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Differences in cephalometric measurements: a comparison of digital versus hand-tracing methods

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SUMMARY The aim of this study was to evaluate the accuracy of cephalometric measurements using computerized tracing of direct digital radiographs in comparison with hand tracing of digital radiographic printouts. Comparisons were made between methods in terms of accuracy of individual measurements as well as evaluation of treatment outcomes. Pre- (T1) and post- (T2) treatment cephalometric digital radiographs of 30 patients were traced using the Vistadent OC 1.1 computer software program (group 1) and manually (group 2) by the same investigator. A total of 26 anatomical landmarks were located and measured. Measurement reproducibility was evaluated by calculating intraclass correlation coefficients, and paired *t*-tests were used to compare differences in individual measurements and treatment outcomes between methods. Differences greater than 0.05 were considered to be statistically significant.

Significant differences were found between the two methods for SNB, Wits appraisal, Cd–A, Cd–Gn, FMA, SN–PP, U1–NA (mm), U1–FH, L1–NB (mm), and Li–E plane. No significant differences were found between the two methods in the measurement of treatment changes. Cephalometric measurements of most parameters were reproducible for both methods. Despite some discrepancies in measured values between hand-tracing and the computerized method, any differences were minimal and clinically acceptable.

Introduction

Cephalometric radiography is an essential tool for studying growth and development of the facial skeleton, diagnosis and treatment planning, and evaluating pre- and post-treatment changes (Brodie, 1941; Baumrind and Frantz, 1971a,b; Ricketts, 1981). Traditionally, cephalometric analysis has been performed by tracing radiographic landmarks on acetate overlays and measuring linear and angular variables. However, despite its widespread use in orthodontics, the technique is time consuming and has several drawbacks, including a high risk of error in tracing, landmark identification, and measurement (Baumrind and Frantz, 1971b, Sandler, 1988). Cephalometric errors can be divided into those related to acquisition, identification, and technical measurement. Reproducibility of measurements by the operator is also a significant factor in determining the accuracy of any method of analysis. Recently, technological advances have made it possible to perform cephalometric tracing using computers. The use of computers in treatment planning is not only expected to decrease the incidence of individual error but also to provide standardized, fast, and accurate evaluation with a high rate of reproducibility.

Early developments in computerized radiography relied on digitizer pads, scanners, and digital cameras to transfer analogue data to a digital format. Recent improvements have enabled the use of direct digital images, which offer advantages including instant image acquisition, reduction in radiation doses, facilitated image enhancement, archiving and image sharing, and elimination of technique-sensitive developing processes (Quintero *et al.*, 1999; Brennan, 2002). In addition to eliminating errors related to digitizing pads and scanners, direct digital imaging reduces potential errors due to operator fatigue. Both digital radiography and the conversion of conventional analogue film to digital format require less storage space than conventional cephalometric film, resulting in improved archiving (Sayinsu *et al.*, 2007).

In view of the increasing use of computer-assisted cephalometric tracing programs in clinical orthodontics, there is a need to evaluate the accuracy of commercially available cephalometric tracing software in order to allow the clinician to select the appropriate software and methods of analysis. To date, several studies have been undertaken to compare the accuracy of measurements of scanned, digitized, and digitally obtained radiographs with that of traditional analogue radiographs (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; Santoro *et al.*, 2006; Sayinsu *et al.*, 2007). However, only one longitudinal study (Ongkosuwito *et al.*, 2002) has evaluated the reproducibility of orthodontic measurements using analogue and digital methods. Therefore, the aim of this investigation was to evaluate the accuracy of computerized tracing of direct digital radiographs using Vistadent OC 1.1 and hand tracing of digital radiographic printouts, and to compare the two methods in terms of accuracy of individual measurements as well as assessment of treatment outcomes.

Materials and methods

Lateral cephalometric radiographs of 30 patients were randomly selected from the archives of the Department of Orthodontics of Baskent University. All were of good quality and had no artefacts that might interfere with the location of the anatomical points. No differentiation was made for gender, occlusal type, or skeletal pattern. For each patient, two cephalometric films were measured, one taken at the beginning (T1) and the other at the end (T2) of treatment. To compare the two methods in terms of accuracy of individual measurements, the cephalograms were combined (n = 60) and differences between the treatment outcomes were evaluated on the differences between T1 and T2 measurements (n = 30).

