Original Article

The Effects of Differences in Landmark Identification on the Cephalometric Measurements in Traditional Versus Digitized Cephalometry

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Abstract: The aim of this study was to explore the effects of differences in landmark identification on the values of cephalometric measurements on digitized cephalograms in comparison with those obtained from original radiographs. Ten cephalometric radiographs were randomly selected from orthodontic patients' records. Seven orthodontic residents identified 19 cephalometric landmarks on the original radiographs and digitized images. Twenty-seven cephalometric measurements were computed with a customized computer-aided program. To assess the concordance between cephalometric measurements derived from landmarks identified on the original radiographs and those from digitized counterparts, the values of 27 cephalometric measurements were compared to quantify the absolute value of measurement difference and the interobserver errors between these two methods. We found that the differences of all cephalometric measurements between original radiographs and their digitized counterparts were statistically significant. The differences in 21 of the 27 cephalometric items were less than two units of measurement (mm or degree), which is generally within one standard deviation of norm values in conventional cephalometric analysis. Moreover, statistically significant differences of interobserver errors between the two methods were noted only for seven of the 27 cephalometric items. In conclusion, the measurement differences between the original cephalograms and the digitized images are statistically significant but clinically acceptable. The interobserver errors for cephalometric measurements on our digitized cephalometric images are generally comparable with those on the original radiographs. The results of our study substantiated the benefits of digital cephalometry in terms of the reliability of cephalometric analysis. (*Angle Orthod* 2004;74:155–161.)

Key Words: Computer-aided cephalometric analysis; Digital imaging; Cephalometric measurement

INTRODUCTION

Rapid advances in computer science have led to its wide application in orthodontics. Computer-based filing systems for patients' records have the benefits of image storage, transmission, and processing.[1] Many commercially available programs have been developed to perform cephalometric analysis directly on the screen-displayed digital image.[2,3] Computer-aided cephalometric analysis on digitized cephalogram could substantially reduce the potential errors in the use of digitizing pads and eliminate the production of hardcopies of digitally born images for conventional cephalometric analysis. Actually, a radiographic system for directly taking digitized cephalograms at a reduced radiation dose is available.[4,5] Otherwise, the conventional cephalometric radiographic films could be transformed into a digital format by a film scanner.

The errors in cephalometric analysis are composed of systematic errors and random errors; the latter involves tracing, landmark identification, and measurements. Computer-aided cephalometric analysis can totally eliminate the mechanical errors in drawing lines between landmarks and in measurements with a protractor. Earlier studies reveal that computer-aided cephalometric analysis does not introduce more measurement error than hand tracing, as long as

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TABLE 1. The 27 Cephalometric Measurements Used in This Study

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
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)
NAPog	Angle determined by points N, A, and Pog
Wit's	Distance between the projections of point A and B onto occlusal plane
ab	Distance between the projections of point A and B onto FH plane
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)
Ar-A	Distance between point Ar and A
Ar-Gn	Distance between point Ar and Gn
A-Gn	Distance between point A and Gn
Ar-A/Ar-Gn	Ratio of Ar-A to Ar-Gn
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
UI-SN	Angle formed between axis of upper incisor to SN plane
UI-NPog	Distance between upper incisor edge to lower facial plane (N-Pog)
UI-LI	Angle formed by the intersection of tooth axis of upper incisor and lower incisor
LI-OP	Angle formed by the intersection of lower incisor axis to occlusal plane
LI-MP	Angle formed by the intersection of lower incisor axis to mandibular plane
au	Distance between the projections of point A and upper incisal edge onto FH plane
bl	Distance between the projections of point B and lower incisal edge onto FH plane
ul	Distance between the projections of upper and lower incisal edges onto FH plane

landmarks are identified manually.[6,7] However, the inconsistency in landmark identification is still an important source of random error in computer-aided digital cephalometry. For digital cephalometry to be a better tool in clinical orthodontics, the cephalometric analysis, represented by widely used linear and angular measurements, must be as comparable and reliable as it is on conventional radiographic film. In the previous study, it was demonstrated that the differences in landmark identification between original cephalometric radiographs and their digitized counterparts were statistically significant.[8] This difference may be the major source of differences in the determination of linear as well as angular measurements on original radiographs and their digitized counterparts. The purpose of this study is to explore the effect of the differences in landmark identification on the values of cephalometric measurements on digitized cephalograms in comparison with those obtained from original radiographs.

