Comparison of hand-traced and computerized cephalograms: Landmark identification, measurement, and superimposition accuracy

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Introduction: The purposes of this study were (1) to investigate the variations of landmark identification between film and digital cephalometric tracings, (2) to compare the ability of Quick Ceph 2000 (Quick Ceph Systems, Inc, San Diego, Calif) to measure the linear and angular measurements with the hand-traced method, and (3) to compare Quick Ceph 2000 superimpositions to the hand-traced method of superimpositions that are currently accepted by the American Board of Orthodontics (ABO). **Materials:** We used 30 sets of serial cephalometric radiographs of growing patients from 1 orthodontic office. Fiduciary x- and y-axes were drawn in pencil on the T1 radiographs in the regions of the cranial base, the maxilla, and the mandible. The fiduciary lines were transferred to the digital and film serial cephalograms by regionally superimposing the tracings as described in the ABO Phase III examination handbook. A Mann-Whitney test was done to compare the median and Δ of the T1 and T2 values for each measurement acquired by hand and by Quick Ceph. **Results and Conclusions:** There was no difference in the identification of cephalometric landmarks made manually vs digitally with Quick Ceph 2000. There was no difference in acquiring consistent cephalometric values for the measurements required by the ABO for the Phase III clinical examination manually vs digitally by using Quick Ceph 2000. There was no difference in the regional superimpositions of the mandible, the maxilla, and the cranial base, manually vs digitally with Quick Ceph 2000. (Am J Orthod Dentofacial Orthop 2008;133:556-64)

Since the introduction of cephalometrics by Broadbent[1] in 1931, its role has been vital in orthodontic diagnosis and treatment planning, and for monitoring treatment and growth changes. Several investigators designed analyses for cephalograms and established numeric norms for various facial types and races.[2-6] These analyses are created by plotting a set of landmarks and anatomical planes on each radiograph. The angular measurements are made by joining specific planes, and the linear measurements are made between the landmarks. Cephalometric landmarks, also used for superimpositions, vary depending on the type of analysis used.

Digitized records are becoming more popular among orthodontists as the model of the contemporary office progresses toward a paperless system of patient management. The cephalometric radiograph is 1 entity of the patient record that has recently received much attention from software developers as they attempt to design the ideal cephalometric analysis program. Many investigators have examined the accuracy of landmark location, measurements, growth forecasting, and surgical visual treatment objective.[7-9] However, little investigation has been done on the accuracy of cephalometric superimposition.

Baumrind and Frantz[10] stated that 2 types of errors are associated with headfilm measurements: projection and identification errors. Projection errors are caused because a cephalogram is a 2-dimensional representation of a 3-dimensional object. Identification errors are associated with specific anatomic landmarks on headfilms. Certain landmarks have greater errors associated with them, and identification errors also vary according to direction; some landmarks have greater error in the horizontal plane and others in the vertical plane.[10-13]

Serial cephalometric radiographs allow the orthodontist to evaluate a patient's growth and treatment changes for a certain time interval. There are several methods of superimposition and regions in which a cephalogram or tracing can be superimposed. Arat et al[14] noted that displacement of landmarks greatly de-

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pends on the superimposition method used. Some methods cause more apparent displacement of the landmarks in the vertical direction, and others cause more in the horizontal direction. Thus, the overall treatment changes reported by a practitioner must be interpreted according to the superimposition method used, and the variation must be considered.

Because of the value of superimpositions to the practitioner, Baumrind et al[15] investigated the errors associated with superimpositions at the cranial base, SN at sella, the palatal plane, and the mandibular border. Their findings strongly imply that, for most landmarks evaluated with respect to superimpositions, rotational effects produce greater total errors of superimposition than do translational effects. The error from translational sources is the same for all landmarks and any tracing for any superimposition. Efstratiadis et al[16] demonstrated that both linear and angular measurements relating to the displacement of all mandibular landmarks were statistically different between the 2 regional superimpositions. These results demonstrated that, in growing patients, the posttreatment displacement of mandibular skeletal and dental components should be assessed by superimposition on the maxilla and the cranial base. The basic reasons for incorporating this method in the cephalometric superimposition regimen are (1) the maxilla is subject to rotational and translational changes that are generally beyond the control of the orthodontist and can obscure the actual displacement of the mandible, and (2) the occlusion of the teeth is associated directly with the positions of the maxillary and mandibular basal bones.

