ORIGINAL ARTICLE

A comparison of scanned lateral cephalograms with corresponding original radiographs

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Introduction: Digital cephalometric radiography is gaining popularity in orthodontic practices. However, few studies have compared measurements and superimpositions on analog radiographs with those made on scanned digital images. The objectives of this study were to evaluate distortion associated with scanning lateral cephalograms and printing to hard copy, and to assess the accuracy of digital images for regular cephalometric tasks. **Methods:** Pretreatment and posttreatment cephalograms from 30 subjects were selected and 3 groups were created: original, digital, and hard copy. All films had 8 fiducial marks punched and were scanned at 150 dots per inch. The hard copies were created with a laser printer. Twenty-three cephalometric measures and 3 superimpositions were evaluated for distortion, measurement accuracy, and superimposition results. Paired *t* tests were used to assess statistical significance. **Results:** Distortion between the original and the scanned image showed 0.8 mm vertical enlargement and 0.4 mm horizontal reduction. Printed radiographs had 1.1 mm vertical and 0.4 mm horizontal enlargement. All differences were statistically significant. Cephalometric comparisons between original and digital images showed statistical differences in Frankfort horizontal (FH)-occlusal plane, maxillary central incisor-FH, facial plane, y-axis, Frankfort plane to mandibular plane angle (FMA), and FH-Naison to point A (NA). Significant differences also were found in facial plane, y-axis, FMA, and FH-NA when comparing the digital and the hard-copy images. All measurements with differences contained the landmarks porion and orbitale. No differences were found between the original and the hard-copy images. Likewise, no significant differences were found between the original and the digital superimpositions. **Conclusions:** Although some distortion was found, the relatively small horizontal and vertical discrepancies were deemed clinically insignificant. Landmark identification errors on scanned images contributed to the discrepancies in cephalometric analysis. Therefore, for clinical orthodontic applications, scanned cephalograms can be used. However, caution must be exercised when determining porion and orbitale. (Am J Orthod Dentofacial Orthop 2006;130:340-8)

Currently, with so much emphasis on evidence-based science, perhaps cephalometrics should not be as popular as it is.[1] Even though we probably all agree that 3-dimensional images of our patients would be the most accurate representations, few orthodontists use them. The transition to using true 3-dimensional images will probably include computerized images of the more commonly used cephalometric radiographs, which would bring more familiarity to the use of computerized images.

Hand-traced cephalometric analysis on traditional radiographic film has been for many years the gold standard for analyzing a cephalometric radiograph and collecting cephalometric values. With the advent of the computer age and today's ever-changing technological environment, new methods for obtaining radiographic images have emerged. Proponents of digitally acquired cephalometric imaging cite numerous advantages, including improved landmark identification through image enhancement techniques, faster cephalometric data acquisition and analysis, more efficient storage and archiving, easier transfer of the image to distant sites, and easy and cost-efficient duplication of radiographs.[2-4] Furthermore, 3-dimensional imaging of dentofacial records in orthodontics is quickly developing as a realistic diagnostic tool. Digital images of the lateral and frontal cephalograms are an integral part of this promising technology.[5]

Digital images can be obtained without a previous hard copy by direct digital radiography or indirectly

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through stored image transmission technology by using phosphor-coated plates. Both techniques require currently expensive devices. Radiographs can easily be scanned into a digital format by using a relatively inexpensive, consumer-grade flatbed scanner equipped with a transparency adapter.

Various computer programs are available to digitally capture scanned lateral cephalometric radiographs and perform many orthodontic functions, including cephalometric landmark identification and analysis, superimposition of sequential radiographs, and printed hard copies of the cephalogram, tracing, or superimposition. But, do scanned radiographic images accurately represent the original radiograph? In essence, can we take a lateral cephalogram from a standard radiograph unit, scan this radiograph into a computerized digital format, and have complete confidence in the accuracy of this digital representation for all clinical applications in orthodontics, thereby rendering the original radiograph dispensable? With the increasing use of technology in today's orthodontic practices, this question becomes vital to both young start-up orthodontists with limited finances and established practitioners, who, although concerned with maintaining precise diagnosis and treatment, aspire to convert their practices to more modern and efficient systems.

Our objectives were (1) to assess potential distortion associated with both scanning a lateral cephalogram into a digital image and printing the digital image to hard copy, (2) to evaluate the accuracy of a digital cephalometric program and a hand-traced printed digital hard copy compared with the original radiograph and traditional hand-traced techniques, and (3) to compare the accuracy of computerized superimpositions with a scanned digital cephalogram with traditional, manual superimposition techniques.

