Original Article

Enhanced Speed and Precision of Measurement in a Computer-Assisted Digital Cephalometric Analysis System

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Abstract: The computer-assisted digital cephalometric analysis system (CADCAS) may reduce the time required for cephalometric analysis, especially for taking measurements. Aimed at estimating the time saved by using CADCAS, we measured the time needed by a clinician to perform the analysis in a traditional manner. We also sought to verify the accuracy achieved by traditional cephalometric analysis by exploring the disagreement between manual measurements and those generated by CADCAS. Our results revealed that, on average, even an experienced clinician needed more than 25 minutes to perform an entire cephalometric analysis using a traditional method, with more than 15 minutes of this needed just for taking measurements. Disagreements between measurements by traditional method and those by CADCAS were most frequently noted in the measurement value of cephalometric items reflecting the severity of a jaw discrepancy by the ''sign'' reflecting the anteroposterior relationship. After excluding the measurements with obvious error, the measurement differences between traditional method and CADCAS were not statistically significant in 23 of a total of 26 cephalometric items. In conclusion, the CADCAS can reduce the time needed for cephalometric analysis and can help reduce the human errors introduced during the manual-measuring procedure in the traditional cephalometric analysis. (*Angle Orthod* 2004;74: 501–507.)

Key Words: Computer-assisted cephalometric analysis; Digitized imaging; Speed; Precision

INTRODUCTION

Since the introduction of cephalometry by Broadbent in 1931, the technique has been an important tool to orthodontists and oral surgeons studying dental malocclusion and underlying skeletal discrepancies.[1] The applications of cephalometric analysis includes case diagnosis, treatment planning, evaluation of treatment results, and prediction of growth.[2–4] Traditional cephalometric analysis is preformed 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.

Rapid advances in computer science have led to the wide application of computers in cephalometry.[5–7] When using computer-assisted software programs for cephalometric analysis, the landmarks are usually digitized first. The software program can then generate the values of cephalometric measurement instantaneously, when the locations of all the required landmarks are entered. The digital cephalometric images can be integrated with patients' records to establish a computer-based filing system and to take advantage of image processing, storage, and transmission.[8,9] Many commercially available or customized programs have been developed to perform cephalometric analysis directly on the screen-displayed digital image.[6,10] Such applications can substantially reduce potential errors in the use of digitizing pads and eliminate totally the need for hard copies of cephalometric images in traditional analysis.

The performance of a computer-assisted digital cephalometric analysis system (CADCAS) from monitor-displayed digital images has been reported.[11] The computer-assisted system may reduce the time needed for traditional cephalometric analysis, especially for taking measurements.

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TABLE 1. Cephalometric Measurements Evaluated in This Study[a]

SNA	Angle determined by points S, N, and A
SNB	Angle determined by points S, N, and B
ANB	Angle determined by points A, N, and B
NAPog	Angle determined by points N, A, and Pog
SN-FH	Angle determined by SN plane and Frankfort horizontal (FH) plane
SN-OP	Angle determined by SN plane and occlusal plane
SN-MP	Angle determined by SN plane and mandibular plane
UFH/LFH	Ratio of upper facial height (N-ANS) to lower facial height (ANS-Me)
UI-SN	Angle formed by the intersection of upper incisor axis and SN plane
UI-LI	Angle formed by the intersection of tooth axes of upper incisor and lower incisor
LI-OP	Angle formed by the intersection of lower incisor axis and occlusal plane
LI-MP	Angle formed by the intersection of lower incisor axis and mandibular plane
AArGn	Angle formed by points A, Ar, and Gn
AGnAr	Angle formed by points A, Gn, and Ar
ArAGn	Angle formed by points Ar, A, and Gn
A-Nv	Distance from point A to Nv line (perpendicular to FH plane from point N)
Pog-Nv	Distance from point Pog to Nv line (perpendicular to FH plane from point N)
UI-NPog	Distance from upper incisor edge to lower facial plane (N-Pog)
Ar-A	Distance between points Ar and A
Ar-Gn	Distance between points Ar and Gn
A-Gn	Distance between points A and Gn
Ar-A/Ar-Gn	Ratio of Ar-A to Ar-Gn
au	Vector formed by the projections of point A and upper incisal edge onto FH plane
bl	Vector formed by the projections of point B and lower incisal edge onto FH plane
ul	Vector formed by the projections of upper and lower incisal edges onto FH plane
ab	Vector formed by the projections of point A and point B onto FH plane

[a] Degree in angular measurement and millimeter in linear measurement.