All radiographs were acquired in a standardized manner using the same direct digital cephalometer (PM 2002 cc Proline; Planmeca, Helsinki, Finland) set at ×1.25 magnification, as recommended by the manufacturer. Digital images were stored in a computer database created using the manufacturer's software (Dimaxis, version 4.0; Planmeca).

For the computerized measurements, direct digital images were imported to the Vistadent OC 1.1 software program (GAC International Inc, Bohemia, New York, USA), which automatically generates measurements after digitizing a set of landmarks. Prior to the digitization of landmarks, all images were calibrated by digitizing two points on the ruler contained within the program's digital cassette. The observer was able to adjust the image using enhancement functions for magnification, brightness, and contrast.

For hand tracing, the digital images were imported to Adobe Photoshop CS (Adobe Systems, San Jose, California, USA) software program, resized to 1:1 scale and printed using a 2400 dpi colour laser printer (Magicolor 5450; Konica Minolta, Osaka, Japan) and semi-gloss paper designed for high-quality photographic images (Hewlett-Packard, Palo Alto, California, USA). Manual tracing was performed on clear acetate placed over the printed image using a 0.35 mm lead pencil. All hard and soft tissue landmarks were traced, with bilateral structures averaged to make a single landmark. All tracings and measurement were performed by the same examiner (OPO). A total of 26 anatomical landmarks were defined and measured and 26 measurements were calculated (Figure 1).