Efstratiadis et al[16] suggested using the following superimposition regimen for serial cephalometric radiographs to evaluate changes related to growth and treatment: (1) superimpose on the cranial base to yield information about maxillary and mandibular displacement; (2) superimpose on maxillary structures to evaluate changes in the maxillary dentoalveolar complex and mandibular displacement; and (3) superimpose on relatively stable mandibular anatomic structures to evaluate dentoalveolar changes in the mandible.

The American Board of Orthodontics (ABO) incorporates similar superimpositional requirements for Phase III of board certification.[17] The candidate's handbook states that the following 3 composite tracings must be made.

1. Craniofacial composite: register on sella with the best fit on the anterior cranial base bony structures (planum sphenoidum, cribriform plate, greater wing of the sphenoid) to assess overall growth and treatment changes.
2. Maxillary composite: register on the lingual curvature of the palate and the best fit on the maxillary bony structures to assess maxillary tooth movement.
3. Mandibular composite: register on the internal cortical outline of the symphysis with the best fit on the mandibular canal to assess mandibular tooth movement and incremental growth of the mandible.

Error is associated with the superimposition of tracings, and this error is primarily related to the operator's ability to superimpose on stable structures. The most accurate manner to superimpose is the implant method described by Bjork.[18,19] To create measurement frames of reference that are stable with respect to modeling and remodeling changes in the surface of the maxilla and the mandible, Bjork[18,19] pioneered the method of placing metal implants as markers in the jaws of growing patients. To the extent that these markers maintain a constant relationship to each other, radiographic images of the jaws at successive times can be superimposed, thus permitting developmental or treatment changes to be measured without reference to the continuously changing bony surface. This type of measurement is invaluable in research but is impractical for practitioners to use in the office to monitor the growth or treatment of patients. As a result, comparative implant structural studies and histologic studies have been done to give the orthodontist information to be used when superimposing serial tracings.

Ford[20] confirmed the observations of de Coster[21] that the distance from sella turcica to foramen caecum does not increase after the eruption of the permanent first molar, thus allowing this region to be used as a reliable landmark for overall superimposition. However, most evidence supporting superimposition on the anterior cranial base can attributed to the work of Melsen.[22] She observed that the internal surface of the frontal bone and the cribriform plate are stable after the age of 6 or 7 years in both the sagittal and vertical planes. Melsen also stated that the anterior part of sella turcica is by far the most stable over 5 years of age. However, because of the remodeling in the sella turcica region, the reference sella is not regarded as stable until long after puberty. This agrees with Bjork and Skieller,[23] who advocated superimposing the anterior wall of sella turcica, the anterior contours of the middle cranial fossae, the contours of the cribriform plate, and the frontoethmoidal crest.

Some investigators have suggested using the structural method of superimposition in which the anterior surfaces of the zygomatic process of the maxilla are superimposed.[24-26] When this method is compared with the implant method, there seems to be little variation in the reported movements of the teeth.[24-26] The best-fit method is often used by orthodontists because of the ease of locating the structures on the cephalometric radiograph. This method overestimates the downward positioning of the maxillary teeth when compared with the implant method of maxillary superimposition.[27]

Due to continuous remodeling, the mandible is also a difficult structure to accurately superimpose on. According to Bjork,[19] the lower border of the mandible is not suitable as a reference for mandibular superimposition. He recommended that the mandible be superimposed on 3 internal structures: the inner cortical structure of the inferior border of the symphysis, detail structures from the mandibular canal, and the lower contour of the molar germ from the time that mineralization of the crown is visible until the roots begin to form. He reasoned that, in most cases, there is definite thickening of the cortical layer of the lower border of the symphysis with growth. The mandibular canal might change position but not to the extent of the remodeling at the lower border of the mandible.