MATERIALS AND METHODS

The criteria to randomly select cephalometric radiographs and the way to perform cephalometric analysis have been described in detail in the previous study.[8] In brief, 10 conventional cephalometric radiographs were selected from orthodontic patients' records, scanned into the digital format with a roller-type scanner (VXR-12, Vidar System Corp. Herndon, Va), and displayed on a high-resolution monochromic monitor (Image Systems, Hopkins, Minn). The digitized image resolution was 150 dpi with 256 gray levels. The 19 landmarks were identified on original radiographs by manual dot tracing and then directly identified on their monitor-displayed digitized counterparts by seven orthodontic residents with an intervening time interval of more than one week. The landmark identification on original radiographs was performed on a superimposed transparent film, which was scanned and processed in the same way as that on digitized cephalometry. The 27 cephalometric measurements listed in Table 1, including 13 linear and 14 angular measurements, were calculated from the coordinates of 19 cephalometric landmarks by computer-aided cephalometric program. Most of the items are the popular and widely accepted measurements, except the items included in ‘‘vector analysis’’[9] and ‘‘jaw triangle analysis,’’[10] which are routinely used in our department (Figure 1). For each cephalometric item, the absolute values of the differences between the values derived from the original radiographs and those from their digitized counterparts were assessed. The mean and standard deviation of cephalometric measurement differences were calculated. Moreover, the mean value for each of the aforementioned 27 cephalometric measurements derived by the seven observers was defined as the ‘‘gold standard,’’ which was used to determine the interobserver errors of measurements on original film and digitized image. The interobserver error was used as an indicator to determine the reliability of each cephalometric measurement. Consequently, the reliability of cephalometric measurement could be quantified and compared between these two methods.

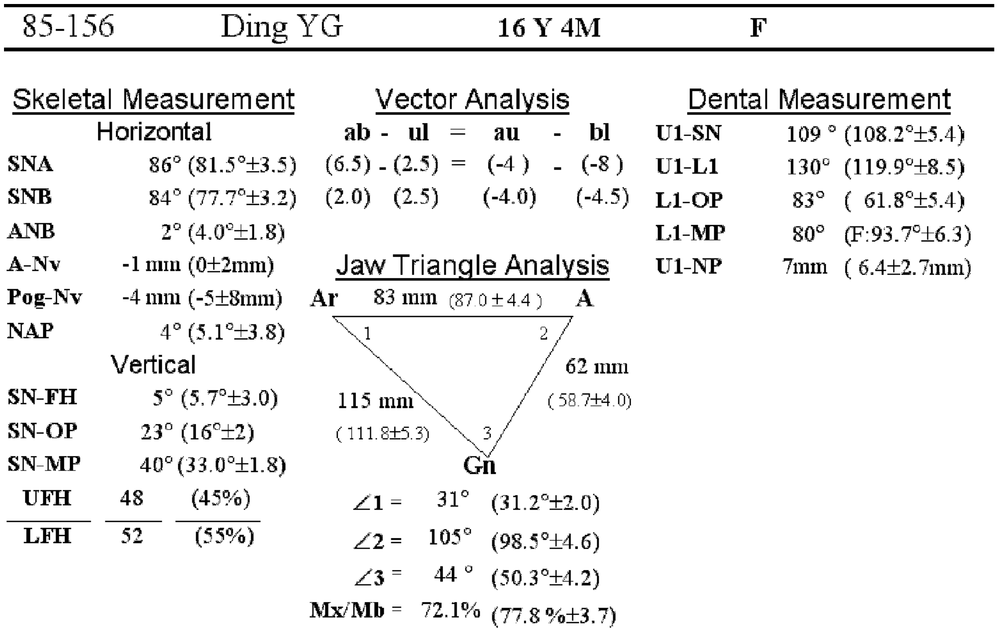

FIGURE 1. The printout record of our computer-aided cephalometric analysis.