MATERIAL AND METHODS

Thirty subjects were chosen based on the following criteria: signed informed consent by patient or parent allowing use of the records for research purposes, and initial and final cephalograms of adequate diagnostic quality with identifiable craniofacial structures and landmarks. All radiographs were obtained from charts of active patients at the Department of Orthodontics, Case Western Reserve University; radiographs were taken with the Bolton cephalometer. The initial and final radiographs were used to create 3 experimental groups: original radiograph, digital image, and hard copy.

The original radiograph group consisted of the 30 initial and 30 final original radiographs. All radiographs were indexed with 4 corner fiducials and 4 internal fiducials by using a template according to the method described by Baumrind and Miller.[6] The 60 radiographs were manually traced by using acetate tracing paper placed over the original radiograph on a standard light-box in a darkened room. A 0.5-mm lead pencil was used to trace all required hard- and soft-tissue landmarks. Bilateral structures were averaged to make a single structure or landmark. Mechanical porion was used as porion. Manual superimpositions were completed by using acetate tracing paper placed on a standard light-box in a darkened room. Superimposition reference planes included S-N at sella for overall superimpositions, ANS-PNS plane registered at ANS for maxillary superimpositions, and Go-Me plane registered at menton for mandibular superimpositions.

After fiducial indexing on the original radiograph, the 30 initial and 30 final cephalograms were scanned into digital format with an Expression 1600 scanner (Epson America, Long Beach, Calif) fitted with an EU-35 transparency unit adapter. All radiographs were scanned by using Adobe Photoshop 6.0 (Adobe Systems, San Jose, Calif) software at the following settings: document source, TPU for positive film; image type, 24 bit color; resolution, 150 dots per inch (dpi); 1200×1600 pixels. The mages were originally created as TIFF images. The computer program used, Dolphin Imaging 9 (Dolphin Imaging and Management Solutions, Chatsworth, Calif), does not accept TIFF files, so the images were converted to JPEG and saved at a maximum quality setting by using Adobe Photoshop 6.0 compression software. The final image file size was approximately 220 KB.

The images were imported into Dolphin Imaging software, and 42 hard- and soft-tissue landmarks were identified with a mouse. Four fiducial points also were digitized by using Dolphin Imaging's custom cephalometric landmark function. Image enhancements, including brightness, contrast, and magnification, were used as needed to identify individual landmarks as precisely as possible. The images were calibrated by identifying 2 crosshairs, 100 mm apart, scanned during initial image acquisition. A MultiSync LCD 1550V (NEC Corporation, Tokyo, Japan) 15-in flat screen monitor with display resolution of 1024×768 pixels was used for image viewing.

Using the superimposition application in Dolphin Imaging, we created superimpositions for the 30 subjects with the digitized initial and final images. Reference planes in the manual superimpositions were maintained in the digital superimposition. To facilitate data collection, superimpositions were printed by using a 1:1 scale representation from the Dolphin Imaging program on standard white paper with a LaserJet

4100N printer (Hewlett-Packard, Palo Alto, Calif) at 1200 dpi.

Hard copies of the 30 initial digital cephalograms were printed from stored JPEG files in Adobe Photoshop 6.0 on plain, standard white paper on the same printer at 1200 dpi. Manual tracings were completed for the 30 hard-copy images directly on the hard-copy printout in a lighted room with the same procedures previously described for the original radiograph tracings.

To test for distortion of the scanned image and printed hard copy, 4 corner fiducial points were measured from both modalities and compared with the measurements from the corresponding original radiographs. Five linear measurements, 2 horizontal (BC and DA), 2 vertical (AB and CD), and 1 transverse (AC), were recorded for each cephalogram (Fig 1). Digital image measurements were made by using the ruler function in Adobe Photoshop. Original and hard-copy measurements were made with a standard millimeter ruler.

Our second objective was to evaluate the accuracy of using a scanned cephalogram with a digital cephalometric program (Dolphin Imaging) and a hand-traced hard copy of the digital image compared with results from the original radiograph and traditional, hand-traced techniques. To achieve this objective, 23 linear and angular measurements from 4 common cephalometric analyses (Downs, Steiner, Tweed, and Riedel) were obtained from the digital image and hard-copy printouts and compared with the original radiograph.