Recent advances in radiographic technology have led to the development of reliable digital cephalograms and panoramic radiographs. This acquisition method has several advantages from the practitioner's and the patient's standpoints. These include transmission, storage, enhancement of images, reduced radiation exposure for patients, and the potential for automated cephalometric analysis. Teleradiology is of benefit to the orthodontist practicing in several offices because this technology allows access to radiographs from any point via the Internet. Digital images allow for more efficient archiving of cephalometric radiographs because they no longer must be physically stored in the chart. Digital images do, however, use much digital memory, so the computer designated for this task requires a more robust hard drive.[28]

The initial step of gathering diagnostic information is the same for digital and conventional cephalometrics. The practitioner must identify landmarks associated with the particular analysis he or she needs and then make the appropriate measurements. However, recent investigations[28-36] have reported conflicting data regarding both the accuracy of landmark identification and the ability of computers to produce accurate measurements on digital cephalograms. Some investigators reported that the ability of operators to locate landmarks digitally and the computer's ability to perform measurements were inferior to the conventional method.[28-32] Although there were statistical differences in some investigations, many authors concluded that the statistical differences did not translate to clinical significance.[29,32] Others reported that the measurements and the landmark identification abilities of the conventional and digital methods are similar for the most common analyses used by orthodontists.[33,34]

Fig 1. Demonstrates how the fiduciary lines were drawn on T1.

Because of conflicting data in the literature, one can make no assumption regarding the accuracy of digital tracing programs. Also, there are no data to support the ability of these programs to perform accurate superimpositions as required by the ABO for Phase III of board certification. Therefore, it was our purpose in this study to compare the ability of Quick Ceph 2000 (version 3.3; Quick Ceph Systems, Inc, San Diego, Calif) to digitize landmarks, make the standard measurements required by the ABO for cephalometric tracings, and perform the regional superimpositions required by the ABO with the hand-traced method of cephalometric analysis.

MATERIAL AND METHODS

The records of 30 patients with serial lateral skull film radiographs were collected from the office of Dr Ronald Gallerano in Houston, Texas. The criteria for selecting the subjects were as follows: 1) 2 cephalometric radiographs taken with the same x-ray machine; 2) growth must have been observed during the time interval between radiographs, with a minimum of 2 years between the radiographs (T1 and T2); 3) all landmarks and soft tissues must be visible on the films.

Once the 30 subjects were selected, the fiduciary x- and y-axes were drawn in pencil on the T1 radiographs in the regions of the cranial base, the maxilla, and the mandible with the x-coordinate parallel to the Frankfort

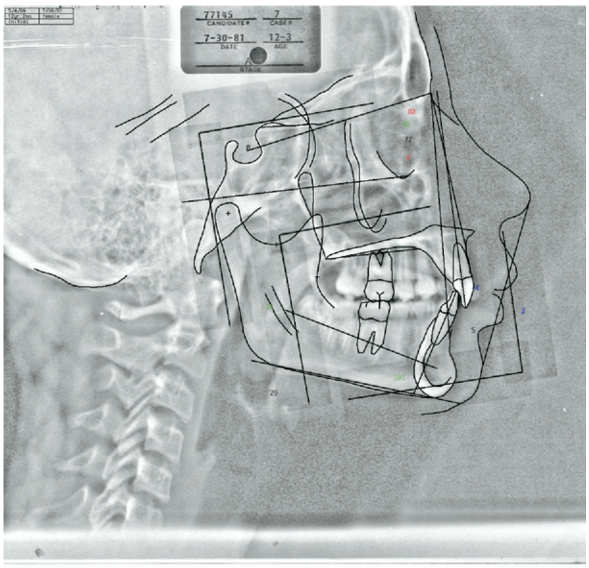

Fig 2. Demonstrates how the T1 cephalograms were traced in Quick Ceph and by hand.