STATISTICAL ANALYSIS

To analyze the variation of cephalometric measurement differences, the mean and standard deviation of the cephalometric measurement differences between the original films and the digitized images were calculated for each of the 27 items. The statistical significance of measurement differences and the comparison of interobserver errors between the two methods were checked by paired Student's *t*-test.

RESULTS

The mean difference and standard deviation for each of the 19 skeletal measurements on original radiographs and their digitized counterparts are presented in Table 2. The mean differences range from 0.88° to 1.82° for angular measurements and from 1.13 to 3.09 mm for linear measurements. The comparable results of eight dental measurements are shown in Table 3. The mean differences ranged from 4.08° to 7.68° for angular measurements and from 0.84 to 1.27 mm for linear measurements. To our surprise, the angular dental measurements with greater values of measurement differences between the two methods were exclusively the items indicating the tooth axis of the incisor. However, the measurement differences were less in the linear dental measurements, which were delineated from an incisal edge to a specific reference plane and indicated the protrusive position of the incisor (eg, UI-N Pog, au, and bl). All the measurement differences for each of these 27 cephalometric items were statistically significant ($P < .05$). However, the values of 21 in the 27 items were less than two units of measurement (mm or degree), which is generally within one standard deviation of norm values in conventional cephalometric analysis.[8–10] To have a better overview, the distribution of cephalometric items can be grouped according to the level of measurement differences

TABLE 2. Differences of Skeletal Cephalometric Measurements Between the Two Methods and Statistical Analysis for Interobserver Errors[a]

Item	Measurement Difference[b]	Interobserver Error on Original Radiograph	Interobserver Error on Digital Image
SNA	1.43 ± 1.64	1.13 ± 1.29	0.90 ± 1.11
SNB	1.07 ± 1.36	0.95 ± 1.04	0.65 ± 0.74[c]
ANB	0.95 ± 0.88	0.62 ± 0.56	0.46 ± 0.49
A-Nv	1.92 ± 1.99	0.99 ± 0.83	1.12 ± 1.16
Pog-Nv	3.09 ± 2.81	1.51 ± 1.50	1.58 ± 1.06
NAPog	1.75 ± 1.76	1.02 ± 1.05	1.13 ± 1.12
Wit's	2.05 ± 3.55	1.64 ± 2.51	0.95 ± 0.85[c]
ab	1.28 ± 1.19	0.95 ± 0.84	0.83 ± 0.52
SN-FH	1.61 ± 1.52	1.05 ± 1.05	0.85 ± 0.71
SN-OP	1.82 ± 1.84	1.29 ± 1.01	1.10 ± 1.08
SN-MP	1.56 ± 1.44	1.17 ± 0.99	1.09 ± 0.96
UFH/LFH	1.16 ± 1.30	0.57 ± 0.62	0.85 ± 0.89
Ar-A	1.29 ± 2.92	0.61 ± 0.55	1.06 ± 2.44
Ar-Gn	1.13 ± 2.83	0.70 ± 0.64	1.08 ± 2.38
A-Gn	1.52 ± 2.83	0.54 ± 0.54	1.44 ± 2.05[c]
Ar-A/Ar-Gn	1.04 ± 1.04	0.54 ± 0.55	0.63 ± 0.76
ArAGn	1.39 ± 1.33	0.72 ± 0.61	1.01 ± 1.01
AArGn	0.88 ± 0.83	0.48 ± 0.39	0.70 ± 0.60[c]
AGnAr	1.02 ± 0.95	0.55 ± 0.56	0.63 ± 0.68

[a] Linear measurement in millimeters, angular measurements in degrees.
[b] The differences for all items reached significant level ($P < .05$).
[c] Significant difference of interobserver errors between the two methods was detected by paired *t*-test ($P < .05$).

TABLE 3. Differences of Dental Cephalometric Measurement Between the Two Methods and Statistical Analysis for Interobserver Errors[a]

Item	Measurement Difference[b]	Interobserver Error on Original Radiograph	Interobserver Error on Digital Image
UI-SN	4.89 ± 6.86	3.16 ± 3.89	3.41 ± 4.91
UI-LI	7.68 ± 4.74	4.26 ± 4.23	4.36 ± 5.11
LI-OP	4.08 ± 6.00	2.41 ± 3.11	3.43 ± 4.22
LI-MP	4.16 ± 5.73	1.79 ± 1.37	3.70 ± 4.33[c]
UI-NPog	0.84 ± 1.22	0.49 ± 0.63	0.69 ± 0.77[c]
au	1.27 ± 1.39	0.91 ± 0.93	0.94 ± 1.02
bl	0.90 ± 0.99	0.67 ± 0.51	0.80 ± 0.88
ul	1.08 ± 1.93	0.57 ± 0.77	1.00 ± 1.36[c]

[a] Linear measurement in millimeters, angular measurements in degrees.

