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Reliability of four different computerized cephalometric analysis programs

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SUMMARY The aim of this investigation was to compare the traditional method of manual cephalometric tracing with four different computerized tracing programs, where the lateral cephalograms were scanned at 300 dpi and digitized onscreen. Thirty randomly selected cephalometric radiographs were used in this study. Four programs Dolphin Imaging, Vistadent, Nemoceph, and Quick Ceph were evaluated. Three dental, 11 skeletal, and 1 soft tissue parameters were measured that consisted of 5 linear and 10 angular measurements. Statistical analysis was carried out using multivariate analysis of variance and Box's and Levene's tests.

No statistically significant difference was found between manual tracing and the computerized tracing programs. The measurements obtained with the cephalometric analysis programs used in the study were reliable.

Introduction

Cephalometric analysis has been used in orthodontic diagnosis, treatment planning, evaluation of treatment results, and prediction of growth, since its introduction by Broadbent (1931). Traditional cephalometric analysis is performed by identifying radiographic landmarks on acetate overlays and measuring the linear and angular values with a protractor and ruler. The advances in the field of computer science have led to the widespread use of computers in orthodontic cephalometry.

The sources of error in conventional cephalometric analysis include radiographic film magnification, tracing, measuring, recording, and landmark identification (Baumrind *et al.*, 1971; Cohen and Linney, 1986; Houston *et al.*, 1986). Conventional cephalometric analysis can be time consuming and there is a risk of misreading the measurements obtained manually. On the other hand, computer-assisted cephalometric analysis reduces the time needed for data acquisition and analysis. Computer-assisted cephalometric tracing requires the acquisition of a digital lateral skull radiographic image. The image is then transferred to a program that identifies digitized points and performs the cephalometric analysis (Sandler, 1988; Chen *et al.*, 2000, 2004a).

In computer-assisted cephalometric analysis, angles and distances are automatically calculated that can eliminate errors in drawing lines between landmarks and in measurements with a protractor. Moreover, the digital image can be manipulated to process the image and alter its visual appearance that can facilitate landmark identification (Jackson *et al.*, 1985). Earlier studies revealed that computer-aided cephalometric analysis does not introduce more measurement error than hand tracing, as long as landmarks are identified manually (Gravely and Benzies, 1974; Enlow and Hans, 1996).

The aim of this investigation was to compare the traditional method of manual cephalometric analysis with four different computerized cephalometric analysis programs.

Materials and methods

Thirty cephalometric radiographs randomly selected from the archives of the Department of Orthodontics, Gulhane Military Medical Academy, Haydarpasa Research and Training Hospital, were used in this study. The cephalometric radiographs were scanned into digital format at 300 dpi using an Epson Expression 1680 Professional transparency scanner (Epson USA, Long Beach, California, USA) and displayed on a 15 inch 1024 × 768 high-pixel resolution monitor. All the scanned images were then processed by the same examiner (HGG) using Dolphin Imaging Version 10.5 (Dolphin Imaging, Chatsworth, California, USA), Nemoceph NX 2006 (Nemotec, Madrid, Spain), Vistadent AT 3.1 (GAC International, Bohemia, New York, USA), and Quick Ceph 2000 (Quick Ceph Systems, San Diego, California, USA) cephalometric analysis programs. Three dental, 11 skeletal, and 1 soft tissue parameters were measured that consisted of 5 linear and 10 angular measurements (Figure 1). The same radiographs were then traced by the same examiner with a 0.3 mm 2H pencil on matte acetate paper and measured using a ruler and