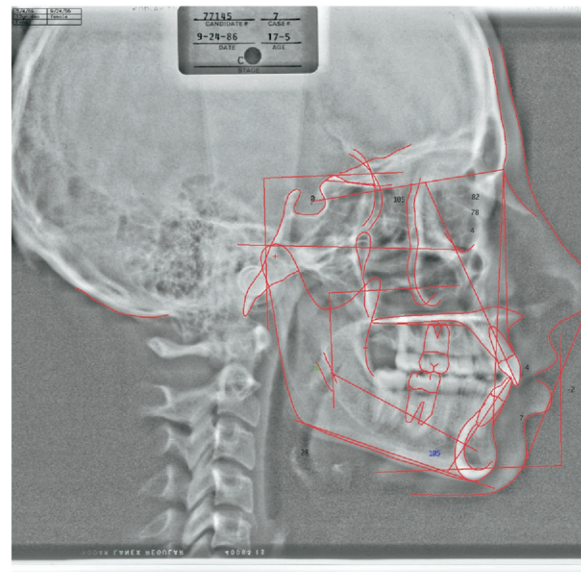

Fig 3. Demonstrates how the T2 cephalograms were traced in Quick Ceph and by hand.

horizontal line (Fig 1). The images were then scanned on an Epson 1600 flatbed scanner (Epson America, Inc, Long Beach, Calif) and stored on an iMac Macintosh computer (Apple, Cupertino, Calif) as Jpeg images and filed by the patients' initials.

For this investigation, Quick Ceph 2000 was chosen as the digital cephalometric program because of the ease in which custom analysis could be designed and the familiarity of the primary investigator (D.R.J.) with the application. A custom analysis was created with the ABO cephalometric measurements in Quick Ceph 2000. The analysis also included x- and y-axes for the cranial base, the maxilla, and the mandible. Quick Ceph 2000 was programmed to perform several measurements from the Cartesian planes to monitor the location of each landmark digitized for each radiograph. This was done to assign an x and y coordinate for each landmark relative to each Cartesian plane on the radiograph.

The images were then acquired by Quick Ceph 2000 and calibrated according to its user manual.[35] The T1 radiographs were traced by hand and with Quick Ceph 2000 (Fig 2). The manual tracings of the conventional lateral cephalometric films were done on a light box designed specifically for this purpose, with a 0.5-mm graphite pencil. After the T1 radiographs were traced, the T2 radiographs were traced (Fig 3), and the Cartesian planes were transferred to the second tracing by superimposing on the appropriate structure as required by the ABO—cranial base, maxilla, and mandible. This allowed for the x and y planes to be coincident for the T1 and T2 computer (C1 and C2) and the T1 and T2 hand (H1 and H2) tracings (Figs 4-6).

After the radiographs were traced by hand and digitally, and the fiduciary lines were transferred appropriately, the measurements (Tables I and II) were made and recorded on an Excel (Microsoft, Redmond, Wash) spreadsheet. The digital recordings were transferred to Excel first, and then the hand measurements were recorded. Each set of cephalograms was traced in 1 sitting by 1 operator. The first author made all tracings, measurements, and superimpositions and has 6 years of experience tracing cephalograms with Quick Ceph and by hand. No more than 1 subject was traced (4 tracings and 6 superimpositions) at a time to reduce the error introduced by operator fatigue. The T1 and T2 radiographs and tracings were compared during the tracing procedure to ensure that each was drawn in the same manner, identifying proper anatomy. A small sample of 10% was then randomly selected by the third author (R.G.) to verify that the points and the lines were accurately traced and plotted on the cephalometric tracings. Both operators agreed on the positions of the plotted points and the accuracy of the anatomical tracings.

A Mann-Whitney test was done to compare the median values for each measurement acquired by hand and Quick Ceph 2000. The Δ of the T1 and T2 for the computer and hand-recorded measurements were also compared with the Mann-Whitney test to determine whether there were any differences between the patients' growth changes.

Fig 4. Demonstrates how the tracings were superimposed on the cranial base.

Fig 5. Demonstrates how the tracings were superimposed on the maxilla.