However, no previous studies have reported the relative time needed for different procedures in traditional cephalometry. The purpose of this study thus sought to evaluate the time needed by a clinician, whether experienced in cephalometric analysis or not, to perform the analysis in a traditional manner. This information will allow quantification of how much a CADCAS can reduce the time for analysis. It also sought to verify the precision of archived traditional cephalometric analysis by exploring the disagreement of manual measurements with those generated by CADCAS.

MATERIALS AND METHODS

Nineteen commonly used landmarks (N, S, Po, Or, Ar, Go, Me, Gn, Pog, B, A, ANS, PNS, UIA, UIE, LIA, LIE, UM, LM) were included in our cephalometric analysis system. Using the traditional method, a cephalometric tracing was made on an acetate overlay superimposed on the original radiograph followed by identification of landmarks. Then 26 linear and angular measurements (Table 1) were measured with a ruler and cephalometric protractor from the 19 landmarks.

Among the commonly used cephalometric items, the analyses of jaw triangle[12] formed by Ar, A, and Gn and the vector analysis[13] of ab, ul, au, and bl were described briefly as follows. The jaw triangle was defined as a triangle formed by the Ar, point A, and Gn. Seven parameters of jaw triangle analysis were effective length of maxilla (Ar-A), effective length of mandible (Ar-Gn), Intermaxillary length (A-Gn), ratio of Ar-A to Ar-Gn (Ar-A/Ar-Gn), upper anterior angle (ArAGn), lower anterior angle (AGnAr), and posterior angle (AArGn).

The linear measurements could reflect the growth of jawbones and relate to the final position of jaw bases. The angular measurements were used to evaluate the anteroposterior and vertical relationships between upper and lower jaws. The a, b, u, and l were the projected points of the points A, B, maxillary incisor tip, and mandibular incisor tip onto the Frankfort horizontal plane. According to the principle of the vector analysis, the vector formula ab-ul = au-bl can always stand irrespective of the variations in the locations of the points a, b, u, and l. If the point "a" was anterior to point "b", a positive value was given to the vector ab, whereas a negative value denoted that "a" was posterior to "b". According to the similar geometric principle, we can denote the sign of vector ab, ul, au, and bl. These vectors represent the anteroposterior linear relationship between the upper jaw and lower jaw, the upper incisor and the lower incisor, the upper incisor to the upper jaw, and the lower incisor to the lower jaw, respectively with reference to the FH plane.

The first part of this study was to quantify the time needed for different procedures in traditional cephalometric analysis and to investigate the effect of the observer's clinical experience. A total of six dentists, divided into two groups (expert and novice) were involved in this prospective study. The three dentists who are experts were undergoing training in orthodontics and had more than two years of experience in cephalometric analysis. The other three novice dentists were doing their first session of mandatory training in orthodontics, part of their general dentistry practices. Each of the dentists was asked to perform the cephalometric analysis for six lateral cephalograms. The procedures of tracing, landmark identification, and measurement were followed step by step, and the time spent for each procedure was recorded in seconds. These times could then be used to determine the impact of a learning curve on the time needed for traditional analysis.

The calibrated CADCAS program was developed with a Borland C++ Builder program (Borland Software Corporation, Scotts Valley, Calif, USA). The 19 cephalometric landmarks were included. The operator controlled the mouse to position a dot indicated by the cursor for landmark identification. The landmark location could be corrected until the operator was satisfied. The position of the landmark was recorded in the format of *x, y* coordinates, which indicated the position of the landmark pixels in the digital image. The output-coordinates file was in the MS Excel format (Microsoft Corp., Redmond, Wash, USA) for data analysis.

