A comparison of sonically derived and traditional cephalometric values

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Prior to orthodontic treatment, it is important to assess the relationships between a patient's skeletal and dental components and to determine how these components affect the soft tissues. In the 1930s, researchers developed the roentgenocephalometric technique to record craniometric (hard tissue) landmarks on children and to apply anthropometric techniques to the practice of orthodontics.[1] Clinicians and researchers have developed numerous analyses to interpret the diagnostic information that the lateral cephalogram provides.[2-6] Contemporary orthodontists use traditional cephalometry, an established and accepted tool, for diagnosis and treatment evaluation.

A disadvantage of traditional cephalometry, however, is that it exposes patients to radiation. Collimation, faster rare earth film/screen combinations, and proper lead shielding are technical advances that reduce radiation exposure.[7-9] Nevertheless, natural and man-made radiation exposure is considered to be cumulative,[10] and the National Council on Radiation Protection recommends that exposures be "...as low as reasonably achievable."[8] Clearly, alternative cephalometric methods are needed.

The Dolphin Imaging Company (Valencia, Calif) has developed the DigiGraph as an alternative to the lateral cephalogram. The DigiGraph uses sound waves and mathematical algorithms

Abstract

The roentgenocephalometric technique is the standard used by orthodontists to assess skeletal, dental, and soft-tissue relationships. However, this technique exposes patients to radiation, preventing orthodontists from taking frequent cephalograms to assess growth and to monitor treatment. Recently, the Dolphin Imaging Company developed the DigiGraph™, a nonradiographic cephalometric method that uses sound waves and mathematical algorithms, and consequently does not expose patients to radiation. But the DigiGraph's accuracy as a cephalometric alternative has not been adequately investigated. The purpose of this study was to compare the values obtained by traditional cephalometrics with those obtained by the DigiGraph technique for 30 well-known measurements, and then to assess the repeatability (intraobserver comparison) and reproducibility (interobserver comparison) for both techniques. Eighteen of the 30 measurements had mean differences that were statistically significant (p>.0067). Regression plots generally illustrate low correlations for the measurements, although Ricketts' esthetic line (upper and lower lip) and Steiner's soft-tissue convexity reveal strong linear relationships between the two methods. Additionally, the radiographically generated measurements showed greater repeatability and reproducibility.

Key words

Cephalometrics • DigiGraph™ • Intraobserver • Interobserver

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Table 1
Means, mean differences, individual standard deviations, and correlation coefficients between methods

Measurements	Mean Ceph.	Mean DigiGraph	Mean difference (Ceph-DigiG)	*p*-value	Standard deviation of differences	Correlation coefficient *r*
Facial angle	87.04	87.69	-0.66	0.5191	+/- 8.47	0.075
Pogonion to N vertical	-14.48	-3.87	-10.61*	0.0000	+/- 7.10	0.606
SNB	76.37	77.74	-1.37	0.0075	+/- 4.17	0.399
ANB	3.33	4.03	-0.69*	0.0066	+/- 2.09	0.755
AB plane - occlusal plane	91.70	86.43	5.27*	0.0000	+/- 10.01	-0.746
Wits analysis	1.44	2.09	-0.65	0.0651	+/- 2.89	0.618
SNA	79.74	81.76	-2.03*	0.0017	+/- 5.19	0.357
A-point to N vertical	-5.76	0.37	-6.13*	0.0000	+/- 3.52	0.696
Condylion to A-point	91.66	93.46	-1.80*	0.0026	+/- 4.81	0.596
Condylion to B-point	118.65	117.14	1.51	0.0179	+/- 5.20	0.783
Interincisal angle	127.54	135.29	-7.75*	0.0000	+/- 11.17	0.690
Occlusal plane to FH	11.81	5.85	5.96*	0.0000	+/- 4.66	0.650
Occlusal plane to SN	16.59	14.25	2.34*	0.0000	+/- 4.37	0.581
Overjet	4.80	3.75	1.05*	0.0000	+/- 1.84	0.677
Overbite	3.57	1.85	1.72*	0.0000	+/- 2.77	0.671
Lower incisor - Mn plane	94.38	92.39	1.99	0.0194	+/- 6.95	0.756
Lower incisor - FH	54.29	65.74	-11.45*	0.0000	+/- 7.61	0.656
Lower incisor - NB (mm)	5.59	2.97	2.62*	0.0000	+/- 1.67	0.842
Lower incisor - NB (deg)	26.56	22.84	3.72*	0.0001	+/- 7.56	0.715
Upper incisor - SN	102.53	101.68	0.84	0.3742	+/- 7.90	0.607
Upper incisor - FH	107.64	110.46	-2.82*	0.0056	+/- 8.24	0.582
Upper incisor - NA (mm)	5.74	1.94	3.81*	0.0000	+/- 3.02	0.436
Upper incisor - NA (deg)	22.57	19.91	2.66	0.0068	+/- 7.97	0.578
Pogonion to NB	2.29	2.03	0.25	0.4855	+/- 3.03	0.626
Y-axis to SN	68.76	67.95	0.81	0.1086	+/- 4.18	0.575
Mn plane to FH	30.74	21.60	9.14*	0.0000	+/- 3.97	0.772
Mn plane to SN	35.73	31.63	4.10*	0.0004	+/- 9.15	0.672
Ricketts' E-line upper lip	-1.76	-1.89	0.13	0.4773	+/- 1.47	0.933
Ricketts' E-line lower lip	-0.59	-0.72	0.13	0.5243	+/- 1.74	0.907