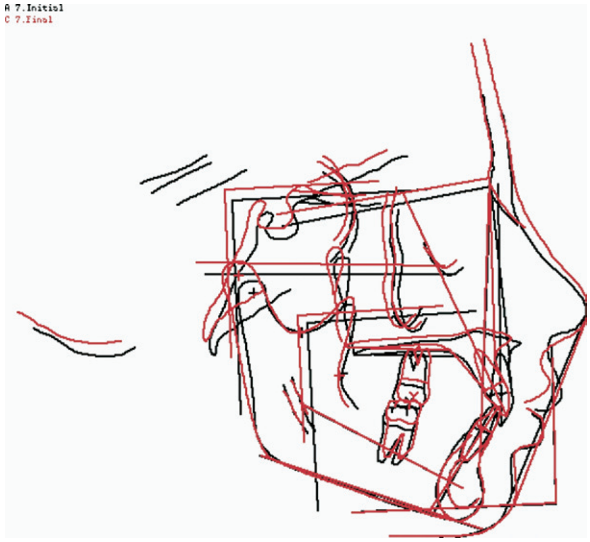

Fig 6. Demonstrates how the tracings were superimposed on the mandible.

RESULTS

The median measurements of H1 and H2 and C1 and C2 are summarized in Table I. The median measurements of H1 and C1 are not different statistically for any measurements, thus illustrating that the landmarks are placed in the same location for both methods, and the measurements made from each of these are congruent. The differences between the H2 and C2 were also not statistically significant.

To compare the superimpositional capabilities of the 2 methods, the Δ for the time intervals was calculated (H2 – H1 = ΔH, C2 – C1 = ΔC), and the Mann-Whitney test compared these values, which are summarized in Table II. The Δ of the vertical position of nasion relative to the cranial base Cartesian plane had statistical significance. From these data, the vertical changes associated with nasion are not congruent statistically between the hand-traced and the digital methods. However, the difference was less than 1 mm between the Δ values of the 2 methods.

DISCUSSION

In this study, we compared the ability of 1 operator to identify landmarks, perform basic standard cephalometric measurements, and superimpose serial cephalograms, digitally and manually. No studies have evaluated the ability of cephalometric programs to regionally superimpose tracings of cephalograms. Some investigations have focused on the ability of operators to locate landmarks and make cephalometric measurements digitally and manually. However, most were designed to determine the ability of several operators to trace only a few cephalograms.[30-33] We used the talents of 1 operator to trace, measure, and superimpose the entire sample of radiographs and did not consider the interoperator error that might be associated with such a task.

Several investigations reported different results regarding the reliability of cephalometric programs to make linear and angular measurements.[28-32] This variation might be attributed to the various programs and by how the radiographs were acquired by the cephalo-