The retrospective aspect of this study again involved a group of expert clinicians and a group of novice clinicians. The expert group consisted of five residents in orthodontic training, each of whom had more than two years of experience in cephalometric analysis. The novice group consisted of 11 interns who were not experienced in cephalometric analysis. For each of the expert and novice groups, 22 archived cephalometric radiographs with a previously performed analysis were selected randomly from the orthodontic patients' files in the Department. Exclusion criteria were (1) unerupted or missing incisors and (2) unerupted teeth overlying the incisors' apices. These two sets of cephalometric radiographs had been traced and analyzed with traditional methods by expert and novice clinicians, respectively.

To verify the manual measurements, the archived cephalometric analysis could be checked with the aid of computer-assisted analysis. The cephalometric tracings on acetate overlays were scanned to transform the analog image into a digital format in the manner described previously.[11] After the digital format of the cephalometric tracing of the original radiographs was displayed on a high-resolution monochromic monitor, the 19 landmarks identified previously on the tracing were recorded with a mouse-controlled cursor (Figure 1). To prevent introducing additional random error, the landmark recording was done by an independent investigator, who was familiar with the CADCAS.

To verify the manual measurements of traditional cephalometric analysis, the value of each item was compared with the corresponding measurements from CADCAS. All differences between these two sets of data were calculated and compared. We further checked the original tracing and the manual measurement for any item with an absolute difference exceeding five units of measurement. Five units was an arbitrary value and mostly could cover two standard deviations of traditional cephalometric norms. The number of original tracings with erroneous manual measurements and the number of mistakes in each tracing were registered.

Statistical analysis

The mean time and standard deviation were calculated for each procedure of the traditional cephalometric analysis. The comparison between the novice and expert groups was analyzed by *t*-test. In the analysis of cephalometric values, the erroneous manual measurements were treated as the outliers and excluded from the statistical analysis. Descriptive statistics (mean and standard deviation) were calculated for all measurement differences between the two sets of data from traditional manual measurements and those from CADCAS. The significance of measurement difference for each item in the overall group and the comparison between novice and expert groups were analyzed by *t*-test at the level of $P < .05$.

RESULTS

The mean and standard deviation of the time needed for each procedure of traditional cephalometric analysis were reported in minutes (Table 2). The novice group needed significantly more time than the expert group to perform cephalometric tracing and landmark location but not in the process of measurement. The standard deviation of mean time needed for tracing in the novice group was more than others, indicating the wider range of individual variation in hand tracing by novice clinicians. They needed significantly more time to complete the overall cephalometric analysis procedure than did the experienced orthodontists. Both the ''expert'' and ''novice'' clinicians required more than 15 minutes just for making measurements. The amount of time spent by the expert clinician for measurement was more than half the time taken for the entire analysis procedure.

The values of manual measurements in traditional cephalometric analysis were compared with the corresponding results from CADCAS. The items with a difference exceeding five units of measurement were checked to further detect any erroneous measurements from the archived cephalometric analysis. The number of errors detected in the manual measurements is shown in Table 3. The number of erroneous measurements was higher in the novice group than that in the expert group (21:8). This difference was also noted in the number of the cephalometric analysis with erroneous measurements in a total of 22 analyses (12:6). One error was detected in each cephalometric analysis of eight tracings in the novice group and each of five tracings in expert group. Contrary to the one tracing only found in the expert group, four tracings in the novice group were found to have more than one erroneous measurement. To our surprise, the number of errors in one analysis in the