[b] The differences for all items reached significant level ($P < .05$).

[c] Significant difference of interobserver errors between the two methods was detected by paired *t*-test ($P < .05$).

TABLE 4. The Distribution of Cephalometric Items According to the Level of Measurement Difference (md) Between Traditional and Digitized Cephalograms[a]

md < 1.0	1.0 < md < 1.5	1.5 < md < 2.0	2.0 < md
ANB	SNA	A-Nv	Pog-Nv
UI-NPog	SNB	NAPog	UI-SN
AArGn	UFH/LFH	SN-FH	UI-LI
bl	Ar-A	SN-OP	LI-OP
	Ar-Gn	SN-MP	LI-MP
	Ar-A/Ar-Gn	Wit's	
	ArAGn	AGn	
	AGnAr		
	au		
	ul		
	ab		

[a] Linear measurement in millimeters, angular measurements in degrees.

between traditional and digitized cephalograms (Table 4). The four items, ANB, UI-NPog, AArGn, and bl, had measurement differences of less than one unit (mm in linear measurement and degree in angular measurement). The items with measurement differences of more than two units were Pog-Nv, UI-SN, UI-LI, LI-OP, and LI-MP, most of which were measurements indicating the tooth axis inclination. The linear dental measurements to evaluate incisal position by the distance between the incisal edge and a specific reference plane were shown to have measurement differences in the middle level (between one and two units). The differences of angular measurements in jaw triangle analysis (AArGn, ArAGn, and AGnAr) were generally smaller than the measurements that indicate the facial divergence by the intersection of two reference planes, which were constructed by four landmark points (SN-FH, SN-OP, and SN-MP).

With regard to the comparison of interobserver errors between these two methods, seven of the 27 items were significantly different (Tables 2 and 3). Generally, the mean value and standard deviation of interobserver error of cephalometric measurements in the digitized images was comparable with those in the original radiographs. The mean interobserver error in the original radiographs ranged from 0.48° to 4.26° for angular measurements and from 0.49 to 1.64 mm for linear measurements. The mean interobserver error in the digitized images ranged from 0.46° to 4.36° for angular measurements and from 0.69 to 1.58 mm for linear measurements. The interobserver errors in the original radiographs and digitized cephalogram was generally comparable with or slightly less than the measurement differences between the two methods. It was noted that the interobserver errors on original radiographs and digitized cephalogram were less than one mm or degree in 16 of the 27 cephalometric measurements. All the three angular skeletal measurements (SN-FH, SN-OP, and SN-MP) that indicate the facial divergence by two reference planes demonstrated interobserver errors of more than 1°. In both modalities, the measurements with larger interobserver error (more than two units) were found to be the measurements representing the tooth axis inclination (UI-SN, UI-LI, LI-OP, and LI-MP). The measurement with the least interobserver error, eg, the most reliable measurement, was AArGn in original radiographs and ANB in digitized counterparts. In the 19 skeletal measurements, the statistically significant differences of interobserver errors between original radiographs and digitized images were demonstrated in two angular measurements (SNB and AArGn) and two linear measurements (Wit's and ab). Surprisingly, the interobserver errors of SNB and Wit's in digitized cephalometry were smaller than those derived from original radiograph. With regard to dental measurements, three items (LI-MP, UI-NPog, and ul) of all the eight items demonstrated significant interobserver errors between these two modalities (Table 3).

