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Comparison of cephalometric measurements with digital versus conventional cephalometric analysis

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SUMMARY The aim of this study was to evaluate the accuracy and reliability of angular and linear cephalometric measurements using a computerized method of direct digital radiographs. This was then compared with the measurements obtained with a computerized method that uses a digitizing pad and hand tracing of printout radiographs.

Pre-treatment digital cephalometric radiographs of 125 patients were traced using Vistadent 2.1 AT and Jiffy Orthodontic Evaluation (JOE) software programs and by hand tracing of the printouts. Twenty-six anatomical landmarks were defined on each radiograph by a single investigator and 28 variables were calculated. Statistical analysis was undertaken using one-way analysis of variance and multiple group comparisons using Duncan's test at a significance level of 0.05.

Low correlation coefficients indicated poor reproducibility for nasolabial angle for each of the three methods ($P > 0.05$). Most of the variables showed consistency between the three methods except for nasolabial angle, ANS–Me, APFH, L1–NB, Nperp–Pg, Go–Me, and U1–NA measurements. The findings indicated that most of the cephalometric measurements were highly reproducible with direct digital radiographs using Vistadent 2.1 AT as well as with printouts using both JOE software and hand tracing. Despite the low correlation for some measurements between the Vistadent 2.1 AT, JOE, and hand-tracing methods, most of the commonly used measurements were accurate. The user-friendly and time-saving nature of the computerized method using digital radiographs makes it the preferred option.

Introduction

Cephalometric radiography is an essential tool in clinical orthodontics. With standardized radiographs, the orientation of various anatomical structures can be studied by means of angular and linear measurements. The use of serial cephalometric radiographs to investigate growth and development of the facial skeleton can assist in treatment planning, and changes between pre- and post-treatment measurements can help in treatment evaluation (Brodie, 1941; Baumrind and Frantz, 1971a,b; Ricketts, 1981). Traditional cephalometric analysis is performed by tracing radiographic landmarks on acetate overlays and measuring the values using a protractor. Despite its widespread use in orthodontics, the technique is time-consuming and has several drawbacks, including a high risk of error during hand tracing, landmark identification, and measurement (Baumrind and Frantz, 1971b; Sandler, 1988).

Technical advances in computer science have made it possible to perform cephalometric tracing both through the use of digitizers and directly on screen-displayed digital images. First-generation computer-based analysis systems used digitizer pads for tracing conventional cephalometric films and software programs to compute the measurements, whereas second-generation systems use scanners or digital cameras to export cephalometric images to measurement programs. Recently, third-generation systems have been introduced that transmit digital radiographs directly to a computer database through the use of photostimulable phosphor plates, charge-coupled device receptors, or direct digital systems. The use of direct digital images offers several advantages, such as instant image acquisition, reduction of radiation dose, facilitated image enhancement and archiving, elimination of technique-sensitive developing processes, and facilitated image sharing (Quintero *et al.*, 1999; Brannan, 2002). Both digital radiography and conversion of conventional analogue film to a digital format require less storage space than conventional cephalometric film. Digital archiving is also a valuable method for overcoming the problem of film deterioration, which has been a major source of information loss in craniofacial biology (Melsen and Baumrind, 1995). Several drawbacks such as the inability to perform structural superimposition and the need for a digital cephalometric radiographic machine and a software program are also present.