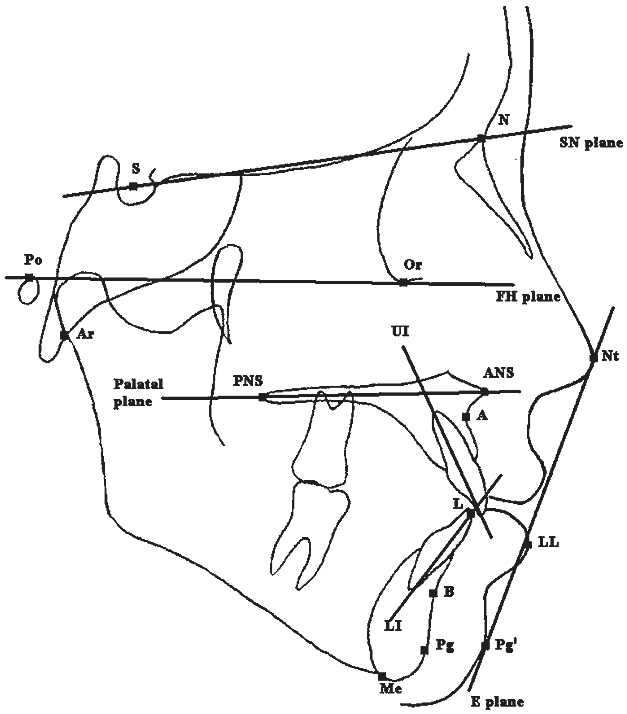

Figure 1 Cephalometric landmarks and measurements used in the study. S: sella; N: nasion; ANS: anterior nasal spine; PNS: posterior nasal spine; Ar: articulare; A: point A; LL: the most anterior point of the lower lip; Nt: nasal tip; Pg': pogonion soft; B: point B; UI: upper incisor axis; LI: lower incisor axis; L: lower incisor tip; Me: menton; Or: orbitale; Po: porion; Pg: pogonion; SN–palatal plane: angle formed between SN plane and palatal plane (ANS–PNS); saddle angle: angle determined by points S, N, and Ar; SNA: angle determined by points S, N, and A; lower lip–E plane: distance between point LL and E plane (Nt–Pg'); SNB: angle determined by points S, N, and B; facial depth: angle formed between FH plane (Po–Or) and N–Pg; convexity angle: angle determined by points N, A, and Pg; ANB: angle determined by points A, N, and B; U1–L1: angle formed by the intersection of upper incisor and lower incisor axes; maxillary depth: angle formed between N–A and FH plane (Po–Or); L–NB: distance between lower incisor tip and N–B; N–ANS: distance between points N and ANS; ANS–Me: distance between points ANS and Me; N–Me: distance between points N and Me; U1–palatal plane: angle formed by the intersection of upper incisor axis and palatal plane (ANS–PNS).

protractor. No more than 10 radiographs were traced in a single day to minimize errors due to examiner fatigue. Landmark identification was performed manually on the original radiograph by dot tracing and on the digital image using a mouse controlled cursor.

Statistical analysis

To evaluate intra-observer reliability, 10 radiographs were randomly selected. The same radiographs were then traced twice manually and digitally with each cephalometric tracing program, with a 10 day interval between evaluations. A linear correlation test was performed, and all measurements presented coefficients greater than 0.9. A measurement with a reliability coefficient greater than 0.7 is generally regarded as acceptable.

The cephalometric analysis methods were evaluated using multivariate analysis of variance (MANOVA). Box's and Levene's tests were used to evaluate the compliance of the MANOVA. Pairwise comparison of estimated marginal means was used to compare the mean values for dependent variables of each cephalometric analysis program and the traditional method.

Results

No statistically significant difference was found between the various methods based on the sum of the dependent variables for each method ($P > 0.05$).

Even though there was no statistically significant difference between the results for the different cephalometric analysis methods, those obtained from the cephalometric analysis programs were compared with those obtained from the traditional method using pairwise comparison of estimated marginal means (Table 1).

The sum of the differences in angles and length between the traditional method and cephalometric analysis programs are shown in Figures 2a, 2b, and 3. It can be seen that the difference was small. However, when compared with the traditional method, the largest difference was found for Vistadent and the smallest for Dolphin.

Discussion

Previous studies comparing digital and manual cephalometric analysis methods revealed that computer-assisted cephalometric analysis yielded comparable results to the manual method (Sandler, 1988; Santoro *et al.*, 2006). Moreover, computer-assisted cephalometric analysis was found to be time saving and more precise because once the landmarks are selected on the digital images and identified, the data processing can be executed and completed immediately, while there are some limitations in measuring a distance or angle with the naked eye with a ruler and protractor. With digital cephalograms obtained by various digitization processes or digital radiography, the clinician needs only to identify the landmarks and let the program calculate the cephalometric measurements (Chen *et al.*, 2004a).