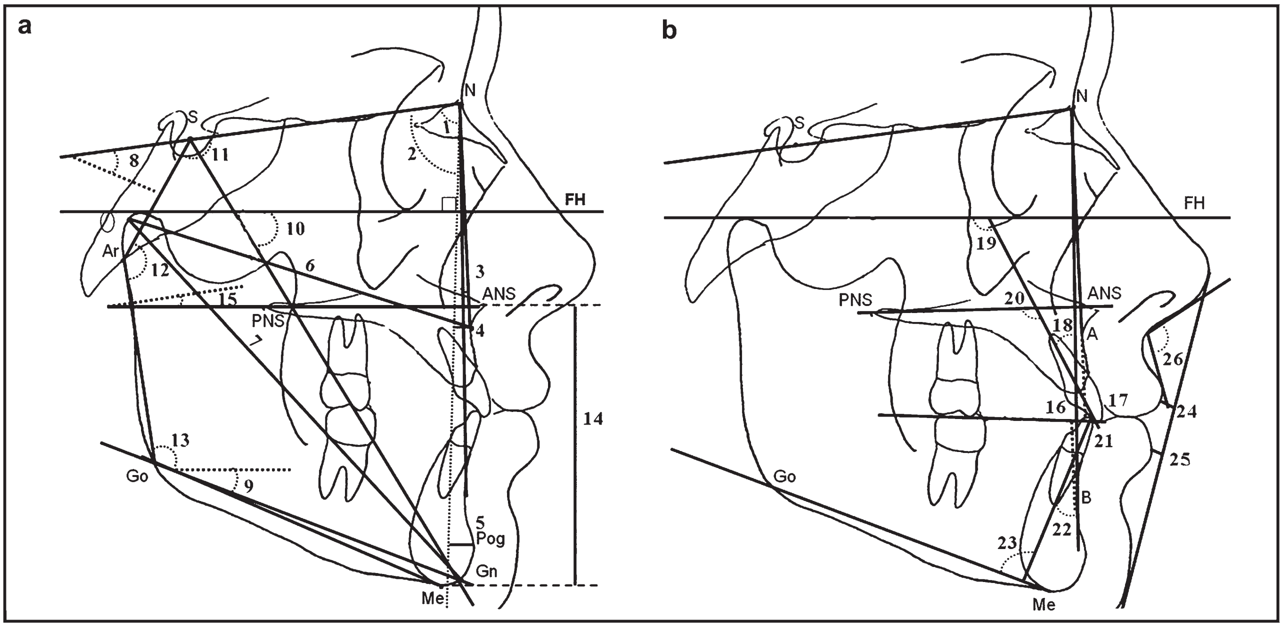

Figure 1 (a, b) Skeletal and dental measurements used in this study. (1) SNA (°), angle formed between sella, nasion, and point A; (2) SNB (°), angle between S, N, and point B; (3) ANB (°), angle between SNA and SNB planes; (4) Nperp–A (mm), distance between point A and N perpendicular line; (5) Nperp–Pog (mm), distance between the pogonion and nasion perpendicular line; (6) Cd–A (mm), distance between condylion and point A; (7) Cd–Gn (mm), distance between condylion and gnathion; (8) GoGn–SN (°), angle between Go–Gn and SN plane; (9) FMA (°), angle between Frankfort horizontal (FH) and the mandibular plane; (10) *y*-axis (°), angle between FH and SGn planes; (11) saddle angle (°), angle between SN and sella articulare planes; (12) articular angle (°), angle between sella articulare and articulare Go planes; (13) gonial angle (°), angle between articulare, Go, and Go menton (Me) planes; (14) ANS–Me (mm), distance between anterior nasal spine and Me; (15) SN–PP (°), angle formed between the palatal and SN planes; (16) Wits appraisal (mm), difference between point A and point B to the occlusal plane; (17) U1–NA (mm), distance between the labial point of U1 and NA plane; (18) U1–NA (°), angle formed between the U1 long axis and NA plane; (19) U1–FH (°), angle formed between the FH plane and the U1 axis; (20) U1–PP (°), angle formed between U1 axis and the palatal plane; (21) L1–NB (mm), perpendicular distance from the tip of the mandibular incisor to the plane between points N and B; (22) L1–NB (°), angle formed by the intersection L1 to the plane between points N and B; (23) IMPA (°), angle formed between L1 and the mandibular plane; (24) Ls–E plane (mm), perpendicular distance from the upper lip point to the E line; (25) Li–E plane (mm), perpendicular distance from the lower lip point to the E line; and (26) nasolabial angle (°), angle determined by points columella, subnasale, and the most prominent point of the upper lip.

Statistical analysis

Statistical analysis was carried out using the Minitab statistical software program (Minitab Inc., State College, Pennsylvania, USA). In order to evaluate examiner error, 15 randomly selected cephalograms were retraced 2 weeks after the initial recordings by the same investigator, and intraclass correlation coefficients (ICCs) were calculated for each parameter (Table 1). Data evaluation was made using both measurements made on cephalograms taken at a single point of time (T1 and T2, n = 60) and differences between T1 and T2 (n = 30). Differences in measurements between the two methods were evaluated using a paired t-test, with a significance level of $P < 0.05$.

Results

Method error

ICCs were above 0.9000 for all parameters, with the exception of Nperp–Pog (r^2 = 0.8932), articular angle (r^2 = 0.8906), SN–PP (r^2 = 0.8470), and nasolabial angle (r^2 = 0.7876) for hand tracing, and Wits appraisal (r^2 = 0.8687), Nperp–A (r^2 = 0.7584), SN–PP (r^2 = 0.6668), nasolabial angle (r^2 = 0.8328), U1–NA (mm; r^2 = 0.8570), and U1–NA (degrees; r^2 = 0.8797) for computerized tracing (Table 1).

Table 1 Intraclass correlation coefficients.