Our third objective was to compare the accuracy of computerized superimposition. Linear changes in the position of the 4 fiducial points were measured on the 30 superimposed radiographs for both the computerized and the manual groups. Sixteen linear and 2 angular measurements were used to evaluate the horizontal and vertical changes in maxilla, mandible, maxillary molar/incisor, mandibular molar/incisor, and soft tissue. Figures 2-4 show how the 18 superimposition and the 4 fiducial measurements were obtained.

For the overall superimpositions, anteroposterior (AP) changes in the maxilla and the mandible were made by constructing perpendicular lines to the reference plane S-N, running through A-point and B-point, respectively, of the initial and the final tracings. The differences in the distance between the initial and final constructed lines were recorded and compared with the same measurements from the digital superimposition. Similarly, vertical changes in the maxilla and the mandible were made by constructing parallel lines to S-N running through A-point and menton, respectively. Fiducial points, soft-tissue menton, A-point, and tip of nose values were obtained by measuring the differences between the initial and final positions after superimposition, compared with the same measurements on the digital superimposition.

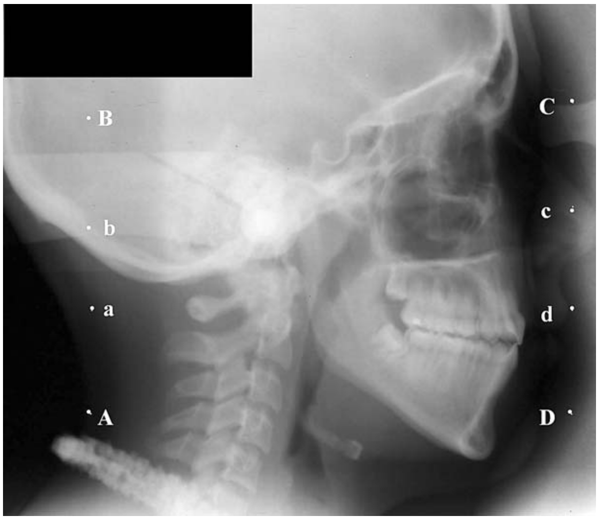

Fig 1. Lateral cephalogram with stamped fiducial points labeled for identification; 4 external points are labeled A, B, C, and D, and 4 internal points are labeled a, b, c, and d.

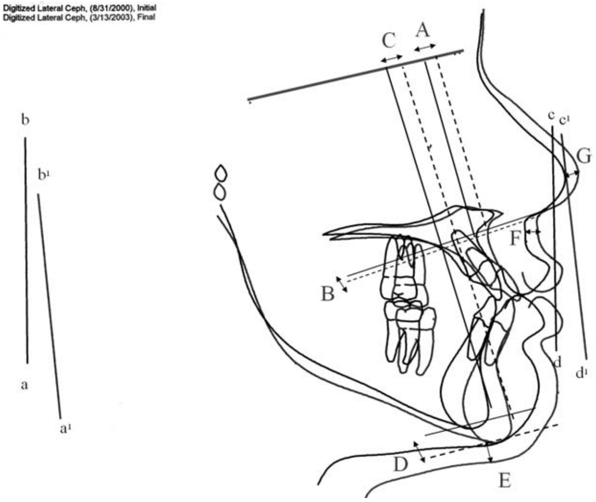

Fig 2. Overall superimposition on SN at S with constructed measurements used to assess maxillary, mandibular, soft-tissue, and fiducial point positional changes. *Solid lines* indicate initial tracing and *dotted lines* final tracing landmarks. *A* and *B* represent AP and vertical changes in maxilla, respectively. *C* and *D* represent AP and vertical changes in mandible, respectively. *E, F,* and *G* represent soft-tissue changes at soft-tissue menton, A-point, and tip of nose, respectively. Initial fiducial points are labeled *a, b, c,* and *d*. Final fiducal points are labeled a^1, b^1, c^1, and d^1.