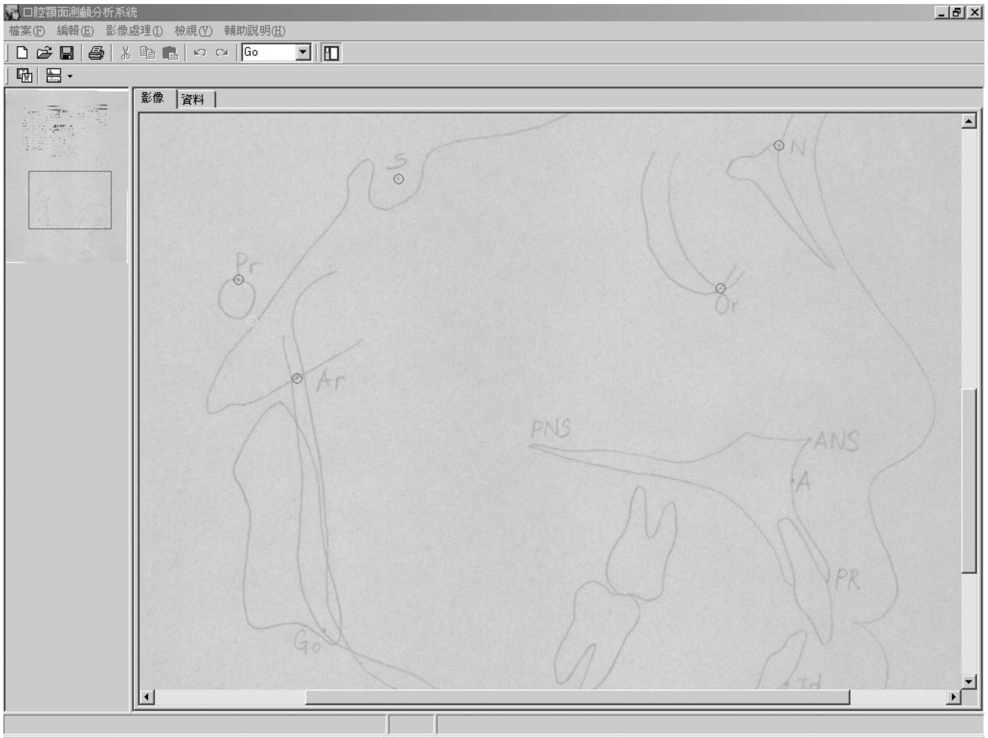

FIGURE 1. A cephalometric tracing was displayed in the computer-assisted digital cephalometric analysis system.

TABLE 2. Mean Time in Minutes Needed for Each Procedure of Traditional Cephalometric Analysis

	Total (n = 36)	Novice (n = 18)	Expert (n = 18)	P value
Cephalometric tracing	14.17 ± 6.43	16.17 ± 6.70	9.33 ± 0.88	*
Landmark location	1.60 ± 0.83	2.00 ± 0.60	0.63 ± 0.37	*
Measurement	15.38 ± 5.28	15.38 ± 6.23	15.37 ± 1.92	NS[a]

[a] NS indicates not significant.

* Significant difference between Novice and Expert groups at $P < .05$.

TABLE 3. Number of Errors in Traditional Cephalometric Analysis Performed With a Ruler and Protractor

	Novice	Expert
Number of errors in all measurements	21	8
Number of analysis with erroneous measurements in 22 tracings	12 (54%)	6 (27%)
Number (N) of erroneous measurement in one analysis		
$N = 1$	8	5
$N = 2$	1	1
$N = 3$	2	0
$N = 4$	0	0
$N = 5$	1	0

novice group could be as high as five. Most of the errors detected were due to a mistake in the measurement sign, especially the NAPog, Pog-Nv, au, bl. The signed measurements were used to quantitatively reflect the anteroposterior relationship.

Tables 4 and 5 show the angular and linear measurement differences between traditional, manual measurements, and their counterparts from CADCAS. The mean and standard deviation for each cephalometric item were listed separately for the overall, novice, and expert groups, respectively. Most of the mean measurement differences in the overall group were statistically nonsignificant from zero, except the three angular measurements: SN-OP, UI-LI, and ArAGn. However, the values were within one unit of measurement, and their clinical significance may not be very important. The comparison between novice and expert groups revealed that most measurement differences between traditional manual measurements and those by computer-aided cephalometric analysis were not statistically significant except for three out of the 26 cephalometric items. The measurement differences of ArAGn, Ar-A/Ar-Gn, and bl were statistically significant between novice and expert groups. However, the values were generally too small to have clinical significance.