	Group 1 (hand tracing)	Group 2 (Vistadent OC 1.1)
SNA	0.9817	0.9644
SNB	0.9413	0.9626
ANB	0.9898	0.9509
Wits appraisal	0.9220	**0.8687**
Nperp–A	0.9280	**0.7584**
Nperp–Pog	**0.8932**	0.9842
Cd–A	0.9740	0.9144
Cd–Gn	0.9669	0.9206
GoGnSN	0.9659	0.9085
FMA	0.9444	0.9162
y-axis	0.9742	0.9502
Saddle angle	0.9456	0.9205
Articular angle	**0.8906**	0.9088
Gonial angle	0.9597	0.9433
ANS–Me	0.9390	0.9647
SN–PP	**0.8470**	**0.6668**
U1–NA (mm)	0.9286	**0.8570**
U1–NA (°)	0.9042	**0.8797**
U1–FH	0.9373	0.9862
U1–PP	0.9207	0.9841
L1–NB (mm)	0.9542	0.9039
L1–NB (°)	0.9695	0.9099
IMPA	0.9680	0.9060
Ls–E plane	0.9617	0.9933
Li–E plane	0.9419	0.9264
Nasolabial angle	**0.7876**	**0.8328**

Values below 0.9000 are shown in bold face.

Comparison of methods: hand-tracing versus computerized measurements

Significant differences between methods were observed only for SNB (P = 0.012), Wits appraisal (P = 0.021), Cd–A (P = 0.02), Cd–Gn (P = 0.007), FMA (0.018), SN–PP (P = 0.000), U1–NA (mm; P = 0.001), U1–FH (P = 0.07), L1–NA (mm; P = 0.014), and Li–E plane (P = 0.005; Table 2). Any other differences between methods were statistically insignificant.

Treatment changes

Hand tracing demonstrated significant differences for T1 and T2 measurements for Cd–Gn (P = 0.007), ANS–Me (P=0.008), and L1–NB (mm; P=0.014; Table 3). Computerized tracing also showed significant differences for T1 and T2 measurements for Cd–Gn (P = 0.000), ANS–Me (P = 0.000), and L1–NB (mm; P = 0.033), as well as in U1–NA (degrees; P = 0.041) and U1–FH (P = 0.026).

Discussion

Digital imaging has been shown to offer several advantages over conventional radiography (Houston, 1983). Data

Table 2 Comparison of the groups using a paired t-test.

Measurements	Conventional hand tracing		Vistadent OC 1.1		Paired t-test
	Mean	SD	Mean	SD	
SNA	81.4	4.1	80.7	3.6	0.130
SNB	78.3	3.4	77.5	3.1	0.012*
ANB	3	2.6	3.3	2.3	0.324
Wits appraisal	1	2.2	0.1	2.2	0.021*
Nperp–A	−0.9	3	−1	3.2	0.900
Nperp–Pg	−5.3	5.3	−6.1	5.5	0.258
Cd–A	84.1	4.7	83.2	4.7	0.020*
Cd–Gn	110.3	5.9	109	6.1	0.007**
SN–GoGn	34.1	4.4	34.2	4.3	0.843
FMA	26.5	4.4	27.5	4.2	0.018*
y-axis	61.1	3	61.4	2.4	0.302
Saddle angle	124	4.3	123.7	4.9	0.494
Artiküler angle	145.4	6.2	147	6.4	0.106
Gonial angle	125.6	7	124.9	6.2	0.230
ANS–Me	64.6	5.1	64.5	5.2	0.635
SN–PP	8.2	3.2	13.9	3.8	0.000***
U1–NA (mm)	4.7	1.3	3.6	2.1	0.001***
U1–NA (°)	22.9	5.6	23.6	5.6	0.118
U1–FH	111.6	6.5	112.7	6	0.070*
U1–PP	112	6	112.9	4.9	0.100
L1–NB (mm)	5.6	2.3	5.2	2.4	0.014*
L1–NB (°)	26.4	7.2	26.7	7.9	0.673
IMPA	93.6	7.5	93.5	7.7	0.852
Ls–E plane	−3.6	1.9	−3.4	2.2	0.167
Li–E plane	−1.4	2.4	−1	2.5	0.005**
Nasolabial angle	107.7	9.5	106	8.1	0.102

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Table 3 Comparison of treatment outcomes between the groups.