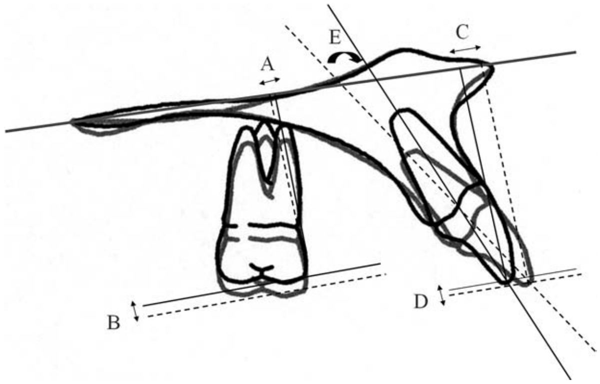

Fig 3. Maxillary superimposition on ANS-PNS at ANS with constructed measurements used to assess maxillary molar and incisor positional changes and incisor angulation change. *Solid lines* indicate initial tracing and *dotted lines* final tracing landmarks. *A* and *B* represent AP and vertical changes in molar position, respectively. *C* and *D* represent AP and vertical changes in incisor position, respectively. *E* represents angular change in incisor position.

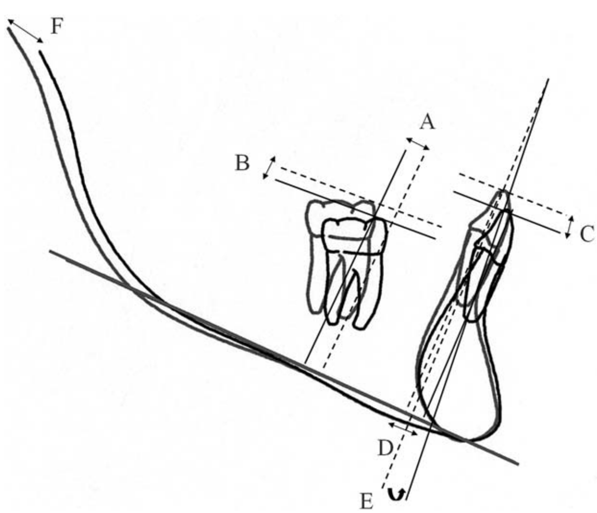

Fig 4. Mandibular superimposition on Go-Me at menton with constructed measurements used to assess mandibular molar and incisor positional changes, incisor angulation change, and mandibular growth. *Solid lines* indicate initial tracing and *dotted lines* final tracing landmarks. *A* and *B* represent AP and vertical changes in molar position, respectively. *C* and *D* represent AP and vertical changes in incisor position, respectively. *E* represents angular change in incisor position. *F* shows mandibular growth measured at articulare.

In the maxillary regional superimpositions, AP changes in molar and incisor position were made from perpendicular lines to the reference plane ANS-PNS running through the most mesial point of the first molar and the incisor tip, respectively. Vertical changes were measured from parallel lines to ANS-PNS running through the mesiobuccal cusp tip of the first molar and the incisor tip. Angular change in the incisor is the difference between the long axes of the initial and final incisor positions.

Me-Go was used as the reference plane in the mandibular regional superimpositions. First molar and incisor AP, vertical, and angular changes were made by using the same technique and points as used in the maxillary superimposition with perpendicular and parallel lines to Me-Go. Additionally, mandibular growth was assessed by measuring the positional change at articulare.

Angular and linear values were measured with an orthodontic protractor and ruler. All measurements were in millimeters to the nearest tenth, stored in an Excel (Microsoft, Redmond, Wash) spreadsheet, and performed by 1 operator (L.Q.B.).

Intraoperator error was examined by randomly selecting 10 cephalograms from the original sample of 30 and analyzed by using software (SPSS, Chicago, Ill).

Statistics

Means, standard deviations, and ranges were calculated for all data with Excel software. Paired Student *t* tests were used to evaluate statistical significance for comparing mean values between corresponding data sets. Statistical significance was initially set at $P < .05$. However, the Bonferroni adjustment (α/total number of measurements) was applied to correct for the many measurements used. Intraclass correlation was calculated for all intraoperator measurements to determine the corresponding correlation coefficient (r value). An r value <0.75 was considered a weak correlation.

RESULTS

Fiducial measurements

Means, standard deviations, and ranges for the 3 modalities of fiducial measurements are shown in Table I. Standard deviations and ranges for the original cephalogram values were quite low, as would be expected.