Errors with the traditional method arise from radiographic acquisition, landmark identification, measurement, and observer experience (Björk and Solow, 1962; Houston *et al.*, 1986; Forsyth *et al.*, 1996a,b). A previous study revealed that computer-aided cephalometric analysis does not introduce more measurement errors when localization of the landmarks is determined by hand (Gravely and Benzies, 1974). A more recent study concluded that the differences between all skeletal and dental measurements derived from the landmarks on original cephalometric radiographs and those identified on their digitized counterparts were statistically significant but clinically

Table 1 The mean difference (M) and standard deviation (SD) of the pairwise comparison based on estimated marginal means of dependent variables from cephalometric analysis programs and those from the traditional method.

	Dolphin				Nemoceph				Vistadent				Quick Ceph			
	Mean D	Std Error	Min	Max	Mean D	Std Error	Min	Max	Mean D	Std Error	Min	Max	Mean D	Std Error	Min	Max
SN–palatal plane (°)	0.08	1.04	−1.98	2.14	−0.83	1.04	−2.89	1.22	−0.1	1.08	−2.23	2.03	−0.78	1.08	−2.24	2.03
Saddle angle (°)	1.14	1.65	−2.13	4.41	1.57	1.65	−1.69	4.84	0.09	1.71	−3.29	3.47	0.84	1.72	−3.26	3.53
SNA (°)	−0.32	1.26	−2.82	2.18	0.18	1.26	−2.32	2.68	−0.36	1.31	−2.95	2.23	−0.43	1.31	−3.03	2.17
Lower lip–E plane (°)	−0.23	0.9	−2	1.54	−0.07	0.9	−1.84	1.7	0.54	0.93	−1.3	2.37	0.37	0.93	−1.47	2.21
SNB (°)	−0.7	1.32	−3.32	1.91	−0.53	1.32	−3.14	2.09	−0.59	1.37	−3.3	2.12	−0.76	1.37	−3.48	1.95
Facial depth (°)	−0.75	1.08	−2.88	1.38	−0.94	1.08	−3.07	1.19	−1.6	1.12	−3.81	0.61	−0.89	1.12	−3.11	1.32
Convexity angle (°)	0.03	1.25	−2.43	2.5	0.68	1.25	−1.79	3.15	−0.52	1.29	−3.08	2.03	0.67	1.3	−2.5	3.08
ANB (°)	0.09	0.62	−1.14	1.32	0.4	0.62	−0.82	1.63	−0.02	0.64	−1.29	1.25	0.05	0.65	−1.23	1.33
U1–L1 (°)	−0.06	3.4	−6.77	6.66	0.56	3.4	−6.16	7.27	−1.49	3.52	−8.44	5.47	0.51	3.53	−6.47	7.49
Maxillary depth (°)	−0.9	0.9	−2.69	0.88	−0.65	0.9	−2.44	1.13	−0.27	0.94	−2.12	1.58	−0.53	0.94	−2.39	1.33
L1–NB (°)	−0.61	1.8	−4.16	2.95	−1.14	1.8	−4.7	2.41	−0.8	1.86	−4.49	2.88	−0.91	1.87	−4.6	2.79
N–ANS (°)	0.21	0.91	−1.59	2	0.48	0.91	−1.32	2.27	−0.16	0.94	−2.02	1.69	−0.51	0.94	−2.37	1.36
ANS–Me (°)	−0.21	1.89	−3.96	3.53	0.42	1.89	−3.32	4.16	2.56	1.96	−1.31	6.44	0.5	1.97	−3.39	4.39
N–Me (°)	−0.9	3.62	−8.05	6.25	0.67	3.62	−6.48	7.82	0.28	3.75	−7.12	7.69	0.94	3.76	1.98	7.72
U1–palatal plane (°)	0.93	2.6	−4.22	6.07	0.14	2.6	−5.01	5.28	1.51	2.69	−3.81	6.84	−0.23	2.7	−5.48	5.22

