A comparison between radiographic and sonically produced cephalometric values

James S. Prawat, DDS; Lewis Nieberg, DDS, MS; George J. Cisneros, DMD, MMSc; George Acs, DMD, MPH

Patients undergoing orthodontic treatment have cephalometric radiographs taken in order to provide diagnostic information relating to their dental, skeletal, or cranial disharmonies. Longitudinal radiographs are frequently used to assess growth and therapeutic results.[1,2]. In addition, radiographs are useful because they can reveal pathologic conditions such as Paget's disease, sickle cell anemia, syphilis, as well as actinomycosis and numerous other pathologies. [3,4.]

Dental patients have voiced concern about the exposure to ionizing radiation associated with radiographs.[5,6] High speed film, rare earth film screens, and protective body drapes have been developed to minimize patient exposure.[7,8] Although the need to minimize radiation exposure is universal, it is particularly important in the pediatric population because children run an increased risk for radiation-induced carcinogenesis.[9] A means of obtaining the necessary diagnostic data without ionizing radiation could prove beneficial. In addition, practitioners and researchers would be free to gather longitudinal data without concern for the potential impact of increased radiographic exposure.

A device which gathers data through the use of sonic waves and generates cephalometric values without the use of ionizing radiation has recently been introduced as an alternative to standard cephalometric radiography. The purpose of this study was to compare the cephalo-

Abstract

Cephalometric radiography has become a standard and invaluable means of obtaining diagnostic information for the management of malocclusion and skeletal disharmony. However, concerns over radiographic exposure, particularly in growing individuals, may limit its use, especially in longitudinal analyses. Less invasive means of obtaining vital information would be desirable. A recently introduced system (Digigraph™, Dolphin Imaging Systems; Valencia, Calif) provides sonically produced representations of cranial landmarks and has been introduced by its manufacturer as an alternative to standard cephalometric radiography. The purpose of the study was to compare the validity and reproducibility of cephalometric values generated sonically on a digital image analyzer (Digigraph™) with those obtained from standard cephalometric radiographs for 43 different measurements. Although 58.1% of the sonically produced measurements showed significant correlation with radiographically produced measurements, there were no trends observed for correlation, either in dental or skeletal structure classifications. Additionally, this study found the data generated from the digital image analyzer to be markedly variable, while the radiographically obtained data were reproducible.

Key Words

Cephalometric • Digital • Sonic • Reproducibility

Submitted: May 1994 **Revised and accepted:** July 1995 The Angle Orthod 1995;65(4):271-276.

Table 1

Measurement	Differences in Means of Replicates	Differences in Variability	Correlation Coefficient	Magnification Factors	Intercept
DENTAL					
Interincisal angle (deg)	S	NS	-.033	NA	NA
Incisor overbite (mm)	SS	S	+0.78*	1.01	-0.68
Incisor overjet (mm)	S	S	+0.78*	0.57	-0.80
Molar relation (mm)	S	S	+0.83*	0.65	-0.33
DENTAL/SKELETAL					
Lower incisor protrusion (mm)	NS	S	+0.69*	NA	NA
Lower incisor inclination (deg)	S	S	+0.86*	1.34	+7.55
Upper incisor protrusion (mm)	S	S	+0.89*	1.13	+5.38
Upper incisor inclination (deg)	S	S	+0.48	NA	NA
IMPA (deg)	S	S	+0.49	NA	NA
FMIA (deg)	NS	S	+0.79*	NA	NA
Upper incisor to FH (deg)	S	S	+0.64*	0.57	+6.68
SKELETAL - VERTICAL					
Mandibular plane to FH (deg)	S	S	+0.46	NA	NA
Mandibular plane to OP (deg)	NS	S	+0.82*	1.18	-11.06
Occlusal plane to FH (deg)	S	S	+0.82*	0.64	+29.68
Gonial angle (deg)	S	S	+0.67*	NA	NA
SKELETAL - HORIZONTAL					
Convexity (mm)	NS	S	+0.81*	NA	NA
ANB (deg)	NS	S	+0.65*	NA	NA
A point to Nasion - Perp. (mm)	S	NS	-0.14	NA	NA
Pogonion to Nasion - perp (mm)	S	S	+0.14	NA	NA
Wits appraisal (mm)	NS	S	+0.47	NA	NA
SOFT TISSUE					
Lower lip to E-plane (mm)	S	S	+0.87*	0.79	+0.62
Upper lip to E-plane (mm)	NS	S	+0.61	NA	NA
DENTAL RELATIONSHIPS					
Molar relations (mm)	S	S	+0.79*	0.57	-0.81
Incisor overjet (mm)	S	S	+0.78*	1.01	-0.68
Incisor overbite (mm)	S	NS	-0.20	NA	NA
Mand. incisor extrusion (mm)	S	S	+0.84*	0.88	+3.98
Interincisal angle (deg)	S	S	+0.50	NA	NA
SKELETAL/DENTAL					
Upper incisor protrusion (mm)	S	S	+0.86*	1.34	-7.56
Lower incisor protrusion (mm)	S	S	+0.48	NA	NA
Upper incisor inclination (deg)	S	S	+0.56	NA	NA
Lower incisor inclination (deg)	NS	S	-0.03	NA	NA
Occlusal plane to FH (deg)	NS	S	+0.90*	NA	NA
Upper molar to vertical (mm)	NS	S	+0.82*	NA	NA
MAXILLOMANDIBULAR RELATIONSHIPS					
Convexity (mm)	NS	S	+0.83*	NA	NA
CRANIOFACIAL RELATION					
Mandibular plane to FH (deg)	NS	S	+0.79*	NA	NA
Maxillary depth (deg)	S	S	+0.71*	1.13	-23.69
Facial axis - Ricketts (deg)	S	S	+0.46	NA	NA
Facial angle (deg)	S	S	+0.28	NA	NA
Facial taper (deg)	S	S	+0.82*	1.14	+5.71
DEEP SKELETAL STRUCTURES					
Porion location (mm)	NS	S	-0.05	NA	NA
Cranial deflection (deg)	S	S	+0.55	NA	NA
Ramus position (deg)	S	S	+0.87*	0.79	+0.62
ESTHETIC					
Lower lip to E-plane (mm)	S	S	+0.90*	0.75	+0.16