to perform cephalometric analyses; this method does not expose patients to radiation.[11] The DigiGraph could be a viable alternative to the lateral cephalogram, but its accuracy has not been adequately investigated. Two published studies have compared DigiGraph cephalometric values with traditionally derived values. Dolphin Imaging Company consultants reported comparable cephalometric values and greater repeatability for some sonically derived measurements.[12] Prawat et al.[13] reported significant differences between the two techniques and less variability with the radiographically obtained data.

The purpose of this study was to compare measurements obtained from the lateral cephalogram with measurements obtained from the DigiGraph, and to assess the repeatability (intraobserver comparison) and reproducibility (interobserver comparison)[14] for the two techniques. If the values are comparable, orthodontists interested in a nonradiographic cephalometric technique could use the DigiGraph instead of the lateral cephalogram, especially in situations requiring frequent measurements.

Materials and methods

Patients starting or finishing orthodontic treatment at the University of Washington require records that include a lateral cephalogram. During the study period, each patient presenting to have a cephalogram taken was asked to participate in the study; a DigiGraph analysis was performed for each consenting patient. (If the patient was considered to be a nongrower [22 years old or older], then a delay of up to 2 weeks prior to digitizing was allowed.) There were no exclusionary criteria. The sample consisted of 70 patients, 41 males and 29 females, with a mean age of 18.2 years (9.1 to 50.9 years). Only one patient declined to participate in this study.

Standard cephalograms were obtained using the following criteria:

Anode-to-subject distance of five feet.

Subject-to-film distance of five inches.

A kVp setting of 78 and a mA setting of 100.

Kodak Lanax Regular film with an exposure of 0.1 second.

A cephalostat with a light indicator was used to orient the patient's head so that Frankfort horizontal was parallel to the ground.

A dodger was used to enhance the soft tissue profile.

The patients closed their teeth together (centric occlusion) and relaxed their lips to provide the most correct reproduction of lip morphology.[15]

The lateral cephalograms were traced by hand on acetate paper using a mechanical pencil with a 0.5 mm diameter lead. Landmarks were identified for each cephalogram, and 30 angular and linear measurements (Table 1) were calculated by hand, using a protractor and millimeter ruler. Measurements were made to the nearest 0.5 mm or degree.

Each subject was digitized in the manner described in the DigiGraph operations manual. The patient was seated in the chair and the head secured with a cephalostat. The patient's head was aligned so that the Frankfort horizontal plane was parallel to the floor; a forehead restraint and three posterior head restraints were used to minimize patient movement. Patients were asked to bring their teeth together (centric occlusion) and to relax their lips. The appropriate landmarks were digitized in the following order: (1) facial landmarks, (2) mouth-closed intraoral landmarks, and (3) mouth-open intraoral landmarks. The fourth category of landmarks cannot be digitized directly (e.g., sella turcica) and are computed by mathematical algorithms. The desired analysis (e.g., Steiner, Downs) was selected and the linear and angular measurements were computed by the DigiGraph system. The average time to digitize a patient once was approximately 10 minutes.