Table I. Mann-Whitney results for H1 vs C1 and H2 vs C2

Measurement	*Median H1*	*Median C1*	P	*Median H2*	*Median C2*	P
SNA angle (°)	81.00	80.90	.9442	80.50	81.00	.6820
SNB angle (°)	77.00	77.50	.9601	78.50	78.20	.6710
Go-Gn-SN (°)	33.00	32.90	.6967	31.50	31.90	.9403
FMA (°)	23.00	22.40	.7796	22.00	21.50	.9841
ANB angle (°)	3.50	3.90	.8455	2.50	2.70	.8455
Mx 1-Na (mm)	4.50	5.00	.5355	4.50	5.30	.1002
Mx 1-SN (°)	102.50	102.00	.8299	105.50	107.80	.6422
Md 1-NB (mm)	5.00	5.50	.0875	5.50	6.40	.0713
IMPA (°)	97.00	96.50	.8769	96.00	96.40	.9562
E-plane (mm)	−1.00	−0.90	.5095	−2.00	−2.40	.5290
Wits appraisal (mm)	1.50	0.10	.1855	1.00	–0.10	.3711
CB-Na H (mm)	100.50	100.70	.4298	101.50	102.60	.5689
CB-Na V (mm)	14.00	13.20	.8533	14.00	14.50	.7605
CB–A-point H (mm)	98.00	99.30	.5290	98.50	100.10	.7004
CB–A-point V (mm)	70.00	69.80	1.0000	75.00	74.70	.8066
CB-ANS H (mm)	106.00	105.70	.7989	108.00	107.90	.8651
CB-ANS V (mm)	66.00	65.60	.8494	68.50	69.20	.6422
CB–B-point H (mm)	91.50	92.80	.6033	93.00	94.30	.7491
CB–B-point V (mm)	107.00	107.60	.9721	113.00	113.40	.9801
CB-Pog H (mm)	92.00	92.90	.7416	96.00	96.50	.9204
CB-Pog V (mm)	120.00	121.60	.2963	127.00	128.30	.4125
CB-Me H (mm)	85.00	85.40	.9960	90.00	89.10	.9006
CB-Me V (mm)	126.50	126.70	.8808	135.00	135.40	.8260
Mx-ANS H (mm)	83.00	82.50	.9045	82.50	81.60	1.0000
Mx-ANS V (mm)	12.00	12.20	.8455	12.00	12.70	.8690
Mx-PNS H (mm)	26.00	26.60	.5290	24.00	24.50	.6068
Mx-PNS V (mm)	12.50	12.50	.8572	12.00	12.30	.7643
Mx-Mx 1 crown H (mm)	79.00	79.90	.6894	80.00	80.40	.6279
Mx-Mx 1 crown V (mm)	40.00	39.70	.9125	40.00	40.50	.9403
Mx-Mx 6 crown H (mm)	37.50	37.70	.4068	40.00	40.10	.8533
Mx-Mx 6 crown V (mm)	26.50	27.30	.7643	29.00	30.40	.7491
Mx–A-point H (mm)	75.00	75.60	.5355	75.00	75.20	.7303
Mx–A-point V (mm)	18.00	17.40	.5894	18.00	17.80	.6279
Md-Md 1 crown H (mm)	19.00	19.40	.9920	18.00	18.00	.8848
Md-Md 1 crown V (mm)	52.00	52.40	.8612	54.00	53.40	.9601
Md-Md 6 crown H (mm)	57.50	57.70	.8299	56.00	56.10	.5588
Md-Md 6 crown V (mm)	52.00	52.00	.8299	54.00	54.70	.6422
Md-Me H (mm)	27.50	28.30	.5160	28.00	28.00	.5000
Md-Me V (mm)	14.00	14.60	.8416	14.00	14.30	.7643
Md–B-point H (mm)	23.00	22.90	.8143	23.00	23.50	.7378
Md–B-point V (mm)	33.00	32.80	.7989	35.00	34.60	.6422
Md-Pog H (mm)	20.50	21.20	.7378	21.00	21.00	.6033
Md-Pog V (mm)	21.00	19.60	.2285	21.00	19.60	.3249

Mx, Maxillary; *Md,* mandibular; *1,* central incisor; *6,* first molar; *CB,* cranial base; *H,* horizontal; *V,* vertical.

metric analysis programs. There are several methods to acquire digital radiographs and transfer them to the cephalometric tracing program. Direct digital radiography allows for the image to be acquired by the computer directly from the x-ray machine. Indirect methods of acquisition require a film to be generated by a conventional machine, and then the film is scanned, or a digital photograph is taken of the radiograph. In this study, each radiograph was scanned on the same scanner, and the same computer was used to trace all radiographs to reduce the variation of scanning machines and ensure proper calibration of Quick Ceph 2000.

The operator must calibrate the system; lack of calibration will result in erroneous data generated by the digital program. Improper calibration will have more effect on the linear than on the angular measurements of a radiograph and is usually sensitive because the science of cephalometrics deals in millimeters and fractions of millimeters.

Cephalograms are difficult to trace, measure, and superimpose properly, and an observer's ability to

Table II. Mann-Whitney results for Δ(H2-H1) vs Δ(C2-C1)