metric values generated sonically on a digital image analyzer (Digigraph™) with those obtained from standard cephalometric radiographs.

Materials and methods

Ten adults who consented to evaluation were included in this study. There were no exclusionary criteria. Standard lateral cephalographs were obtained, with a constant object-to-film distance of 13 cm. Each radiograph was traced three times by a single examiner. Landmarks were located and recorded following millimeter rule and protractor measurement. Each patient was then seated in the sonic workstation. The patient was aligned with a video representation of the Frankfort horizontal reference plane, and landmarks were recorded with the digitizing probe. As directed by the manufacturer, landmarks were identified either by visualization or palpation, while maintaining minimal but steady probe pressure. Facial landmarks were identified on the basis of oral points and deeper landmarks, such as sella turcica, which were extrapolated from profile landmarks by software algorithims.[10] Each patient submitted to a total of three complete digital probe examinations. The examinations were separated by brief rest periods. Each examination and subsequent tracings repeated all 43 linear and angular measurements (Table 1).

A repeated measures analysis of variance was used to test for trends in the replicates as a measure of reproducibility of the results. A two-way analysis of variance (ANOVA) was performed to assess differences between methods and interactions between subjects and methods. Following computation of mean values for each landmark, a paired t-test was used to assess differences in measured values between methods. Additionally, the Pearson correlation was computed in order to determine the degree of agreement between methods. The resultant correlations were evaluated for significance using a t-test. Those measurements that demonstrated significantly different method results but exhibited a high and significant correlation were analyzed by linear regression in order to determine magnification correction factors.

Reproducibility of methods was assessed by one-way ANOVA testing, using variance components to compute the intraclass correlation coefficient (ICCC) and the proportion of variance due to random error (1ICCC). The significance of the differences in variability between the methods was determined following computation of standard deviations of the replicate measurements for each subject and application of a paired t-test on transformation of scale data. Finally, estimates of the number of replicates required to reduce the proportion of random error to comparable variability of the method associated with the lower variance were computed using the inverse Spearman-Brown formula.

Results

In general, no trend was found for the replicates. In only two of the 43 measures were there significant replicate effects. Both of these were linear measurements involving the maxillary incisors.

Differences in methods (Table 1)

Differences in linear and angular measurements between methods were found to be significant for 30 of the 43 measures taken.

Variability of replicate measurements (Table 1)

Variability between methods differed significantly for all but three of the measures. The cephalometric values consistently showed smaller standard deviations.

Correlation of measurements (Table 1)

Significant correlation ($P \leq .05$) was found between 25 of the measurements. However, only 16 of 30 measurements that had significant differences in absolute measurements were noted to have high correlation. Of the absolute measurements that did not exhibit significant differences, 9 of 13 were significantly correlated.

Magnification factors (Table 1)

For those measurements that exhibited significant correlation as well as significant absolute measurement differences, linear regression analysis was performed in order to provide both slope and intercept. Slopes for the 17 measurements that satisfied inclusion criteria ranged from 0.57 to 1.34.