To assess the intraobserver error, 15 randomly selected subjects were immediately digitized a second time by the primary examiner. The corresponding cephalograms were traced a second time after a 2-week interval. To assess interobserver error, 15 subjects were chosen at random, and immediately following the initial procedure, a second examiner, who was also a second-year orthodontic resident, independently digitized the patients. The second examiner also independently traced the corresponding cephalograms. Prior to the start of this study, to standardize the two examiners, 10 cephalograms not associated with this sample were used to coordinate landmark identification and measuring techniques. Similarly, the two examiners were trained by the same DigiGraph representative, they digitized each other multiple times and they digitized five patients not associated with this study before digitizing the study participants. The method error values were then calculated using the following equation:

$$S_x = \sqrt{\Sigma D^2 / 2N}$$

where D is the difference between the duplicated measurements, and N is the number of double measurements.[16]

Means for both techniques were calculated for all 30 measurements, and the differences between the means were tested for significance using a paired *t*-test. Significance was established at $p < .05$ level and then adjusted according to Bonferonni to $p < .0067$. Standard deviations of the differences were calculated to assess variation within the sample. Linear regression analyses with accompanying scatterplots were performed for all 30 variables in order to numerically and graphically assess the agreement between the two techniques. Statistically significant correlations were established at $r > .37$. Repeatability and reproducibility of the two methods were assessed by intraclass correlation coefficients (ICCC), estimated from ANOVA results.[17]

Results

Differences in techniques

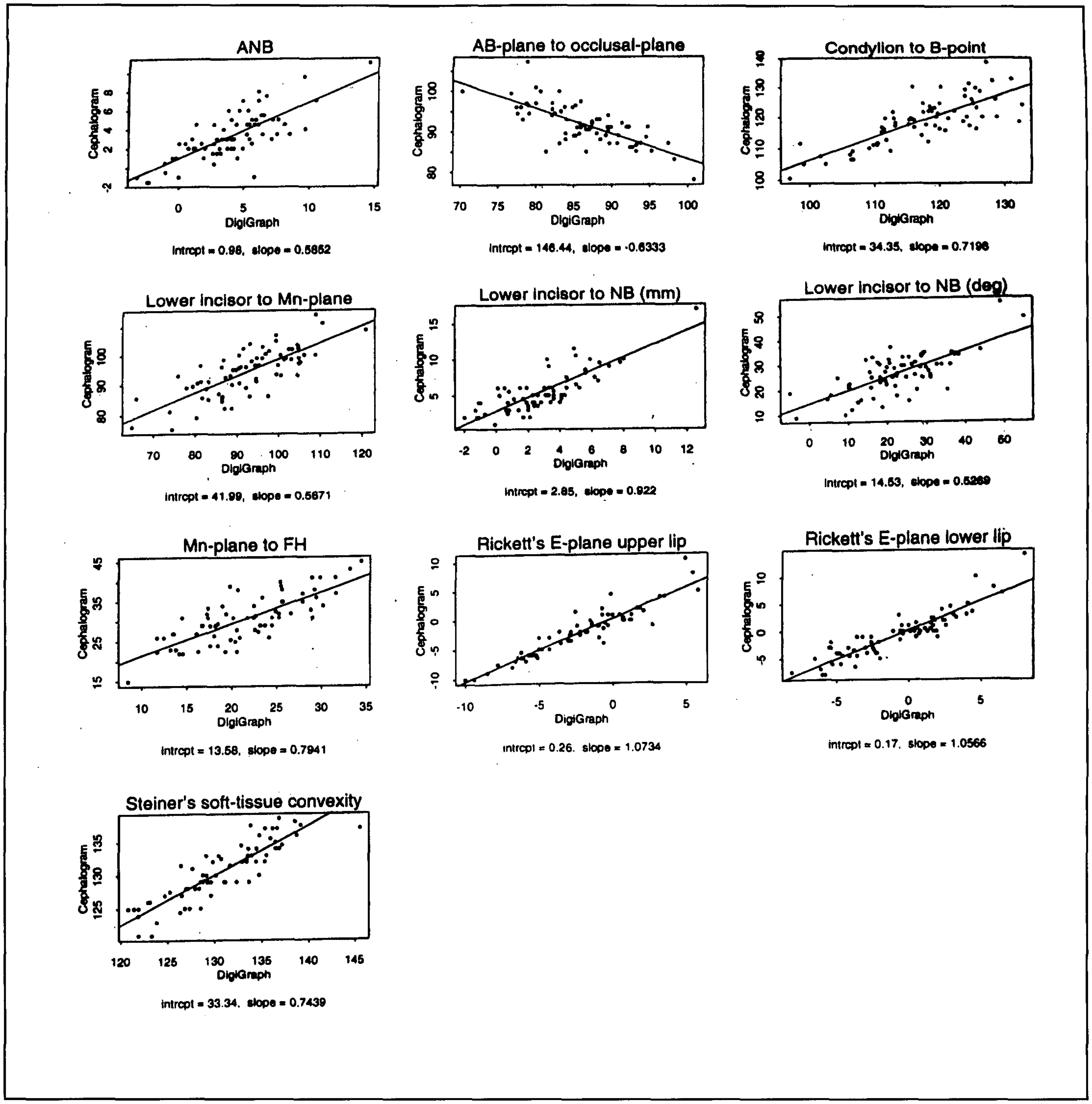
The means, mean differences, and standard deviations of the differences for the two techniques are listed in Table 1. There was a statistically significant mean difference for 18 of the 30 measurements ($p > .0067$). Eighteen of the measurements had standard deviations equal to or greater than +/- 4.0 degrees/millimeters.