Reproducibility of measurements is a prerequisite for determining the accuracy of any method of analysis. The use of computers in treatment planning is expected to reduce the incidence of personal errors due to operator fatigue and provide standardized, fast, and effective evaluation with a high rate of reproducibility. In clinical orthodontics, the efficacy of both commercially available cephalometric tracing software programs and commonly used cephalometric analyses need to be evaluated for accuracy in order to allow the clinician to select appropriate software and methods of analysis. Several studies have been undertaken to compare the accuracy of scanned, digitized, and digitally obtained radiographs with analogue methods (Oliver, 1991; Macrì and Wenzel, 1993; Nimkarn and Miles, 1995; Geelen *et al.*, 1998; Chen *et al.*, 2000, 2004; Ongkosuwito *et al.*, 2002; Gregston *et al.*, 2004; Sayinsu *et al.*, 2007). However, no clear consensus has arisen as to which method is preferable because the conversion of analogue film to digital format requires several additional steps that are not only time-consuming but may also introduce magnification errors. This can be overcome through the use of direct digital images. The literature contains only a few studies comparing the accuracy of digital cephalometric measurements with the hand-tracing method (Geelen *et al.*, 1998, Gregston *et al.*, 2004, Santoro *et al.*, 2006). There is still a need to evaluate any possible differences in errors between newly emerging cephalometric software and earlier programs. Therefore, the objective of this study was to evaluate and compare the reliability of angular and linear cephalometric measurements obtained from the direct digital Vistadent 2.1 AT and the first-generation Jiffy Orthodontic Evaluation (JOE) programs with those of hand tracing.

Materials and method

Pre-treatment cephalometric radiographs of 125 patients were selected from the archives of the Department of Orthodontics, Baskent University, according to the following criteria:

1. Good quality radiographs without any artefacts that could interfere with locating anatomical points;
2. Permanent dentition with no impacted or missing teeth;
3. No craniofacial deformity or asymmetry;
4. No excess soft tissue (as determined from the radiographs) that could interfere with locating anatomical points.

All the lateral cephalometric radiographs had been acquired using the same digital cephalometer (PM 2002 cc Proline, Planmeca, Helsinki, Finland) set at ×1.25 magnification, as recommended by the manufacturer. The digital images were stored in a computer database with the manufacturer's software (Dimaxis, version 4.0, Planmeca) and imported to the Vistadent 2.1 AT (GAC International Inc., Bohemia, New York, USA) software program. Before digitization of the landmarks with Vistadent 2.1 AT, the films were calibrated by digitizing two points on the ruler within the digital cassette, which is an automatic function of the software. The observer was able to adjust the image using enhancement functions for magnification, brightness, and contrast. Variables are automatically generated by the program once a set of landmarks has been digitized. For manual hand-tracing and JOE (version 5.0, Rocky Mountain Orthodontics, Denver, Colorado, USA) software measurements, digital images were resized to 1:1 scale using Adobe Photoshop CS (Adobe Systems, San Jose, California, USA) and printed on semi-gloss paper designed for high-quality photographic images (Hewlett-Packard, Palo Alto, California, USA) using a 2400 dpi color laser printer (Magicolor 5450, Konica Minolta, Osaka, Japan). Manual tracings were performed on clear acetate placed over the printed images using a 0.35 mm lead pencil. All hard and soft tissue landmarks were traced, with bilateral structures averaged to make a single structure or landmark. Measurements by JOE software were carried out using printed images, and digitization was performed using a digitizing pad. A total of 26 anatomical landmarks were defined on each radiograph (Figure 1), and 28 variables were calculated (Table 1). All measurements were carried out by the same investigator (EC).

Statistical analysis

Statistical analysis was undertaken using the Minitab statistical software program (State College, Pennsylvania, USA). No differentiations were made for age or gender. To evaluate the method error, 30 randomly selected radiographs were retraced 1 month after the initial measurements and intraclass correlation coefficients were calculated. For statistical evaluation of the principal data, differences in measurements between the three groups were evaluated using one-way analysis of variance (ANOVA) and multiple group comparisons using Duncan's test. A level of $P < 0.05$ was considered to be significant.