Variation due to error (Table 2)

The computation of 1-ICCC indicated that the variation due to error was much higher for the Digigraph™ group. The range of variation due to error for the cephalometric measurement group was 0.01 - 0.19, and the corresponding range for the Digigraph™ group was 0.06 - 0.80. In the cephalometric group, the error was greater than 0.10 in only one instance, while for the Digigraph™ group, the error was less than 0.10 in only one instance.

The wide range in the Digigraph™ group is further evidenced by the inverse Spearman-Brown calculation, which describes the number of replicates needed in the Digigraph™ group, in order to make its random error comparable to that of the cephalometric group. Depending upon the

Table 2

Measurement	Reproducibility Ceph ICCC	Reproducibility Digigraph ICCC	Variation Ceph 1-ICCC	Variation Digigraph 1-ICCC
DENTAL				
Interincisal angle (deg)	0.99	0.89	0.91	0.11
Incisor overbite (mm)	0.95	0.22	0.05	0.78
Incisor overjet (mm)	0.98	0.52	0.02	0.48
Molar relation (mm)	0.97	0.53	0.03	0.47
DENTAL/SKELETAL				
Lower incisor protrusion (mm)	0.97	0.19	0.03	0.81
Lower incisor inclination (deg)	0.99	0.64	0.01	0.36
Upper incisor protrusion (mm)	0.99	0.75	0.01	0.75
Upper incisor inclination (deg)	0.96	0.31	0.04	0.69
IMPA (deg)	0.93	0.62	0.07	0.38
FMIA (deg)	0.91	0.72	0.09	0.28
Upper incisor to FH (deg)	0.92	0.56	0.08	0.44
SKELETAL - VERTICAL				
Mandibular plane to FH (deg)	0.96	0.20	0.04	0.80
Mandibular plane to OP (deg)	0.96	0.78	0.04	0.22
Occlusal plane to FH (deg)	0.94	0.25	0.06	0.75
Gonial angle (deg)	0.91	0.75	0.09	0.25
SKELETAL - HORIZONTAL				
Convexity (mm)	0.94	0.80	0.06	0.20
ANB (deg)	0.96	0.61	0.04	0.39
A pt. to Nasion - Perp. (mm)	0.94	0.20	0.06	0.80
Pogonion to Nasion - perp (mm)	0.81	0.24	0.19	0.76
Wits appraisal (mm)	0.90	0.23	0.10	0.77
SOFT TISSUE				
Lower lip to E-plane (mm)	0.97	0.88	0.03	0.12
Upper lip to E-plane (mm)	0.97	0.26	0.03	0.74
DENTAL RELATIONSHIPS				
Molar relations (mm)	0.98	0.52	0.02	0.48
Incisor overjet (mm)	0.95	0.22	0.05	0.78
Incisor overbite (mm)	0.91	0.94	0.09	0.06
Mand. incisor extrusion (mm)	0.94	0.28	0.06	0.72
Interincisal angle (deg)	0.93	0.61	0.07	0.39
SKELETAL/DENTAL				
Upper incisor protrusion (mm)	0.99	0.64	0.01	0.36
Lower incisor protrusion (mm)	0.96	0.31	0.04	0.69
Upper incisor inclination (deg)	0.95	0.39	0.05	0.61
Lower incisor inclination (deg)	0.87	0.21	0.13	0.79
Occlusal plane to FH (deg)	0.97	0.62	0.03	0.38
Upper molar to vertical (mm)	0.97	0.78	0.03	0.22
MAXILLOMANDIBULAR RELATIONSHIPS				
Convexity (mm)	0.95	0.57	0.05	0.43
CRANIOFACIAL RELATION				
Mandibular plane to FH (deg)	0.91	0.72	0.09	0.28
Maxillary depth (deg)	0.98	0.73	0.02	0.27
Facial axis - Ricketts (deg)	0.96	0.30	0.04	0.70
Facial angle (deg)	0.93	0.40	0.07	0.60
Facial taper (deg)	0.93	0.26	0.07	0.74
DEEP SKELETAL STRUCTURES				
Porion location (mm)	0.95	0.82	0.05	0.18
Cranial deflection (deg)	0.97	0.41	0.03	0.59
Ramus position (deg)	0.97	0.88	0.03	0.12
ESTHETIC				
Lower lip to E-plane (mm)	0.97	0.83	0.03	0.17

landmark chosen, the number of replicates necessary ranged from 2 to 32.

Reproducibility (Table 2)

The intraclass correlation coefficients (ICCC) showed that for all measurements, other than incisal overbite, the cephalometric group had a higher degree of agreement between replicates than did the Digigraph™ group.