Correlation of methods

Correlation coefficients between both methods were calculated (Table 1). Twenty-eight of the 30 variables had statistically significant correlation coefficients ($r > .37$), but only four had correlation coefficients greater than 0.80. Figures 1 through 10 illustrate regression plots for the individual measurements that had correlation coefficients greater than 0.70. Intercepts, regression coefficients (slopes) and correlation coefficients are listed below each figure.

Repeatability / Reproducibility

Table 2 lists the intraobserver and interobserver mean error values with corresponding ranges for the angular and linear measurements. Focusing on the range, the DigiGraph angular and linear mean error values were two to three times that



Figures 1-10
Regression plots

of the cephalogram mean error values. For both angular and linear measurements, the interobserver error for the two methods was greater than the intraobserver error. Table 3 lists the intraclass correlation coefficients (ICCC), which qualitatively indicate greater agreement as the value approaches 1. For all the intraobserver measurements, there was greater agreement for the traditional cephalometric values than for the DigiGraph values. Except for measurement 30, Steiner's soft-tissue convexity, interoperator measurements for the cephalogram show greater reproducibility.

Discussion

To compare the DigiGraph cephalometric technique with traditional cephalometric technique may imply that the traditional method is without limitations, but this is not true. The tradi-

Table 2
Mean angular and linear intraobserver/interobserver error

		Repeatability		Reproducibility	
		Cephalogram	DigiGraph	Cephalogram	DigiGraph
Angular measurements	mean	1.0°	3.2°	1.8°	3.6°
	range	0.5 to 1.8°	1.2 to 6.7°	0.5 to 2.8°	1.3 to 6.7°
Linear Measurements	mean	0.8 mm	1.9 mm	0.9 mm	2.51 mm
	range	0.4 to 1.3 mm	1.0 to 3.4 mm	0.5 to 2.0 mm	1.0 to 6.0 mm

Table 3
Intraclass correlation coefficients

	Repeatability		Reproducibility	
Measurements	Cephalogram	DigiGraph	Cephalogram	DigiGraph
Facial angle	0.83	0.32	0.62	0.20
Pogonion to N vertical	0.95	0.39	0.72	0.23
SNB	0.89	0.48	0.48	0.36
ANB	0.70	0.27	0.24	0.18
AB plane to occlusal plane	0.57	0.17	0.48	0.21
Wits analysis	0.63	0.17	0.54	0.21
SNA	0.61	0.53	0.30	0.27
A-point to N vertical	0.86	0.33	0.72	0.27
Condylion to A-point	0.62	0.39	0.32	0.02
Condylion to B-point	0.91	0.40	0.72	0.09
Interincisal angle	0.83	0.33	0.69	0.31
Occlusal plane to FH	0.72	0.13	0.59	0.21
Occlusal plane to SN	0.69	0.16	0.50	0.41
Overjet	0.86	0.34	0.69	0.23
Overbite	0.82	0.25	0.66	0.16
Lower incisor to FH	0.80	0.45	0.64	0.25
Lower incisor to SN	0.64	0.35	0.60	0.11
Lower incisor to NB (mm)	0.88	0.25	0.83	0.38
Lower incisor to NB (deg)	0.73	0.31	0.68	0.17
Upper incisor to SN	0.87	0.20	0.31	0.05
Upper incisor to FH	0.93	0.25	0.53	0.14
Upper incisor to NA (mm)	0.49	0.18	0.20	0.11
Upper incisor to NA (deg)	0.83	0.23	0.32	0.00
Pogonion to NB	0.90	0.24	0.67	0.10
Y-axis to SN	0.92	0.67	0.60	0.47
Mn plane to FH	0.93	0.55	0.85	0.32
Mn plane to SN	0.96	0.71	0.70	0.54
Ricketts' E-line upper lip	0.61	0.44	0.93	0.60
Ricketts' E-line lower lip	0.92	0.32	0.94	0.60
Steiner's soft-tissue convexity	0.77	0.38	0.56	0.63

tional technique has inherent inaccuracies; however, clinicians and researchers have developed ways to control and minimize them.