Results

Method error

The method errors are shown in Table 2. Correlation coefficients were found to be above 0.9000 for all parameters,

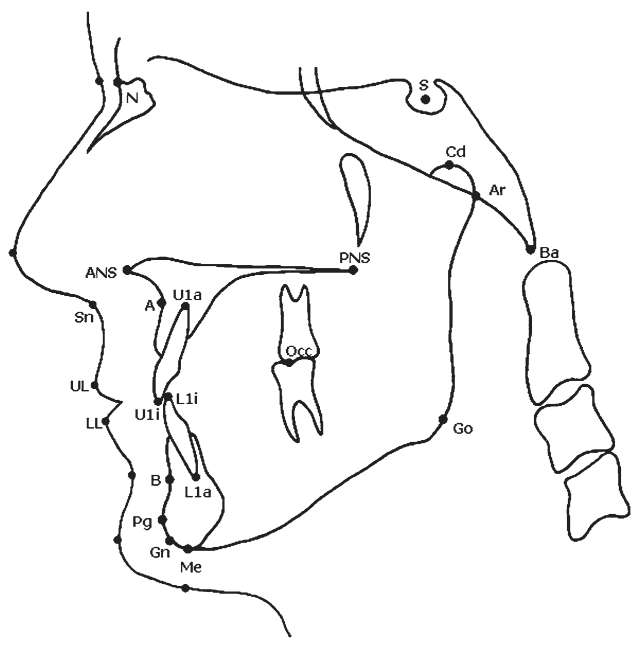

Figure 1 Cephalometric landmarks and measurements used in this study.

Table 1 Measurements used for this study.

Cranial parameters	
BaNA (°)	Angle formed between Ba–N and N–A planes
Maxillary parameters	
SNA (°)	Angle determined by points S, N, and A
Cd–A (mm)	Distance between points Cd and A
Nperp–A (mm)	Distance between point A and a line drawn perpendicular to Frankfort Horizontal (FH) from point N
Mandibular parameters	
Nperp–Pog (mm)	Distance between pogonion point and a line drawn perpendicular to FH from point N
Cd–Gn (mm)	Distance between points Cd and Gn
Go–Me mandibular plane (mm)	Distance between Go and Me points
SNB (°)	Angle determined by points S, N, and B
Maxillomandibular parameters	
ANB (°)	Angle determined by points A, N, and B
Max–Mand difference (mm)	Difference between Cd–A and Cd–Pog
Wit's appraisal (mm)	Distance between points of A and B to the occlusal plane
PP–MP (dg)	Angle formed between palatal and mandibular planes
Vertical parameters	
GoGnSN (°)	Angle formed between GoGn and SN lines
APFH (%)	The ratio between posterior and anterior face heights
ANS–Me (mm)	Distance between ANS and Me
ARGoGn (°)	Angle formed between GoAr and GoGn lines
Dental parameters	
IMPA (°)	Angle formed between Go–Me and the mandibular incisor axis
U1–NA (mm)	Perpendicular distance from the tip of the maxillary incisor to the plane between points N and A
U1–NA (°)	Angle formed by the intersection of the maxillary incisor axis to the plane between points N and A
L1–NB (mm)	Perpendicular distance from the tip of the mandibular incisor to the plane between points N and B
L1–NB (°)	Angle formed by the intersection of the mandibular incisor axis to the plane between points N and B
Interincisal angle (°)	Angle formed by the intersection of the mandibular incisor axis to the maxillary incisor axis
Overbite (mm)	Horizontal distance between the tips of maxillary and mandibular central incisors
Overjet (mm)	Vertical distance between the tips of maxillary and mandibular central incisors
Occ–MP (°)	Angle between the occlusal and mandibular planes
Soft tissue parameters	
LL–E Line (mm)	Perpendicular distance from the lower lip point to E line
Nasolabial angle (°)	Angle determined by points columella, SN and UL
Upper lip length (mm)	Distance between upper lip stomion to a horizontal line drawn from ANS

with the exception of lower lip–E line ($r^2 = 0.8932$), U1–NA distance ($r^2 = 0.8906$), and nasolabial angle ($r^2 = 0.5060$) in the JOE group.

Between-group comparisons

The results of the one-way ANOVA and Duncan's test are shown in Table 3.

Cranial parameters. No statistically significant differences were found in BaNA measurements between the three groups ($P > 0.05$).