	Conventional hand tracing method		Computerized method (Vistadent OC 1.1)		Student's *t*-test
	Increments	Paired *t*-test	Increments	Paired *t*-test	
SNA	3.0 ± 1.9	NS	1.0 ± 1.1	NS	NS
SNB	1.0 ± 1.8	NS	2.0 ± 1.1	NS	NS
ANB	2.0 ± 1.3	NS	1.0 ± 1.0	NS	NS
Wits appraisal	4.0 ± 2.8	NS	5.0 ± 1.8	NS	NS
Nperp–A	1.0 ± 2.1	NS	4.0 ± 2.0	NS	NS
Nperp–Pg	−1.0 ± 3.5	NS	−0.7 ± 3.0	NS	NS
Cd–A	−2.0 ± 2.0	NS	−0.9 ± 2.7	NS	NS
Cd–Gn	−1.5 ± 2.8	0.007**	−2.6 ± 3.2	0.000***	NS
SNGoGn	−8.0 ± 2.3	NS	−3.0 ± 1.2	NS	NS
FMA	5.0 ± 2.7	NS	3.0 ± 1.2	NS	NS
y-axis	4.0 ± 1.8	NS	2.0 ± 2.0	NS	NS
Saddle angle	7.0 ± 3.2	NS	6.0 ± 2.2	NS	NS
Articular angle	0.0 ± 5.3	NS	5.0 ± 2.6	NS	NS
Gonial angle	−4.0 ± 3.6	NS	−1.0 ± 2.3	NS	NS
ANS–Me	−1.6 ± 3.0	0.008**	−2.1 ± 1.9	0.000***	NS
SN–PP	−0.7 ± 2.1	NS	−0.1 ± 2.4	NS	NS
U1–NA(mm)	−2.0 ± 1.4	NS	−5.0 ± 1.8	NS	NS
U1–NA (°)	−1.6 ± 4.8	NS	−2.2 ± 5.7	0.041*	NS
U1–FH	−0.9 ± 6.0	NS	−2.6 ± 6.0	0.026*	NS
U1–PP	−1.5 ± 5.9	NS	−2.1 ± 5.8	NS	NS
L1–NB (mm)	−0.9 ± 1.8	0.014*	−0.7 ± 1.8	0.033*	NS
L1–NB (°)	−0.6 ± 7.4	NS	−0.8 ± 5.7	NS	NS
IMPA	0.7 ± 6.9	NS	−0.4 ± 5.4	NS	NS
Ls–E plane	0.0 ± 1.0	NS	0.2 ± 1.1	NS	NS
Li–E plane	−2.0 ± 1.5	NS	4.0 ± 1.4	NS	NS
Nasolabial angle	0.8 ± 8.8	NS	1.0 ± 7.5	NS	NS

NS, not significant. $^*P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

processing is faster, radiation dose is reduced by 30 per cent, and since there is no film processing, and chemical and environmental risks are eliminated. Exposure errors can be corrected, and images can be enhanced using different techniques in order to provide more precise landmark identification. Storage of digital images is also easier than for traditional analogue films. In addition, a number of different software packages are available that can perform cephalometric analysis by digitally tracing digital cephalometric images.

The increasing use of digital cephalometrics has highlighted the need to evaluate the accuracy of these new computerized software programs and compare them with traditional manual measurement techniques. Several studies have examined the performance of commercially available software programs used for cephalometric analysis (Nimkarn and Miles, 1995; Kublashvili *et al.*, 2004; Santoro *et al.*, 2006); however, this study appears to be the first to evaluate Vistadent OC 1.1, a software programme that uses on-screen direct digitization, to analyse both direct digital cephalometric radiographs and scanned radiographs. Comparisons were made between this computerized technique and hand tracing in terms of accuracy of individual measurements as well as measurement of T1 and T2 changes.

According to Santoro *et al.* (2006), any investigation aiming to demonstrate the accuracy of digital cephalometrics should focus on several significant factors, such as the use of measurements instead of landmarks, sources of error, and sample collection. In this study, the use of measurements was preferred to landmark identification because measurements are the end product of the cephalometric tracing process and provide data for treatment planning. Although early studies investigated landmark identification, recent research has focused on cephalometric measurements.