Diverging X-ray beams enlarge radiographic images, but a constant anode-to-film distance of 5 feet limits the magnification to approximately 8%.[18] Additionally, cephalometric analyses which focus more on angular measurements and ratios of linear measurements, permit the effects of enlargement to be safely ignored.[18] Projecting a 3-dimensional object onto a 2-dimensional surface results in image distortion. However, by maintaining a constant subject-to-film distance, points which lie outside the midsagittal plane can be averaged and, in theory, projected to the midsagittal plane.[18] Previous studies have shown that the greatest errors in traditional cephalometrics are landmark identification[19-22] and measurement errors resulting from antecedent errors in landmark identification.[20,23]

The present study attempts to minimize inherent sources of error by maintaining constant operational criteria and by strict standardization of the examiners. The resulting cephalogram intraobserver and interobserver error values in this study reflect these efforts, and they are similar to those found in previous studies.[19,23] Additionally, the cephalogram intraclass correlation coefficients qualitatively exhibit good reproducibility and even better repeatability. Even though the cephalogram does not exhibit perfect repeatability or reproducibility, the clinical significance of the method error mean value and range is questionable. Traditional cephalometric technique may not be a "gold standard," but it is justifiably a standard with which the DigiGraph cephalometric technique can be compared.

Sixty percent of the variables had mean differences between methods that were statistically significant. The greatest differences were found for the measurements involving sella, orbitale, A-point, and incisor position. Measurements relying on soft-tissue landmarks, which were digitized directly, showed no difference between techniques. Standard deviations of the differences reflect the variation of each measurement. Since the range for the intraobserver and interobserver error was 0.5 to 2.8 degrees/millimeters, standard deviations of the differences between both techniques greater than 4.0 degrees/millimeters were arbitrarily determined to be clinically significant. Eighteen of the 30 measurements satisfied this criterion.

A statistically significant finding is not always clinically significant. For example, the mean difference between methods for angle ANB was -0.69° (p=.0067). Taking into consideration the cephalograms mean intraobserver and interobserver error values for angle ANB of 1.0° and 1.8°, respectively, it is unlikely that a discrepancy of this magnitude would result in a different clinical decision. Alternatively, the mandibular plane-Frankfort horizontal angle had a mean difference of 9.14° (p=.0067). This difference between techniques is much greater, and it is likely to influence the practitioner's diagnosis and treatment plan.

Correlation coefficients of $r > .37$ indicate a statistically significant relationship between methods. Twenty-eight of 30 measurements had correlation coefficients that were greater than 0.37. However, this was a test for accuracy, and therefore, a correlation coefficient of $r = .80$ or greater was arbitrarily considered to indicate good agreement between techniques. The soft-tissue variables, Ricketts' esthetic line and Steiner's soft-tissue convexity, had correlation coefficients that were 0.85 or greater.

The sonically generated values consistently showed less agreement between examiners. There are several possible explanations for the differences. One explanation may be that while two consecutive digitizations were taken for each patient, only one cephalogram was taken. Ideally, two consecutive cephalograms would have been used for the method error evaluation. Instead, a single cephalogram was traced twice. In an attempt to standardize the study techniques and to minimize repositioning error, patients were asked to remain in the DigiGraph head positioner between digitizations. It must be noted that a head-holder can minimize movement but cannot prevent it. Another explanation for the observed differences is that superficial skeletal landmarks such as orbitale are not digitized directly, but necessitate palpation and firm pressure. Obviously, not being able to directly visualize a landmark increases the likelihood of identification error. Also, deep skeletal structures, such as sella turcica and the root apices, are derived from mathematical algorithms, which can only estimate the position of the true landmark. Finally, since only the subject's right-sided structures are digitized, any asymmetry that is projected on the cephalogram will not be represented by the DigiGraph.