Skeletal parameters. Maxillary. No statistically significant differences were found in SNA, Cd–A, or Nperp–A measurements between the three groups ($P > 0.05$).
Mandibular. The mean Nperp–Pg measurement was significantly lower for the Vistadent (−4.53 ± 0.80) than for the JOE (−7.92 ± 0.59) and hand-tracing (−7.89 ± 0.59) groups ($P < 0.001$). The mean Go–Me value was also significantly lower for the Vistadent (59.72 ± 0.43) than for the JOE (63.66 ± 0.46) and hand-tracing (63.70 ± 0.45) groups ($P < 0.05$).

Maxillomandibular. No statistically significant differences were found for ANB, Wits appraisal, PP–MP, or maxillomandibular measurements between the three groups ($P > 0.05$).

Vertical parameters. No statistically significant differences were found in GoGnSN or ArGoGn measurements between the three groups ($P > 0.05$). The mean values for APFH measurements were significantly higher for the JOE group than for the Vistadent and hand-tracing groups ($P < 0.05$), whereas the mean values for ANS–Me measurements were significantly lower for the Vistadent group than for the JOE and hand-tracing groups ($P < 0.05$).

Dental parameters. The mean L1–NB measurement value was significantly higher for the Vistadent (25.41 ± 0.58) than for the JOE (23.17 ± 0.59) and hand-tracing (23.19 ± 0.59) groups ($P < 0.001$), whereas the mean U1–NA (mm) value was significantly lower for the Vistadent (3.68 ± 0.24) than for the JOE (4.82 ± 0.19) and hand-tracing (4.84 ± 0.18) groups ($P < 0.001$). Differences in IMPA, U1–NA angle, L1–NB angle, interincisal angle, overbite, overjet,

Table 2 Intraclass correlation coefficients to evaluate the method error of the study.

	Hand tracing	JOE	Vistadent 2.1 AT
Cranial			
BaNA (°)	0.9854	0.9615	0.9981
Maxillary			
SNA (°)	0.9882	0.9767	0.9806
Cd–A (mm)	0.9835	0.978	0.9979
Nperp–A (mm)	0.9447	0.9730	0.9634
Mandibular			
Nperp–Pog (mm)	0.9948	0.9826	0.9999
Cd–Gn (mm)	0.9922	0.9881	0.9984
Go–Me–mandibular plane (mm)	0.9267	0.9647	1
SNB (°)	0.9930	0.9812	0.9747
Maxillomandibular			
ANB (°)	0.9418	0.9756	0.9813
Max–Mand difference (mm)	0.9693	0.9816	0.9995
Wits appraisal (mm)	0.9889	0.9434	0.9983
PP–MP (°)	0.9929	0.9674	0.9756
Vertical			
GoGnSN (°)	0.9901	0.9768	0.9228
APFH (%)	0.9815	0.9976	1
ANS–Me (mm)	0.9921	0.9745	0.9995
ARGoGn (°)	0.9888	0.9838	0.9033
Dental			
IMPA (°)	0.9972	0.9782	0.9898
U1–NA (mm)	0.9857	0.9703	0.9194
U1–NA (°)	0.9944	0.9854	0.8906
L1–NB (mm)	0.9649	0.9031	0.9041
L1–NB (°)	0.9844	0.9689	0.9543
Interincisal angle (°)	0.9920	0.9897	0.9828
Overbite (mm)	0.9756	0.9160	0.9969
Overjet (mm)	0.9983	0.9824	0.9963
Occ–MP (°)	0.9692	0.9692	0.9271
Soft Tissue			
LL–E Line (mm)	0.9754	0.8932	0.9966
Nasolabial angle (°)	0.9737	0.5060	0.9736
Upper lip length (mm)	0.9819	0.9734	0.9664

and Occ–MP values between the groups were not statistically significant ($P > 0.05$).

Soft tissue parameters. There were no significant differences in lower lip–E line or upper lip thickness measurements between the groups ($P > 0.05$). However, there were significant differences in nasolabial angle values between the JOE (142.38 ± 1.53), hand-tracing (122.82 ± 1.03), and Vistadent (116.26 ± 0.95) groups ($P < 0.05$).

