. Since some landmarks were found to be more reproducible vertically than horizontally and vice versa, this factor must be taken into account in assessing the suitability of points, planes or lines for a particular investigations.
4. The amount of error is different for each considered landmark, the smaller the error in the determination of relevant landmark, the smaller the error involved in angles or distances in the system of analysis.
5. Hand measurement, if done carefully, compares reasonably well with methods involving the CADCAS and there is no reason why results using traditional methods should be considered any less valid. Misreading the measuring instrument must be borne in mind as a possible source of error.
6. Direct digitization (CADCAS) was slightly more reproducible than the other two methods for most measurements, although in the majority there was no significant difference statistically.
7. CADCAS was slightly unreliable with linear measurements involving bilateral structures such as Gonion and Articulare.
8. Scanning of cephalometric radiograph at a resolution of 300 dpi is sufficient for clinical purposes and comparable with analog cephalometric radiograph.

The CADCAS program can reduce the time required for making cephalometric measurements than that required with the ruler and protractor. Further work comparing various available cephalometric softwares for their accuracy and reliability is required.

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