The concept of a nonradiographic technique to perform cephalometric analyses is encouraging, but the diagnostic information must be comparable to the traditional technique if it is to used by the orthodontist. The lateral cephalogram provides information that the DigiGraph cannot and therefore raises the question of whether or not a direct comparison between the two techniques can be made. If a three-dimensional analysis can be developed based on landmarks that can be digitized directly, perhaps the DigiGraph can be an adjunct to the lateral cephalogram.

Conclusions

1. Eighteen of 30 sonically generated measurements were statistically different from the radiographically generated measurements; however, the differences for some measurements may not be clinically significant. The soft tissue variables revealed no significant difference between the two techniques.

2. The regression analyses showed low correlations for all measurements except lower incisor to NB (mm), Ricketts' esthetic line, and Steiner's soft tissue convexity.

3. Intraobserver and interobserver errors were found with both techniques, but overall repeatability and reproducibility were greater for the radiographically generated measurements.

4. The DigiGraph's soft tissue measurements involving landmarks that were digitized directly were comparable to those obtained by the radiographic cephalometric analysis.

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References

1. Broadbent BH. A new x-ray technique and its application to orthodontia. Angle Orthod 1931;1:45-66.
2. Tweed CH. The Frankfort-Mandibular Plane Angle in orthodontic diagnosis, classifications, treatment planning and prognosis. Am J Orthod and Oral Surg 1946;32:175-230.
3. Downs WB. Variations in facial relationships: their significance in treatment and prognosis. Am J Orthod 1948;34:812-840.
4. Riedel RA. The relation of maxillary structures to the cranium in malocclusion and in normal occlusion. Angle Orthod 1952;22:142-145.
5. Steiner C. Cephalometrics for you and me. Am J Orthod 1953;39:729-755.
6. Ricketts RM. A foundation for cephalometric communication. Am J Orthod 1960; 46:330-357.
7. Goaz PW, White SC. Oral radiology; principles and interpretation, 2nd ed. St Louis: Mosby, 1987.
8. Taylor TS, Ackerman RJ, Hardman PK. Exposure reduction and image quality in orthodontic radiology: a review of the literature. Am J Orthod 1988;93:68-77.
9. Tyndall DA, Matteson SR, Soltmann RE, Hamilton TL, Profitt WR. Exposure reduction in cephalometric radiology: a comprehensive approach. Am J Orthod Dentofac Orthop 1988;93:400-412.
10. Lurie, AG : Risk/benefit considerations in orthodontic radiology. J Clin Orthod 1981;25:469-479.
11. Chaconas SJ, Engel GA, Gianelly AA, Gorman JC. The DigiGraph work station. Part 1: basic concepts. J Clin Orthod 1990;24:360-367.
12. Chaconas SJ, Jacobson RL, Lemchen MS. The DigiGraph workstation. Part 3: accuracy of cephalometric analyses. J Clin Orthod 1990;24:467-471.
13. Prawat JS, Nieberg L, Cisneros GJ, Acs G. A comparison between radiographic and sonically produced cephalometric values. Angle Orthod 1995;4:271-276.
14. Haynes S, Chau MNY. Inter and intra-observer identification of landmarks used in the Delaire analysis. Eur J Orthod 1993; 15: 79-84.
15. Hillesund E, Fjeld D, Zachrisson BU. Reliability of soft-tissue profile in cephalometrics. Am J Ortho 1978;74:537-550.
16. Dahlberg G. Statistical methods for medical and biological students. London: George Allen and Unwin Ltd., 1940:122-123.
17. Winer BJ. Statisical principles in experimental design. New York: Mcgraw Hill, 1971
18. Thurow, RC. Cephalometric methods in research and private practice. Angle Orthod 1951;21:104-116.
19. Hixon, EH. Cephalometric and longitudinal research. Am J Orthod. 1960;46:36-42.
20. Savara BS, Tracy WE, Patricia AM. Analysis of errors in cephalometric measurements of three-dimensional distances on the human mandible. Arch Oral Biol. 1966;11:209-217.
21. Richardson A . An investigation into the reproducibility of some points, planes, and lines used in cephalometric analysis. Am J Orthod. 1966;52:637-651.
22. Baumrind S, Frantz RC. The reliability of head film measurements; 1. landmark identification. Am J Orthod. 1971;60:111-127.
23. Baumrind S, Frantz RC. The reliability of head film measurements; 2. conventional angular and linear measurements. Am J Orthod. 1971;60:505-517.