Discussion

The interpretation of cephalometric films is a prerequisite in the diagnosis of malocclusion and the analysis of treatment results. Developments in computer technology have led to increasing use of digital systems both for tracing and analyzing cephalometric films. The main advantages of digital radiology are the reduced radiation dose and improved data storage, information access, and image manipulation (Chen *et al.*, 2000). Regardless of whether the chosen method is mechanical or digital, it is essential that it is accurate, precise, and shows a high rate of reproducibility in both tracing and analysis to ensure that errors are kept to a minimum. The present study evaluated the reliability and reproducibility of commonly used cephalometric measurements obtained using a computerized program on direct digital radiographs with measurements obtained from a first-generation cephalometric software program as well as with the hand-tracing method.

The two software programs chosen for this study employ different types of digital technology. Vistadent 2.1 AT uses on-screen direct digitization to analyze digital cephalometric radiographs and scanned radiographs, whereas JOE offers computerized analysis of measurements acquired using a digitizing pad on a hard copy. Neither of the two programs has been evaluated previously.

Studies of conventional cephalometric analysis have reported the major sources of error to stem from magnification, tracing, measuring, recording, and landmark identification (Baumrind and Frantz, 1971a,b; Houston, 1983; Houston *et al.*, 1986). Most research evaluating the accuracy of on-screen computer tracing software transferred conventional cephalometric film to a digital format by scanning, a procedure that can potentially result in image distortion. Bruntz *et al.* (2006) found that both vertical and horizontal distortion occurred when analogue film was converted to digital format using a scanner. Nowadays, the use of digital cephalometrics in orthodontic clinics is becoming more widespread, and direct transfer of images to a computer database has become available.

In order to eliminate errors due to magnification, the present study relied on digital radiographs rather than scanned images. However, it was not possible to use a sandwich technique in which digital and conventional radiographs are obtained simultaneously, and hand tracing of measurements was carried out on hard-copy printouts of the digital radiographs. Although slight enlargements have been observed in hard-copy printouts of digital cephalograms, it has been shown that the differences are minimal and have been regarded as clinically acceptable (Bruntz *et al.*, 2006). The use of digital cephalometric film also eliminated any errors that might have occurred during film processing.

In order to obtain a quantitative and objective evaluation of the accuracy of cephalometric measurements, a large sample size is essential. The number of cephalometric films used in this study appears to be the largest sample size studied, which is thought to increase the reliability of the results. The sample population was selected excluding the variables craniofacial defects, thick soft tissue, and impacted teeth that could prevent the location of a landmark. No differentiation was made for chronological or skeletal age or gender.

Overall, a high level of reproducibility was found for all three of the methods studied. Nasolabial angle was the only

Table 3 Statistical evaluation of the three groups using analysis of variance and Duncan's tests.