Discussion

When new or different recording or measurement techniques are compared with one another, or with a standard technique, several criteria must be evaluated in order to determine the potential use of the measurement tool. Conceptually, an ideal comparison would reveal measurements that do not differ significantly from one another and exhibit high correlation. In addition, as indicators of reproducibility and reliability, standard deviations and measurement of random error would be comparable. Although one may envision other acceptable scenarios when comparing measurements, the requirements of reproducibility and reliability are not subject to compromise.

The data gathered in this study indicate that 69.7% of the absolute values generated by the Digigraphic and the cephalometric techniques differed significantly from one another. Although magnification or correction factors may be used to compensate for such significant differences, they can be used only when there is a concomitant significant correlation between values. However, only 53.3% of those measurements exhibiting significant differences had high correlation. In addition, the sonically generated values were more variable than the radiographic values and were more subject to random error.

Previous studies of the reproducibility and reliability of the cephalometric technique have indicated that error is introduced at different stages.[11,12] Inconsistencies in positioning, landmark identification, and tracing error account for differences observed in derived measurements, when repeat radiographs are exposed.

In the sonically generated system assessed in this study, measurements are carried out as the patient remains motionless. Therefore, the potential for error was introduced in at least three stages: positioning, probing, and inadvertent patient movement. Tracing a living subject can be troublesome because movement can occur after the digitization has begun. Head position may change without the subject's or operator's knowledge, and the operator may exert pressure on the patient during digitization without knowing it. Children could be particularly difficult to manage. In some cases, a trained eye may be able to detect an error on the television monitor. If the points for a given landmark are close together, as with incisor angulation, the issue of movement becomes critical.

Although evaluating the validity of the software algorithms was not the objective of this study, the derivation of data is based upon these algorithms. The difficulty in consistent derivation of such data is reflected in the poor agreement and great variation for deep skeletal structures, whose measurements are derived from profile data. In fact, the deep skeletal structures expressed the poorest agreement and the greatest differences in variation of all the measurements.

It should be kept in mind that the cephalometric radiograph yields critical information that cannot be produced with the Digigraph™. A radiograph allows assessment of the patient airway for conditions such as enlarged adenoidal and tonsillar tissue, which are capable of causing airway obstruction.[13] At present, radiographs remain uniquely able to provide information which is of considerable clinical importance in the diagnosis and treatment of orthodontic patients. For example, palatal plane to occlusal and mandibular planes are important relationships in the treatment and the diagnosis of hyperdivergent skeletal patterns,[14] and corpus length and symphysis shape are useful characteristics in the diagnosis and treatment of Class II and III skeletal patterns. Considering the voluminous data base which surrounds radiographic assessment of hard and soft tissue relationships, it must continue to be considered the standard for assessment of dental, skeletal, airway, and soft tissue structures.

The exposure of patients to ionizing radiation must always be a consideration for the clinician and the research scientist. With the use of rare earth intensifying screens, satisfactory films are obtained with 1/25th the exposure necessary without a screen.[7,15] Shielding the patient's body further reduces exposure. Despite these advances, patient exposure should be kept to a minimum; any radiographic exposure is additive to radiation received from natural sources, and some authors believe that there is carcinogenic risk no matter how small the exposure.[16] Cephalometric radiographs have been in use for 60 years. They have stood the test of time and have been validated.[2,16,17,18,19,20] Any technology which purports to supplant another must meet those standards and offer other tangible benefits.

Summary

A study has been completed which compares cephalometric values generated by conventional radiographic tracings with those produced sonically by the Digigraph™ Workstation. Differences between the sets of data were variable and, at times, considerable. Correlations between values were inconsistent. The Digigraph™ consistently produced larger standard deviations than conventional radiographic tracings.

Conclusions

Significant differences exist between the values generated by the two techniques. Information gathered from the lateral cephalometric radiographs in this study produced values which consistently had significantly lower standard deviations than those produced by the Digigraph™.

With a reduction of variation and a consistently high correlation with radiographic measurements, The Digigraph™ could be a clinically useful apparatus for the generation of some cephalometric data. Further refinements in technique and, perhaps, resident software algorithms may be required for an acceptable sonically produced diagnostic tool.

Author Address

Dr. George J. Cisneros
Director, Division of Orthodontics
Montefiore Medical Center
111 E. 210th St.
Bronx, N.Y. 10467

J.S. Prawat is in private practice in Richmond, Indiana.

L. Nieberg is an instructor, Division of Orthodontics, Montefiore Medical Center, Bronx, N.Y.

G.J. Cisneros is director, Division of Orthodontics, Montefiore Medical Center, Bronx, N.Y.

G. Acs is chairman of the Department of Dentistry, Children's National Medical Center, Washington, D.C.

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