DISCUSSION

The major errors associated with conventional cephalometry include projection errors and tracing errors. The most important source of tracing errors is uncertainty in landmark identification, and intraobserver error is generally less than interobserver error.[6,11] The mechanical errors introduced by drawing lines between landmarks manually and by measuring with a ruler and protractor were common in conventional cephalometric analysis. However, these errors were eliminated from our study because the analysis was performed by computer-aided cephalometric program. When we take advantage of digital cephalometry, it is important to be certain that the digitized image yields the similar performance to conventional radiographic film in terms of cephalometric measurements. The major source of error in the determination of linear and angular cephalometric measurements in this study was supposed to be the errors in landmark identification, which were assessed in the previous work.[8] In our previous study, the overall differences of landmark identification between the two methods, conventional radiographs and digitized images, were statistically significant. The extent of the difference for each landmark depended on the radiographic complexities, which were also associated with the reliability of the landmarks. The representation of head films and observers should be considered as possible sources of error when comparing computer-aided cephalometric analysis based on conventional radiographs and digitized images. The head films used in this study were randomly selected from the patients' files. They were representative of the films that we considered satisfactory for routine clinical use. The observers in this study were the residents under the three-year postgraduate training program and were considered to be competent clinicians with average training in cephalometrics.

In clinical orthodontics, cephalometric analysis has long been used as an important clinical tool in diagnosis, treatment planning, and evaluation of growth or treatment results. Many parameters were proposed to analyze the relationship of teeth to teeth, teeth to jaws, jaws to cranial base, and the interjaw relationship. For example, the anterioposterior jaw relationship could be evaluated by many linear and angular measurements in cephalometrics. Linear measurements may be affected by the inclination of the reference line, and angular measurements cannot indicate correctly the jaw relationship in the case of extreme facial divergency.[12] Therefore, it is reasonable to evaluate a set of structural relationships by multiple cephalometric parameters rather than by a single parameter. This is the reason why we included as many as 27 measurements in our customized cephalometric analysis to evaluate the routine orthodontic cases. However, the dependence of measurement error should be considered during the interpretation of multiple cephalometric measurements. When a landmark common to a pair of measurements is reused in computing each of those measurements, the significant correlation between measurements may result from the error of measurement, which is contributed to the value for measurements. Houston et al[13] had discussed that the error of identifying a common landmark between linear or angular variables may result in a purely topographic correlation between them, which may exaggerate or attenuate a true biologic correlation. The most practical way to avoid such error is to measure the two variables independently on a separate tracing of each structure.

In terms of random errors of cephalometric measurements, the effect of projection errors caused by incorrect patient positioning should be considered. The effect of incorrect patient positioning on linear and angular measurements was reported by Achlqvist et al.[14,15] When the misalignment of the patient's head was less than $\pm5°$, the errors were generally less than 1% in length measurement and less than $\pm1°$ in angle distortion. A misalignment of the patient's head of more than 5° is easily detected and should be corrected immediately. This information means that the percent error of cephalometric measurements from error in landmark identification might be greater than that from projection error. Many previous studies have shown that it is impossible to estimate the positions of landmarks without error. However, we should make efforts to minimize the effect of error in landmark identification on the cephalometric measurements, especially the items with inherited lower reliability in digitized cephalometry. The impact of the error in landmark identification on the cephalometric measurements can be considered in different aspects. The first is the magnitude of the error inherited in the identification procedure for the specific landmark, which was investigated in the previous work. The average value of measurements by all observers was used as the gold standard for a specific landmark to quantify the actual error. The second is the distance between two landmarks, which are connected to construct a reference plane or calculate a given linear measurement. In the case of linear measurement, the shorter the line segment measured, the greater the percentage of error produced by a given measurement error. This topographic problem is also true for angular measurements. The closer the points in the construction of an angle, the greater will be the impact of measurement error on the angular measurement calculated.

In this study, all the cephalometric measurements demonstrated significant differences between conventional radiographs and digitized cephalograms. The differences in dental measurements were generally larger than those in the skeletal measurements, especially the angular dental measurements. In the previous study, the significant differences of interobserver error in landmark locations between these two methods were demonstrated only at Po, Ar, ANS, and UM. However, these four landmarks were involved in the definition of 19 items of the 27 cephalometric measurements in our study. In this study, the significant differences of interobserver error were noted only in seven of the 27 cephalometric measurements. It means that the high reliability of landmark identification in digitized cephalogram implies the comparable reliability of the subsequently derived cephalometric measurements. In our study, each of the 27 measurements calculated from a total of 19 landmarks involved a minimum of three landmarks for a given measurement. In other words, each landmark estimation was used in more than four measurements and contributed its inherent estimating error to the computation of each measurement. In this study, the statistically significant reliability of SNB and Wit's in digitized cephalometry compared with original radiographs was noted. This finding may be partly explained by the complex interaction among their relevant landmarks. Although statistically significant differences were detected in all cephalometric measurements in the comparison of conventional cephalograms and their digitized counterparts, their clinical significance should be referred to the standard deviation of norm values for each item.[16]