	Group 1 (hand tracing)	Group 2 (JOE)	Group 3 (Vistadent 2.1 AT)	*F*-test	1_2	1_3	2_3
Cranial							
BaNA (°)	62.16 ± 0.28	62.19 ± 0.28	62.60 ± 0.30	ns			
Maxillary							
SNA (°)	81.34 ± 0.36	81.36 ± 0.37	81.81 ± 0.39	ns			
Cd–A (mm)	81.02 ± 0.41	80.96 ± 0.41	80.68 ± 0.46	ns			
Nperp–A (mm)	−0.28 ± 0.34	−0.33 ± 0.34	−0.55 ± 0.34	ns			
Mandibular							
Nperp–Pog (mm)	−7.89 ± 0.59	−7.92 ± 0.59	−4.53 ± 0.80	***		***	***
Cd–Gn (mm)	107.33 ± 0.6	107.17 ± 0.61	107.18 ± 0.64	ns			
Go–Me–mandibular plane (mm)	63.70 ± 0.45	63.66 ± 0.46	59.72 ± 0.43	***		***	***
SNB (°)	77.66 ± 0.37	77.66 ± 0.37	77.97 ± 0.37	ns			
Maxillomandibular							
ANB (°)	3.69 ± 0.28	3.82 ± 0.26	3.85 ± 0.25	ns			
Max–Mand difference (mm)	26.18 ± 0.46	26.27 ± 0.49	26.37 ± 0.5	ns			
Wits appraisal (mm)	1.61 ± 0.38	1.67 ± 0.38	1.18 ± 0.39	ns			
PP–MP (°)	25.24 ± 0.59	25.26 ± 0.59	25.41 ± 0.59	ns			
Vertical							
GoGnSN (°)	33.41 ± 0.63	33.39 ± 0.63	33.61 ± 0.53	ns			
APFH (%)	0.67 ± 0.01	0.89 ± 0.04	0.68 ± 0.01	***	***	***	
ANS–Me (mm)	62.28 ± 0.53	62.26 ± 0.53	58.8 ± 0.53	***		***	***
ARGoGn (°)	124.94 ± 0.63	124.93 ± 0.63	126.82 ± 0.72	ns			
Dental							
IMPA (°)	92.38 ± 0.75	92.21 ± 0.75	93.46 ± 0.72	ns			
U1–NA (mm)	4.84 ± 0.18	4.82 ± 0.19	3.68 ± 0.24	***		***	***
U1–NA (°)	21.86 ± 0.71	21.86 ± 0.72	19.93 ± 0.73	ns			
L1–NB (mm)	4.82 ± 0.17	4.81 ± 0.17	4.26 ± 0.22	ns			
L1–NB (°)	23.19 ± 0.59	23.17 ± 0.59	25.41 ± 0.58	**		**	**
Interincisal angle (°)	131.44 ± 1	131.44 ± 1	129.96 ± 0.93	ns			
Overbite (mm)	1.98 ± 0.21	1.96 ± 0.21	1.78 ± 0.20	ns			
Overjet (mm)	4.55 ± 0.27	4.54 ± 0.27	4.10 ± 0.23	ns			
Occ–MP (°)	24.66 ± 0.44	24.66 ± 0.44	24.73 ± 0.49	ns			
Soft tissue							
LL–E Line (mm)	−1.34 ± 0.26	−1.33 ± 0.26	−1.44 ± 0.25	ns			
Nasolabial angle (°)	122.82 ± 1.03	142.38 ± 1.53	116.26 ± 0.95	***	***	***	***
Upper lip length (mm)	25.22 ± 0.27	25.22 ± 0.27	24.62 ± 0.22	ns			

**$P < 0.01$, ***$P < 0.001$; ns, not significant.

parameter that demonstrated low levels of reproducibility. This finding is in line with the results of Sayinsu *et al.* (2007), Kublashvili *et al.* (2004), and Baumrind and Frantz (1971b). During conventional hand tracing, different reference planes may be constructed to identify the innermost point of a curve; therefore, measurements of nasolabial angle, which is constructed on a curve, may show great variation. Similar results have been reported for gonion, porion, orbitale, and lower incisor apex that make these points inconsistent and unreliable, regardless of the method used (Chen *et al.*, 2000). In order to eliminate errors that may occur during cephalometric tracing, measurements should incorporate easily locatable anatomic landmarks.

According to the results of the present study, differences in measurements of linear parameters were greater than those of angular parameters. The differences could result from calibration or image distortion. Nperp–pogonion, Go–Me, ANS–Me, and U1–NA distances were different between the groups. Previous studies have demonstrated that points Go, Me, Or, and Po have low rates of reproducibility (Chen *et al.*, 2000, 2004). However, it should be noted that not all linear parameters showed low rates of reproducibility.

Conclusions

With the exception of one soft tissue measurement (nasolabial angle), cephalometric analysis was highly reproducible for all three of the methods studied. Although some measurements made using direct digital imaging (Vistadent 2.1) exhibited low correlation with both the JOE and hand-tracing methods, the differences were minimal and clinically acceptable. Therefore computerized cephalometric measurement using direct digital imaging is inherently preferable for its user-friendly and time-saving characteristics. Considering the rate at which new computerized cephalometric software programs are becoming available, program should be evaluated with large sample sizes to ensure these new technologies are free from error.

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