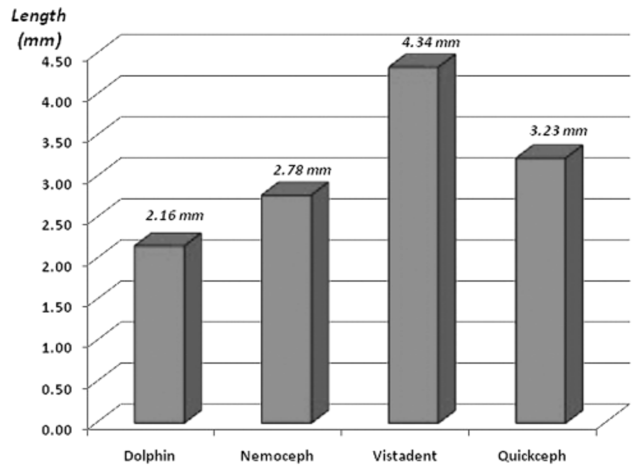

Figure 2 The sum of differences in length between the traditional method and cephalometric analysis programs.

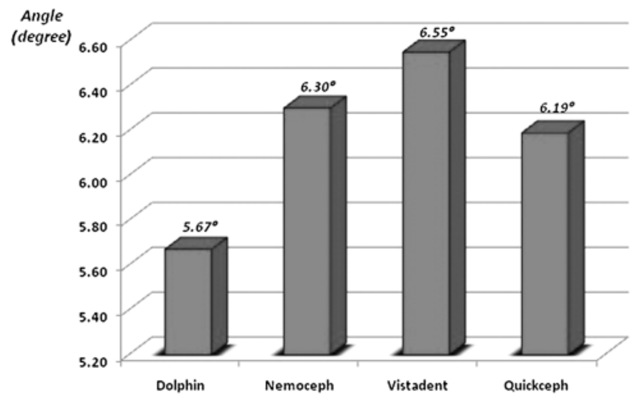

Figure 3 The sum of differences in angle between the traditional method and cephalometric analysis programs.

acceptable (Chen *et al.*, 2004b). Santoro *et al.* (2006) detected larger differences for dental angular measurements between traditional and computerized methods.

Ongkosuwito *et al.* (2002) demonstrated that the image quality of a cephalogram scanned at a resolution of 300 dpi is sufficient for clinical purposes and comparable with original analogue cephalometrics. It has been suggested that the settings of resolution and grey scale or colour when digitizing a cephalometric film using a scanner does not significantly affect the precision of landmark identification when standard scanner settings are used. Therefore, in the present study, the radiographs were scanned at a resolution of 300 dpi.

Because standardization is essential in comparative studies and inter-examiner error has been found to be greater than intra-examiner error, all measurements in this study were carried out by one experienced examiner to minimize errors. The identification process, in both manual and computerized methods, was performed with low luminosity and under the same conditions, as recommended by Houston (1983). Operator stress in conducting the cephalograms was controlled by undertaking five manual and five computerized tracings each day.

Sayinsu *et al.* (2007) found a difference between traditional and computerized methods for the measurements; maxillary height, maxillary depth, *y*-axis, FMA, nasolabial angle, and the distance N perpendicular. In another study, the measurement differences of 23 out of a total of 26 cephalometric variables were found to be statistically insignificant between manual measurements and those measured with a computerized method. It was concluded that comparable measurement results are possible between the traditional method and a computer-aided system (Chen *et al.*, 2004a).

The present study did not test the reliability of computerized cephalometrics for a single landmark or a combination of landmarks. Most studies, however, have reported a difference in errors in the horizontal and vertical directions for single landmarks (Chen *et al.*, 2000; Liu *et al.*, 2000). The findings of the present investigation indicate that computerized cephalometric analysis yields comparable results to traditional cephalometric analysis.

Conclusions

The measurements obtained with the computerized cephalometric analysis programs used in the present study were shown to be reliable. Therefore computer-aided cephalometric analysis can be used by the clinician.

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