The items with relatively larger measurement differences and a wide range of variation were angular measurements reflecting the axis of the upper and lower incisors (UI-SN, UI-LI, LI-OP, and LI-MP). The differences in these dental measurements may be associated with their larger interobserver errors and wider range of variation in both original and digitized modalities. The short distances among landmark points used to construct the tooth axis of upper and lower incisors could explain the larger interobserver errors of dental angular measurements. In other words, the more closely located two landmark points are, the greater the angular measurement error tends to be. This geometric relationship was reported and discussed by other researchers. Nagasaka et al[17] have illustrated the theoretical relationship between the interlandmark distance and the possible angular measurement error when the linear measurement error is set at a certain level.

In the experimental design of our study, the best estimate for each measurement or gold standard for determining the interobserver errors was defined as the mean value of measurements from seven different observers. The interobserver error was used as a variable to determine the reliability, ie, the dispersion of error around the best estimate for each measurement.The interobserver errors of the 27 cephalometric items in original cephalometric radiographs and digitized images must be exclusive results of error in landmark identification because identical data processing was used in both methods in the study. Every effort should be made to minimize the errors of measurements in cephalometry. However, the quest for precision should not obscure the validity of some cephalometric landmarks and measurements.[16] More replications of landmark identification may help reduce their random errors and, subsequently, the errors in cephalometric measurements.

The source of error in landmark identification associated with the complexity of radiographic images is the difficulty of delineating a landmark on a curved anatomical boundary. We may expect that the powerful tool of digitized image processing could help with landmark identification on poorly defined structures. However, it was reported that the landmark reliability in digitized radiographs of lower quality could not be improved by digital processing.[18] Instead, we should make efforts to improve the precision of landmark identification by enhancing the image quality at the beginning. The image revealed on radiographic film is considered an analog, which means that the gray level is continuous. A digital image is composed of many picture elements (pixels), which are represented by discrete pixel values. The quality of a digital image strongly depends on both the number of pixels and the number of gray levels. The reliability of landmark identification on digital images with a pixel size of 0.47 mm was demonstrated to be inferior to that on conventional radiographs.[19] However, the reliability on a digitized cephalogram with a pixel size of 0.03 mm was better than that on original radiographs with conventional equipment. The cephalometric radiographs used in this study were randomly selected and represented the quality of daily routine work. For the consideration of both digital image quality and their memory size, the image resolution was set at 150 dpi with a pixel size of 0.17 mm.

The reliability of landmark identification is expected to be affected by the image quality. There are several ways of acquiring a digitized cephalometric image, and the image quality would depend on how the image was acquired. In this study, the digitized images were secondarily captured by a film scanner from the images on conventional films. Inevitably, image signal deterioration would occur in the digitization process of scanning and transformation into digital format. In this case, the quality of the digitized images would be less than that of the original images on film. However, the result of this study implied that the parameter setting for our digitized cephalogram was almost adequate in terms of performance of cephalometric analysis, which was demonstrated by the low level of measurement differences and the generally comparable interobserver errors between original and digitized cephalograms. The rapid technological advances in equipment in digital dental radiology have led to the increased popularity of direct digital cephalometric images, which are either captured by computed radiography or by digital radiography. How directly acquired digital cephalometric measurements vary from traditional ones should be further studied.

CONCLUSIONS

In our computerized digital cephalometric analysis, the differences between the measurements derived from the landmarks identified on original cephalometric radiographs and those identified on their digitized counterparts were statistically significant but clinically acceptable. The interobserver errors of cephalometric measurements on digitized images were generally comparable with those from original radiographs. In conclusion, the results of our study substantiated the benefits of digital cephalometry in terms of the reliability of cephalometric analysis.

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