Lines AB and CD represent vertical measurements, whereas lines BC and DA characterize the horizontal component. Line AC incorporates both a vertical and a horizontal vector, but the horizontal component appears to be more heavily emphasized in this measurement because of the rectangular shape of the template. The total mean difference between the original cephalogram and the digital version for the 2 vertical fiducial components was 0.8 mm for each. This represents an 0.8-mm enlargement in the vertical dimension. The total mean difference for the 2 horizontal measurements

Table I. Means and standard deviations from manually traced film, digital image from Dolphin Imaging, and manually traced printed hard copy

	Original		*Digital*		*Hard copy*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
AB (V) (mm)	159.3	0.1	160.1	0.5	160.4	0.5
BC (H) (mm)	177.2	0.1	176.8	0.2	177.5	0.2
CD (V) (mm)	152.3	0.1	153.1	0.2	153.4	0.3
DA (H) (mm)	177.6	0.1	177.1	0.1	178.1	0.1
AC (T) (mm)	233.8	0.1	234.3	0.2	234.7	0.2
Total (mm)	900.2	0.2	901.5	0.9	904	1.1
Average (mm)	180	0	180.3	0.2	180.8	0.2

V, Vertical; *H,* horizontal; *T*, transverse.

(BC and DA) was 0.4 mm. However, a decrease in the mean values from the original to digital format indicates a reduction in the horizontal dimension.

Mean differences between the digital image and the hard-copy fiducial measurements show a slightly different trend. The vertical measurements AB and CD shared a 0.3-mm increase in size. However, the horizontal measurements BC and DA had increases of 0.7 and 0.9 mm, respectively, indicating magnification in the horizontal dimension as the digital image was printed to hard-copy form.

The results comparing the original cephalogram and the hard copy show the total dimensional discrepancy from the scanning and printing processes. A 1.1-mm enlargement occurred in both vertical measurements. Enlargements of 0.23 mm in the upper and 0.47 mm in the lower measures describe the overall distortion in the horizontal dimension.

All measurements used in the comparisons were subjected to a Student *t* test to evaluate statistical significance. Statistical significance was set at $P < .01$ after applying the Bonferroni adjustment. All fiducial measurements used in the data comparisons showed highly significant values.

Cephalometric measurements

Means, standard deviations, and ranges of individual cephalometric measurements are summarized in Table II. Table III shows the calculated mean differences and statistical significance of the 3 experimental groups. Statistically significant values were found for 6 of the 23 measurements when the manually traced cephalogram and the computerized cephalometric analysis were compared (Table III). The 6 statistically significant measurements included the facial plane, y-axis, occlusal plane, maxillary incisor to Frankfort horizontal (FH), FH to nasion-A-point, and Frankfort-mandibular plane angle (FMA). Similar results were found when comparing the computerized analysis to the hard-copy tracing, showing statistically different values in 4 out of the 23 measured values. These measurements included the facial plane, y-axis, FH to nasion-A-point, and FMA. Of note, maxillary incisor to FH ($P = .002$) was also close to statistical significance. Conversely, no statistical significance was noted when comparing the manually traced radiograph and the printed hard copy. Standard deviations for individual measurements were relatively consistent between each modality.

Superimpositions

No statistically significant differences were found in the distances between fiducials when comparing the digital superimpositions with the manual superimpositions. Accordingly, means and standard deviations were fairly similar between techniques for all 4 measurements. A slightly dissimilar presentation was noted for the measurements used to assess skeletal, dental, and soft-tissue changes. No statistically significant differences were found for any of the 18 measurements (Table IV). However, means and standard deviations were more variable compared with those from superimposition fiducial measurements (Table IV).

Intraoperator error was used to assess the reliability of data collection. All but 1 statistically significant difference had strong correlations ($r > 0.75$) between the 2 time-point data sets. The occlusal plane-FH measurement had an r-value of 0.72, but this was close to the 0.75 threshold.

Nevertheless, no cephalometric value was higher in the intraoperator analysis than the difference among comparisons shown in Tables III and IV.

DISCUSSION

The purpose of this investigation was to evaluate the process of scanning an analog lateral cephalogram into digital format and assessing the accuracy of the digital radiograph in reliably accomplishing the everyday tasks of a cephalogram, including cephalometry, superimposition, and hard-copy printout duplication.

The results showed some distortion when the analog film was converted to a digital format. Data showed a vertical enlargement of 0.5% and a horizontal reduction of 0.3%. Marci and Wenzel[7] reported a 2% enlargement in the vertical plane and no horizontal distortion on video-recorded cephalograms. Nimkarn and Miles[8] found a 1% vertical magnification and a 3% horizontal magnification of measurements made on digitized images from lateral cephalograms also obtained in video-camera recordings. No studies were found about the distortional effects in scanning radiographs.