TABLE 4. Differences of Angular Cephalometric Measurements Generated by Traditional Method and Computer-assisted Digital Cephalometric Analysis System

	Total	Novice	Expert
SNA	0.10 ± 0.74	0.00 ± 0.89	−0.19 ± 0.57
SNB	0.08 ± 0.91	−0.15 ± 0.95	0.02 ± 0.37
ANB	0.05 ± 0.60	0.15 ± 0.54	−0.15 ± 0.62
NAP	0.46 ± 2.34	0.36 ± 1.85	0.59 ± 2.94
SN-FH	−0.10 ± 0.86	−0.05 ± 0.97	−0.15 ± 0.76
SN-OP	−0.68 ± 1.70*	−1.03 ± 1.92	−0.35 ± 1.43
SN-MP	−0.18 ± 1.40	−0.34 ± 1.52	−0.04 ± 1.31
UFH/LFH	0.35 ± 1.47	0.83 ± 1.44	−0.13 ± 1.36
UI-SN	−0.21 ± 1.03	−0.06 ± 1.13	−0.37 ± 0.92
UI-LI	0.78 ± 1.67*	0.82 ± 1.94	0.74 ± 1.39
LI-OP	−0.10 ± 3.16	−0.61 ± 3.52	0.40 ± 2.74
LI-MP	−0.24 ± 2.98	−0.34 ± 3.84	−0.14 ± 1.68
AArGn	0.52 ± 1.74	0.80 ± 2.20	0.25 ± 1.14
AGnAr	−0.08 ± 2.19	0.31 ± 2.20	−0.47 ± 2.16
ArAGn	−0.55 ± 1.42*	−0.85 ± 1.74	−0.26 ± 0.99**

* $P < .05$, significant different from expected value (0).
** Indicate significant difference between Novice and Expert groups at $P < .05$.

TABLE 5. Differences of Linear Cephalometric Measurements Generated by Traditional Method and Computer-assisted Digital Cephalometric Analysis System

	Total	Novice	Expert
A-Nv	−0.07 ± 1.22	−0.10 ± 0.86	−0.04 ± 1.51
Pog-Nv	0.05 ± 1.54	−0.05 ± 1.87	0.15 ± 1.18
UI-NP	0.04 ± 1.65	0.02 ± 2.02	0.07 ± 1.24
Ar-A	0.04 ± 1.17	0.18 ± 1.52	−0.10 ± 0.68
Ar-Gn	0.04 ± 1.34	0.05 ± 1.85	−0.04 ± 0.57
A-Gn	0.22 ± 1.61	0.19 ± 1.56	0.25 ± 1.71
Ar-A/Ar-Gn	0.27 ± 1.23	0.58 ± 1.58	−0.03 ± 0.66**
au	0.01 ± 0.86	−0.09 ± 0.97	0.06 ± 0.74
bl	−0.29 ± 1.38	−0.37 ± 0.96	−0.21 ± 1.74**
ul	0.08 ± 1.17	0.15 ± 1.52	0.01 ± 0.68
ab	0.23 ± 1.56	0.17 ± 1.63	0.29 ± 1.53

** Indicate significant difference between Novice and Expert groups at $P < .05$.

DISCUSSION

The time required for different procedures in traditional cephalometric analysis was measured in this study. The focus of interest was the time needed for making measurements with a ruler and protractor in the traditional manner. The result demonstrated that training in cephalometric analysis reduces the time needed for cephalometric hand tracing and landmark identification but not in the process of measurement. Expertise does not increase the speed of measurement, which unfortunately takes up more than half of the total time needed for a trained person to perform a cephalometric analysis.

Consequently, the computer is a very helpful tool in determining measurements of this kind, because once the landmarks are chosen on the digital images and identified, the data processing can be executed and completed immediately. The measurement results from CADCAS are available almost in a split second. In terms of efficiency, CADCAS significantly reduces the time needed for the process of measurement. We did not measure the overall time required to perform the analysis using CADCAS, including the time needed to scan the original radiographs, boot up the computer program, and identify the landmarks. The exact time needed for data processing to generate the measurements with the aid of computer may depend on the level of computer components, especially the hardware and peripherals. The equipment of our CADCAS was popular and could be established conveniently.