Studies of conventional cephalometric analysis have reported magnification, tracing, measuring, recording, and landmark identification to be the major sources of error (Baumrind and Frantz, 1971a,b; Houston *et al.*, 1986; Kublashvili *et al.*, 2004). Most studies evaluating the accuracy of on-screen computer tracing software have transferred conventional cephalometric film to a digital format by scanning, a procedure that may result in image distortion. Bruntz *et al.* (2006) found both vertical and horizontal distortion 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 was based on digital radiographs rather than scanned images. Moreover, because it was not possible to use a 'sandwich technique' in which digital and conventional radiographs are obtained simultaneously (Houston, 1983), conventional measurements were taken using hard-copy printouts of the digital radiographs. Although a previous study found that slight enlargement may occur when printing hard copies of digital cephalograms, the size difference is minimal and regarded as clinically acceptable (Bruntz *et al.*, 2006).

Designing *in vivo* studies to compare conventional and digital radiographs presents a number of difficulties. Taking sequential analogue and digital radiographs is considered unethical because of the increased radiation dose and cannot be relied on technically to produce equivalent data due to possible changes in head position. Using a sandwich technique to simultaneously obtain digital and conventional films may be useful; however, it may not always be possible. In the present study, hand tracing was performed on hard copies of digital radiographs printed at 1:1 using a high-resolution laser colour printer. Therefore, calibration of only the digital image prior to on-screen digitization was undertaken.

Overall, ICC indicated a high level of reproducibility for both methods studied. Low levels of reproducibility were observed for SN–PP, nasolabial angle, Nperp–Pog, and articular angle measurements using hand tracing, and for SN–PP, nasolabial angle, Wits appraisal, Nperp–A, U1–NA, and U1–NA using Vistadent. However, with the exception of hand-tracing measurements of nasolabial angle and computerized measurements of nasolabial angle, Nperp–A, and SN–PP, ICC values were close to 0.9000.

Differences were observed between hand-tracing and computerized cephalometric measurements of SNB, Wits appraisal, Cd–A, Cd–Gn, FMA, SN–PP, U1–NA, U1–FH, L1–NB, and Li–E plane. Previous studies on manual and computerized methods have found difficulties in locating the landmarks Cd, Gn, Go, Po, ANS, lower incisor apex, Me, and Sn (Houston *et al.*, 1986; Gregston *et al.*, 2004; Santoro *et al.*, 2006). While different reference planes may be constructed to assist in identifying points Cd, Gn, Go, and Me during hand tracing, this may not be possible with on-screen digitization. Although Vistadent OC incorporates reference planes in its measurements, some discrepancies remain between computerized and hand tracing. Identification of the landmarks, ANS and lower incisor apex, is often affected by the superimposition of other anatomical structures and has shown poor reproducibility (Houston *et al.*, 1986). In order to eliminate errors that may occur during cephalometric tracing, measurements should incorporate easily identifiable anatomical landmarks.

Treatment outcome was evaluated by examining changes in measurements between the T1 and T2 radiographs. Both hand-tracing and computerized measurements indicated significant changes in Cd–Gn, ANS–Me, and L1–NB. In addition, Vistadent measurements showed significant changes in U1–NA and U1–FH. Several reports have mentioned difficulties in tracing incisor positions as well as variations in incisor angular measurements between tracing methods (Baumrind and Frantz, 1971a; Gravely and Benzies, 1974; Lim and Foong, 1997). However, since data on treatment differences were small, evaluation of these may show significance. In general, both methods investigated in this study demonstrated consistency in the evaluation of treatment changes.

Conclusions

With the exception of a few measurements, cephalometric analysis was highly reproducible for both methods studied. Although there was low correlation between hand tracing and Vistadent direct digital imaging for some measurements, these measurements incorporated anatomical points such as Cd, Gn, Go, Po, ANS, lower incisor apex, and Me, which have been proven to show low levels of reproducibility. Evaluation of treatment outcome was consistent between the two methods. Although small discrepancies were found between the hand-tracing and computerized measurements, the differences were minimal and clinically acceptable. Therefore, it can be concluded that the user-friendly and time-saving characteristics of computerized tracing of direct digital images makes this method inherently preferable to hand tracing for cephalometric analysis of radiographs used in diagnosis, treatment planning, and the evaluation of treatment outcome.

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