Table II. Means and standard deviations of cephalometric measurements from manually traced film, digital image from Dolphin Imaging, and manually traced printed hard copy

	Manual		*Digital*		*Hard copy*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Downs						
FP (°)	88.82	3.16	87.15	3.38	89.47	3.38
CON (°)	5	5.7	4.88	5.88	5.54	5.64
AB (°)	−4.04	4.41	−5.57	2.78	−5.64	2.65
Y (°)	57.87	3.6	59.76	3.84	57.46	3.57
OP (°)	6.04	4.57	7.83	4.58	6.07	4.07
INT (°)	129.1	11.15	129.26	10.1	127.92	11.97
L1OP (°)	20.69	7.91	20.03	7.4	20.48	8.42
L1MP (°)	2.79	8.67	2.41	8.03	2.95	8.71
U1AP (mm)	6.77	2.62	6.83	2.65	6.73	2.73
Riedel						
SNA angle (°)	81.45	2.94	81.02	3.7	81.74	3.56
SNB angle (°)	78.21	3.2	77.77	3.95	78.8	4.63
ANB angle (°)	3.24	2.35	3.25	2.28	2.94	1.99
U1FH (°)	114.96	6.2	113.26	6.31	115.78	6.33
FH/NA (°)	91.08	3.81	89.69	4.22	92.12	4.41
Tweed						
FMA (°)	24.09	5.94	25.62	6.07	23.61	5.75
IMPA (°)	92.79	8.67	92.41	8.03	92.95	8.71
FMIA (°)	63.12	7.77	61.97	7.62	63.44	8.51
Steiner						
U1NA (mm)	5.7	2.48	5.25	2.74	5.68	2.33
U1NA (°)	23.74	6.66	22.97	6.76	22.85	6.74
L1NB (mm)	5.64	3.01	5.56	4.23	6.04	2.98
L1NB (°)	24.35	7.02	24.22	6.72	24.97	6.63
PONB (°)	2.13	1.85	1.97	1.98	2.05	1.78
POL1NB (°)	3.51	4.03	3.59	5.31	3.99	4.05

FP, Facial plane; *CON,* angle of convexity; *AB,* A point-B point plane to Naison-Pogonion plane; *Y,* y-axis; *OP,* occlusal plane; *INT,* interncisal angle; *L1OP,* lower incisor to occlusal plane; *L1MP,* lower incisor to mandibular plane; *U1AP,* upper incisor to A point-Pogonion plane; *U1FH,* upper incisor to Frankfort horizontal plane; *FH/NA,* Frankfort horizontal plane to Nasion-A point plane; *U1NA,* upper incisor to Naison-A point plane; *L1NB,* lower incisor to Naison-B point plane; *PONB,* Pogonion to Naison = B point plane; *POL1NB,* Pogonion-lower incisor plane to Naison-B point plane.

Further results from this study indicate additional distortion when the digitized cephalogram was printed to a hard copy. Average enlargements of 0.3 mm in the vertical dimension and 0.8 mm in the horizontal dimension were observed; both were statistically significant. Thus, net enlargement of 1.1 mm vertically and 0.4 mm horizontally occurred in transferring from the original cephalograms to hard copies.

Converting an analog radiographic image into a digital representation and ultimately to a printed hard copy requires many steps involving hardware, software, and computer functions and settings. In addition, the conversion of digital images into viewable, printable, and storable formats often requires data compression, alteration, or transfer to peripheral hardware, increasing the likelihood of image distortion.[3]

Of importance, however, is how the observed distortion might affect the clinical aspect of orthodontic diagnosis and treatment planning. Although all fiducial measurement comparisons were statistically significant, the clinical significance must be assessed separately. Linear distortion was no greater than 1.1 mm, and the greatest standard deviation for any measurement was 0.5 mm. Moreover, because the standard deviations were so low, statistical significance was found, even though only minimal differences in mean values were recorded. Because the width of the fiducial mark itself was approximately 0.5 mm, one might contend that the total disparity between modalities truly is clinically insignificant. O'Callaghan[9] found that identification of fiducial marks on a digitized image using a mouse and crosshair was accurate only to within 0.5 mm. He further reported that identification of the fiducial marks on the original radiograph showed better interoperator accuracy, but similar patterns of vertical and horizontal displacement were documented when comparing on-screen digital fiducial measurements.