The original radiographic cephalograms could be converted into a digital image by a scanner or video camera. The quality of the digital image and the efficiency of image conversion correlate highly with the choice of method and the equipment used.[14] Digital image processing could be applied to the digitized cephalograms captured by a video camera for better landmark identification in cephalometric analysis.[15]

Ongkosuwito et al[16] demonstrated that the image quality of a cephalogram scanned at a resolution of 300 dpi is sufficient for clinical purposes and comparable to original analog cephalometrics. It has been suggested that the settings of resolution and grayscale or color when digitizing a cephalometric film by scanner does not significantly affect the precision of landmark identification when standard scanner settings are used. The direct digital cephalogram can be conveniently integrated with computer-based filing system of patients' records and totally eliminate the need for scanning the traditional radiographic film. Recently, the photostimulable phosphor digital cephalometric radiograph was developed and had demonstrated a better subjective image quality than traditional cephalometric image.[17] In comparison with the traditional screen-film system, a substantial reduction of radiation exposure could be achieved without detrimental effect on the determination of the cephalometric landmarks.[18]

With digital cephalogram obtained by various digitization process or digital radiography, the clinician needs to only identify the landmarks and let the program calculate the cephalometric measurements. Many previous studies demonstrate how the reliability of landmark identification varies with different landmarks and with the experience of the observer.[19–21] The data in this study revealed that the experienced clinicians could identify landmarks in statistically significant less time than the novices. The time taken for landmark identification on monitor-displayed digital image may also depend on the experience of the observers.

There are some limitations in measuring a distance or angle by the naked eye with the ruler and protractor. The smallest scale of the measuring device, which is millimeter for linear and degree for angular measurement, limits the precision. The carefulness and experience of the observer also limit the precision. These limitations may help explain the statistically significant measurement differences for some of the cephalometric items between traditional method and CADCAS, though they might not be of clinical significance. It is evident that computers can make linear and angular measurements with a degree of precision that is not possible with the traditional method.

In this study, the disagreement between the measurements from traditional naked-eye method and with CADCAS could be explained partly by another inherent factor in the traditional method. In measuring a tracing by 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. It might have been expected that cephalometric tracing before digitizing the landmarks would make identification of the landmarks more reliable. However, Cohen's study[20] demonstrated the reverse.

The CADCAS has many advantages in image storage, transmission, and processing. However, the attitude of some clinicians may be difficult to change, if they tend to be skeptical toward the performance of cephalometric analysis. A previous study demonstrated that the CADCAS differed significantly from traditional cephalometric tracing in locating four out of 19 commonly used landmarks.[11] Difficulties in locating these landmarks are likely because of the indistinct appearance of these structures in cephalograms. Fortunately, the inferior reliability of some landmarks directly identified on digital images may have little impact in our application of digital cephalometry. Another previous study revealed that the measurement differences between the original cephalograms and digital images were statistically significant but clinically acceptable.[22] This study demonstrated that the reliability of cephalometric measurements on the digital cephalogram is generally comparable to those on original radiographs.

In the present study, we demonstrated that the time required for making measurements using the traditional method could be sped up with the application of CADCAS. Moreover, errors in manual measurements could be avoided, especially for the novice clinician. These results imply that every effort should be made to correctly locate landmarks on digitized radiographs or tracings, and then cephalometric analysis can be more efficiently performed.

The accuracy and reliability of cephalometric measurement, which should be assessed by comparison with a "gold standard", were not tested in this study. The disagreement of measurements from the traditional method and those from CADCAS was assumed to result from the difference in measuring processes, namely manual and computer-aided. We checked the differences by sorting out the items with difference values exceeding five units of measurement, which was supposed to be easily appreciable and have clinical significance in most of the cephalometric items.

Most erroneous measurements were the items reflecting the severity of jaw discrepancy by measurement value and the anteroposterior relationship by the "sign". It is probable for a novice clinician to introduce error in reporting the sign of measurement value. After excluding the obvious error, the measurement differences of 23 in a total of 26 items were not statistically significant between manual measurements and those from CADCAS. This insignificance implies that comparable measurement results are possible between the traditional method and a computer-aided system.

The reliability and efficiency of digital cephalometry may be related to the expertise of observers. Further study is needed to highlight the effects of training level and learning curve of the user on the performance of CADCAS.

CONCLUSIONS

In this study, we demonstrated that the time spent for tracing anatomical structures and identifying landmarks were significantly different between novice and expert clinicians. However, the experience and expertise could not accelerate the hand-measuring process.

The CADCAS program can reduce the time required for making cephalometric measurements with the ruler and protractor. Furthermore, we demonstrated that this system could help reduce the human errors introduced in the manual-measuring procedure.

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