Original Article

Comparison of Hand-Traced and Computer-Based Cephalometric Superimpositions

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ABSTRACT

Objective: To determine the ability to produce comparable superimpositions using hand tracing and digital methods (Dolphin v10). In addition, if the two methods were comparable, we wanted to determine if a difference existed between the best-fit cranial base superimposition and S-N superimpositions using the digital method.

Methods and Materials: Sixty-four initial (T_1) and final (T_2) cephalometric film radiographs were obtained. Cranial base and regional superimpositions were completed independently for each pair of radiographs by either hand tracing and digital methods. To quantitatively evaluate the differences between the two methods, the hand and digital superimpositions were digitized to obtain x-y coordinates of routine cephalometric landmarks at T_2. Linear distance between multiple corresponding (hand and digital) T_2 cephalometric landmark locations (e.g., A point) were measured and defined as the T_2 landmark distance (T_2 LD). Additionally, 61 patient records were used to compare the digital method for best-fit cranial base superimpositions versus S-N superimpositions. A Friedman test was applied to examine for differences.

Results: The upper 95% confidence limit for the mean of the T_2 LD for hand and digital superimposition methods was $<$1 mm for all landmarks except maxillary incisor tip and apex. The upper 95% confidence interval for best-fit vs S-N was $>$1 mm for most landmarks.

Conclusion: This study validates the use of superimpositions produced by Dolphin Imaging version 10 and is a necessary step forward toward widespread acceptance of digital superimpositions. (*Angle Orthod.* 2009;79:428–435.)

KEY WORDS: Cephalometrics; Superimpositions; Hand; Digital; Computerized

INTRODUCTION

Orthodontic practitioners are transitioning to paperless offices and acquiring digital records.[1] This transition has been led in part by recent advances in technology, which have resulted in the development of inexpensive filmless cephalometric radiographic equipment. Digital radiology has several advantages over film-based systems.[2–4] Superimposition, the overlay of cephalometric radiographs on specific anatomical structures, is a method used by clinicians and researchers to visualize growth changes and the effects of orthodontic treatment on the jaws and the teeth. Superimpositions are routinely used as an outcome measure for clinical orthodontic studies and the American Board of Orthodontics requires cephalometric superimposition for board case analyses.[5]

Considering the importance of cephalometric analyses and superimposition for orthodontic diagnosis, the accuracy of computer-based tracing software must be established by comparing them to hand tracing on acetate paper, the current gold standard. There are no differences in identifying cephalometric landmarks on traditional film-based or digital lateral cephalometric radiographs.[6–8] Cephalometric analyses using the most popular computer programs generate similar lin-

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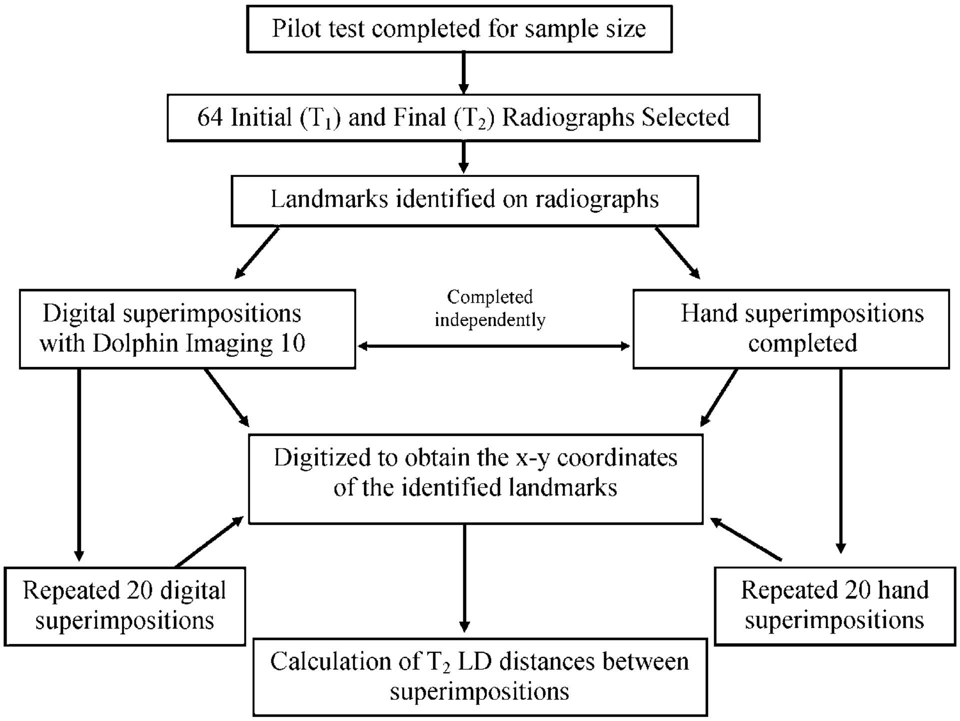

Figure 1. Schematic of experimental design of study.

ear and angular measurements compared with hand measurements.[9–12] However, only a few studies have examined cephalometric superimpositions produced by these software programs.[12,13] We are unaware of any study that uses the custom landmark feature in Dolphin Imaging to produce digital superimpositions.