The results showed that 6 of the 23 cephalometric

Table III. Mean differences from 4 common cephalometric analyses

	Manual/digital	Manual/hard copy	Digital/hard copy
	Mean difference	*Mean difference*	*Mean difference*
Downs			
FP (°)	1.67*	0.65	2.32*
CON (°)	0.12	0.54	0.66
AB (°)	1.53	1.6	0.07
Y (°)	1.89*	0.41	2.3*
OP (°)	1.79*	0.03	1.76
INT (°)	0.16	1.18	1.34
L1OP (°)	0.66	0.21	0.45
L1MP (°)	0.38	0.16	0.54
U1AP (mm)	0.06	0.03	0.09
Riedel			
SNA angle (°)	0.43	0.29	0.72
SNB angle (°)	0.44	0.59	1.03
ANB angle (°)	0.01	0.31	0.31
U1FH (°)	1.7*	0.83	2.53
FH/NA (°)	1.38*	1.04	2.43*
Tweed			
FMA (°)	1.53*	0.48	2.01*
IMPA (°)	0.38	0.16	0.54
FMIA (°)	1.15	0.31	1.47
Steiner			
U1NA (mm)	0.45	0.02	0.43
U1NA (°)	0.77	0.89	0.12
L1NB (mm)	0.08	0.39	0.48
L1NB (°)	0.13	0.61	0.74
PONB (°)	0.16	0.08	0.08
POL1NB (°)	0.08	0.47	0.39

FP, Facial plane; *CON,* angle of convexity; *AB,* A point-B point plane to Naison-Pogonion plane; *Y,* y-axis; *OP,* occlusal plane; *INT,* interncisal angle; *L1OP,* lower incisor to occlusal plane; *L1MP,* lower incisor to mandibular plane; *U1AP,* upper incisor to A point-Pogonion plane; *U1FH,* upper incisor to Frankfort horizontal plane; *FH/NA,* Frankfort horizontal plane to Nasion-A point plane; *U1NA,* upper incisor to Naison-A point plane; *L1NB,* lower incisor to Naison-B point plane; *PONB,* Pogonion to Naison = B point plane; *POL1NB,* Pogonion-lower incisor plane to Naison-B point plane.
*Significant at $P < .002$ after Bonferroni adjustment ($\alpha = .002$).

measurements were significantly different from the digital image measurements. Four of these significant measurements also showed statistically significant differences when comparing the digital with the hard-copy measurements. No significant differences were found in the manual to hard-copy measurements. Moreover, intraoperator error for all measurements involving statistically significant differences indicated strong correlations between the 2 time points. Interestingly, all measurements with statistical significance were associated with the FH plane.

Several studies showed that inconsistency in landmark identification is an inherent cause of errors in conventional cephalometry.[9-11] Our results indicate that the FH plane is unreliable in identification with digital media. Chen et al[12] showed discrepancies in the vertical component when identifying the landmarks porion, orbitale, and gnathion on digital media. Further results showed landmarks porion, articulare, PNS, and UM had lower reliability in landmark identification as observed from interobserver error. Thus, porion and orbitale (the 2 landmarks contributing to FH plane) showed significant unreliability in landmark identification; this might have affected our results. A possible cause might be that using the digital enhancement features for landmark digitization allowed for a less obscured view of porion or orbitale, resulting in a different location of the FH plane. Previous studies showed mixed results when comparing the accuracy in landmark identification by using digital enhancement features compared with identification on the original radiograph.[3,13-16]

An additional potential contributing factor to our significant results in cephalometric analysis could be the initial quality of the radiograph or the quality after scanning. Marci and Wenzel[7] found a statistical difference in low-quality digital and low-quality original cephalograms, and concluded that digital processing did not improve the overall reliability of landmark identification in poorer quality radiographs. We made every effort to select cephalograms of adequate diagnostic quality with identifiable craniofacial structures and landmarks. However, on data acquisition, it was noticed that certain films were poorer quality than originally suspected, with large bilateral structure discrepancies, less than ideal contrast, or soft-tissue burnout. An even more closely scrutinized case selection might improve the accuracy in landmark identification and digitization.

Radiographs were scanned at 150 dpi according to the recommendation from Dolphin Imaging. Recommendations by Rogers[4] and Held et al[17] indicate that 75 dpi is sufficient for scanning lateral cephalograms. During landmark digitization, magnification often was used to more accurately identify certain structures. In several instances, the magnification caused significant pixelation and blurriness of the image, increasing the difficulty of accurate identification. Selecting a higher scanning dpi might assist in circumventing this problem in future studies.