Measurement	*Δ(H2-H1) median*	*Δ(C2-C1) median*	P
SNA angle (°)	0.000	0.300	.4211
SNB angle (°)	1.000	1.500	.2800
Go-Gn-SN (°)	−0.500	−1.400	.2153
FMA (°)	−1.000	−0.800	.6457
ANB angle (°)	−1.000	−1.200	.5689
Mx 1-NA (mm)	0.500	1.100	.4936
Mx 1-SN (°)	4.300	5.200	.3080
Md 1-NB (mm)	1.000	0.800	.9363
IMPA (°)	2.000	1.500	.7911
E-plane (mm)	−1.000	−1.300	.7758
Wits appraisal (mm)	0.500	−0.100	.5588
CB-Na H (mm)	2.000	1.700	.6208
CB-Na V (mm)	0.500	0.800	*.0294
CB–A-point H (mm)	0.500	1.100	.9601
CB–A-point V (mm)	4.000	3.900	.7681
CB-ANS H (mm)	2.000	0.600	.5723
CB-ANS V (mm)	3.000	3.400	.4328
CB–B-point H (mm)	1.500	1.900	.9801
CB–B-point V (mm)	7.000	6.700	.9841
CB-Pog H (mm)	2.500	2.800	.6422
CB-Pog V (mm)	8.000	7.900	.9841
CB-Me H (mm)	3.000	2.500	.6565
CB-Me V (mm)	8.000	8.300	.8651
Mx-ANS H (mm)	0.000	0.100	.4657
Mx-ANS V (mm)	0.000	0.100	.5521
Mx-PNS H (mm)	−1.000	−1.700	.4842
Mx-PNS V (mm)	0.000	−0.400	.8533
Mx-Mx 1 crown H (mm)	1.000	0.200	.9482
Mx-Mx 1 crown V (mm)	0.500	0.700	.6967
Mx-Mx 6 crown H (mm)	3.000	2.200	.1288
Mx-Mx 6 crown V (mm)	3.000	2.700	.7835
Mx–A-point H (mm)	0.000	−0.400	.6208
Mx–A-point V (mm)	0.500	0.500	.7567
Md-Md 1 crown H (mm)	−1.000	−0.500	.7116
Md-Md 1 crown V (mm)	1.500	1.500	.9204
Md-Md 6 crown H (mm)	−2.000	−1.500	.2209
Md-Md 6 crown V (mm)	2.000	2.200	.3605
Md-Me H (mm)	0.000	−0.300	.8690
Md-Me V (mm)	0.000	−0.100	.8651
Md–B-point H (mm)	0.000	0.400	.3349
Md–B-point V (mm)	1.000	1.200	.8533
Md-Pog H (mm)	−0.500	−0.300	.3658
Md-Pog V (mm)	0.000	0.100	.3057

Mx, Maxillary; *Md,* mandibular; *1,* central incisor; *6,* first molar; *CB,* cranial base; *H,* horizontal; *V,* vertical.
*Statistical significance; $P < .05$.

successfully do this depends on the quality of the radiograph and his or her experience. Kvam and Kogstad[36] reported that postgraduate students showed significantly less variability than dental students when they were asked to trace and measure cephalometric radiographs. To superimpose serial radiographs accurately requires more experience and is more sensitive to slight tracing errors because there are 2 or more cephalograms; this compounds the opportunity to introduce error.[15] There are also calibration issues between the cephalograms due to patient position in the cephalostat and the machine itself. If in 1 radiograph the patient's head is rotated more or if the ear rods are not properly positioned, there will be foreshortening of certain structures and double images of others.[37] If 1 radiograph in the series is not taken on the same x-ray machine, calibration errors could be introduced into the series so that the linear measurements are erroneous. Although all cephalostats are to be set up in the same manner, one cannot assume that each was done precisely the same. For these reasons, all radiographs collected for this study were taken on 1 machine, and great care was taken when the patent was placed in the cephalostat for quality control.

When the median values of H1 and C1, and H2 and C2 are compared in Table I, there is no statistical difference between the values. The comparison shows that the landmarks were placed in relatively the same position on both the digital tracing and the hand tracing. Because each landmark was given an x-y coordinate, the relative position to that Cartesian plane was monitored. Most values for the x-y coordinate system were within the acceptable limits of error of ±1 mm.[13,38] Maxillary central incisor to SN, cranial base to nasion horizontal, and cranial base to A-point horizontal had differences greater than 1 mm from computer to hand-traced measurements. However, the variation was less than 1.5 mm for all of them; this leaves the clinical significance questionable because the width of the pencil used to trace the cephalograms was 0.5 mm. Therefore, this study confirms the findings of other investigators showing that the differences in landmark identification between hand and computer are not significant clinically.[29,32,39]