No statistically significant differences were noted for any of the 18 structural or 4 fiducial measurements. *P* values for the 18 structural comparisons tended to fall closer to significant levels than those of the fiducial measurements. Similarly, means and standard deviations were more variable in the structural measurements

Table IV. Means and standard deviations from 18 angular and linear measurements from manually traced superimpositions and digital cephalometric superimposition program

	Manual		*Digital*	
	Mean	*SD*	*Mean*	*SD*
Overall superimposition measurements				
SN − A-pt (max AP) (mm)	0.35	3.4	1.02	3.2
SN − A-pt (max vertical) (mm)	1.99	3.1	2.16	2.9
Pog-Pog (mand AP) (mm)	1.21	5.8	1.73	5.4
Me-Me (mand vertical) (mm)	5.21	5	5.45	5.2
Maxillary regional superimposition measurements				
M6-M6 − ANS/PNS (AP molar ptn) (mm)	1.28	3.2	1.08	2.7
O6-O6 − ANS/PNS (vertical molar ptn) (mm)	1.69	2.3	1.98	1.9
T1-T1 − ANS/PNS (AP incisor ptn) (mm)	−0.92	3.4	−0.98	3.7
T1-T1 − ANS/PNS (vertical incisor tip ptn) (mm)	0.53	2.1	0.82	1.9
A1-A1 (incisor angulation) (°)	6.22	5.2	6.67	6.1
Mandibular regional superimposition measurements				
M6-M6 - Go/Me (AP molar ptn) (mm)	0.42	2.48	0.24	2.61
O6-O6 - Go/Me (vertical molar ptn) (mm)	2.01	1.95	2.49	2.1
T1-T1 - Go/Me (AP incisor ptn) (mm)	−0.7	3.81	−1.11	3.97
T1-T1 - Go/Me (vertical incisor tip ptn) (mm)	0.97	2.33	1.53	2.51
A1-A1 (incisor angulation) (°)	7.13	6.55	7.38	5.76
Ar-Ar (mandibular growth) (mm)	5.29	4.09	5.74	4.37
Soft-tissue superimposition measurements				
Me-Me (mm)	7.36	6.54	7.01	6.22
Soft-tissue A-pt - soft-tissue A-pt (mm)	4.43	4.13	4.5	3.75
Tip of nose-tip of nose (mm)	4.32	4.63	4.25	4.44

Max, Maxillary; *pt,* point; *mand,* mandibular; *ptn,* position; *M,* molar; *O,* occlusal; *T,* tip; *A1,* angulation of upper incisors.

than those corresponding to the fiducial measurements. This difference most likely involves landmark identification errors and a more complex analysis associated with the 18 structural measurements.

A drawback of the digital superimposition program was the limited options for reference plane selection. Biologically stable structures as described in previous studies were not available for superimpositioning.[18-20]

Potential systematic bias was inherent in all phases of this study; this could be especially pronounced during landmark identification. Although a single operator eliminated interoperator error, several operators, ideally, could reduce and balance out the errors associated with landmark identification, thus improving the accuracy of the comparisons. In addition, better- quality cephalograms might have enhanced the accuracy in landmark identification for all 3 modalities. The cephalograms we used had a rectangular radiopacity in the posterior cranial base area because of the cephalometer used. This radiopacity made the identification of porion difficult, possibly affecting the proper position of the FH plane and all related measurements.

CONCLUSIONS

1. Distortion was found in both scanning a lateral cephalogram and printing to a paper hard copy; however, there was at most a discrepancy of only 1.1 mm in any 1 dimension, denoting clinical significance as questionable.
2. Cephalometric analysis measurements made from a computerized program and printed hard copy with a scanned cephalogram showed significant discrepancies when compared with a manually traced original cephalogram. However, all significant measurements contained the landmarks porion and orbitale, both of which had inconsistent and unreliable landmark identification in previous studies. Our results can be attributed to difficulty in identification of these landmarks.
3. Superimpositions made from a computerized cephalometric program by using a scanned cephalogram appear to be as accurate as those made from the original cephalogram with conventional manual-traced techniques.
4. The hard-copy image printed from the scanned digital image showed minimal distortion, yet cephalometric analysis and superimpositions showed comparable accuracy to the original and digital cephalograms by using manual techniques and can be regarded as clinically acceptable for duplication purposes.

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