The comparisons in Table I also demonstrate that the angular and linear cephalometric measurements required by the ABO for Phase III examination are not statistically or clinically different, digitally or manually. All measurements are within ±1 mm and ±1°, deeming them clinically congruent.[13,38]

Baumrind et al[15] pointed out that there are 2 methods of comparing serial cephalograms—the individual and the superimpositional methods. In the individual film method, headfilms of patient taken at several times are first evaluated individually by making the same measurements on tracings of each in the film series. Then the measured values from 1 tracing are subtracted from those on the other tracings, and the differences are taken as a measure of between-time point changes.

The superimpositional method allows comparisons between time points to be assessed by placing the tracing of 1 time point on the other; they are then superimposed at specific anatomic landmarks proximate to the structures whose displacement is to be measured. This evaluation of treatment and growth allows for subtle displacements to be evaluated more accurately than by the individual method of comparison.

In this study, the individual method of comparison was combined with the superimpositional method to quantitatively analyze the ability of Quick Ceph 2000 to superimpose accurately. It is difficult to measure the quality of a superimposition from 1 modality to another; this is the most likely reason that this type of study has not been previously conducted. When comparing 1 superimpositional technique with another, it is possible to move and measure the tracings on each other and perform measurements. Several studies compared how specific structures move relative to each other depending on the superimposition.[14,16,33,40] For example, Bjork[18,19,22] conducted several studies comparing the implant method of superimposition with the structural method on the maxilla and the mandible. When one compares the hand-traced method to the digital method of superimposition, the tracing cannot be directly compared to the other by superimposing the superimpositions. Therefore, a coordinate system must be designed that is the same on each cephalogram in the series so that the displacement of the landmarks can be determined by the Δ of the radiographs in the series. Once the Δ values of the landmarks are established for the hand and the computer tracings, T1 and T2 can be compared. If there is discrepancy in the values, it would reflect the variation in the superimposition and the location of the fiduciary Cartesian planes.

Table II compares the median Δ values of the computer and hand-traced methods, and illustrates 2 points relative to the accuracy of the serial cephalometric comparisons. First, the Δ values of the ABO measurements have no statistical difference. This is a comparison by the individual method as described by Baumrind et al.[15] This further confirms the information in Table I because, if there is no difference in the values individually measured (Table I), there should be no difference in the Δ values.

The second point that Table II illustrates is that almost all Δ values for the serial radiographs of the 2 modalities are congruent. The only value with statistical significance is the vertical displacement of nasion. However, the difference is less than 1 mm, so the statistical difference is not clinically significant. From the results in Table II, there appears to be no difference in the ability of Quick Ceph 2000 to superimpose compared with the conventional manual method of cephalometric superimposition currently accepted by the ABO.

One shortcoming of this investigation was that the Mann-Whitney U test was used; it is a nonparametric tool for the analysis of 2 independent samples. This test was chosen because the data did not have parametric distribution, and therefore a 2-sample independent *t* test could not be used. Normalization of the data and usage of an independent *t* test might give different results.

We also did not consider interoperator error, when 2 persons trace the cephalograms. A random sample of tracings was verified by a second operator for landmark location and anatomic tracing accuracy, but there was no independent tracing by the second operator to generate the interoperator error. This study could be improved upon if a second tracing and superimposition were performed on the data and compared with the data from this study.

CONCLUSIONS

We compared the ability of Quick Ceph 2000 to identify landmarks, make cephalometric measurements required by the ABO for Phase III of board certification, and superimpose regionally on the cranial base, the maxilla, and the mandible, with the conventional method of manual cephalometric analysis. The following conclusions were drawn.

1. There is no difference in the identification of cephalometric landmarks manually or digitally.
2. There is no difference in acquiring consistent cephalometric values for the measurements required by the ABO for Phase III of board certification manually or digitally.
3. There is no difference on the regional superimpositions on the mandible, the maxilla, and the cranial base, manually or digitally.
4. There is no reason that the ABO should not allow computer superimpositions to be used in Phase III of board certification.

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