As digital radiology becomes more prevalent, hand superimpositions are becoming less appealing. However, many problems (magnification issues, ability to trace specific structures) that exist in current digital software are not under the operator's control. The purpose of this study was to determine the ability of an operator to produce comparable superimpositions using digital (Dolphin Imaging version 10) and hand methods (gold standard) and to determine if a difference existed between the best-fit digital cranial base superimposition and S-N digital superimposition methods.

MATERIALS AND METHODS

Sample Selection

The experimental design is outlined in a flow chart (Figure 1). After Institutional Review Board approval, patient charts from a university archival database were reviewed for possible inclusion in this study. All patients received comprehensive orthodontic treatment and only radiographs with excellent quality and similar magnification were selected. Patients who underwent orthognathic surgery and those with congenital syndromes and dental and skeletal asymmetries were excluded from the sample. A power analysis from five sets of radiographs was used to determine a sample size. We determined that at least 42 pairs of radiographs were needed to detect a difference of 1 mm between the superimposition methods with a power of 95%. Sixty-four pairs of pretreatment (T_1) and posttreatment (T_2) radiographs were selected. Of the subjects, 31 were female and 33 were male. The age for T_1 ranged from 9.3 to 18.5 years (mean = 12.9 years). T_2 ages ranged from 11.8 to 21.1 years (mean = 15.6 years).

Landmark Identification

Traditional cephalometric landmarks (Table 1) were identified on all radiographs with a 0.3-mm HB lead pencil. An orthogonal axis was drawn in pencil on the T_1 films. Radiographs were scanned and imported into a commercially available software (Dolphin Imaging and Management Solutions, Chatsworth, Calif) using an Epson Expression 1680 Professional transparency scanner (Epson USA, Long Beach, Calif). Standard scanning resolution was set to 400 dots per inch (dpi) gray scale.[14,15]

The orthogonal axes served to identify the locations of landmarks between superimposition methods for the same subject. For the cranial base superimpositions, a horizontal axis was drawn through sella-nasion with a vertical axis through sella (Figure 2A). For the

Table 1. Cephalometric Landmarks Identified on Radiographs

Landmarks
Cranial Base superimposition
Posterior nasal spine (PNS)
Harvold defined anterior nasal spine (ANS)
A point
B point
Pogion (Pog)
Gonion (Go)
Maxillary regional superimposition
Maxillary incisor tip (U1 tip)
Maxillary incisor root apex (U1 apex)
Maxillary mesial buccal cusp tip (U6 tip)
Maxillary mesial root apex (U6 apex)
Mandibular regional superimposition
Mandibular incisor tip (L1 tip)
Mandibular incisor root apex (L1 apex)
Mandibular mesial buccal cups tip (L6 tip)
Maxillary mesial root apex (L6 apex)

maxillary regional superimpositions a horizontal axis was constructed through the Harvold defined anterior nasal spine (where the vertical thickness of the bony process was 3 mm) and a vertical axis through the posterior nasal spine (Figure 2B). For the mandibular regional superimpositions, a horizontal axis was constructed through gonion and menton with a vertical axis through gonion (Figure 2C).

Tracing

Radiographs were traced by the hand and digital method and standard cephalometric measurements (SN-FH, SN-MP, SNA, SNB, ANB, U1-SN, L1-MP) were calculated for each tracing. These measurements were available for reference to aid in performing the superimposition. Hand superimpositions were traced on acetate paper in a darkened room on a standard light box. T_1 tracings were traced on the original radiograph in black using a 0.3 mm 2H mechanical pencil. This tracing was best-fit directly onto the T_2 radiograph, which was then traced in red on the same acetate.

Digital superimpositions were completed using Dolphin Imaging 10, the most current version of the software available at the time of this study. All standard default anatomic structures, as defined by the software, were traced.

Superimpositions

Superimpositions were completed randomly and independently, at least 5 days apart, for each subject by

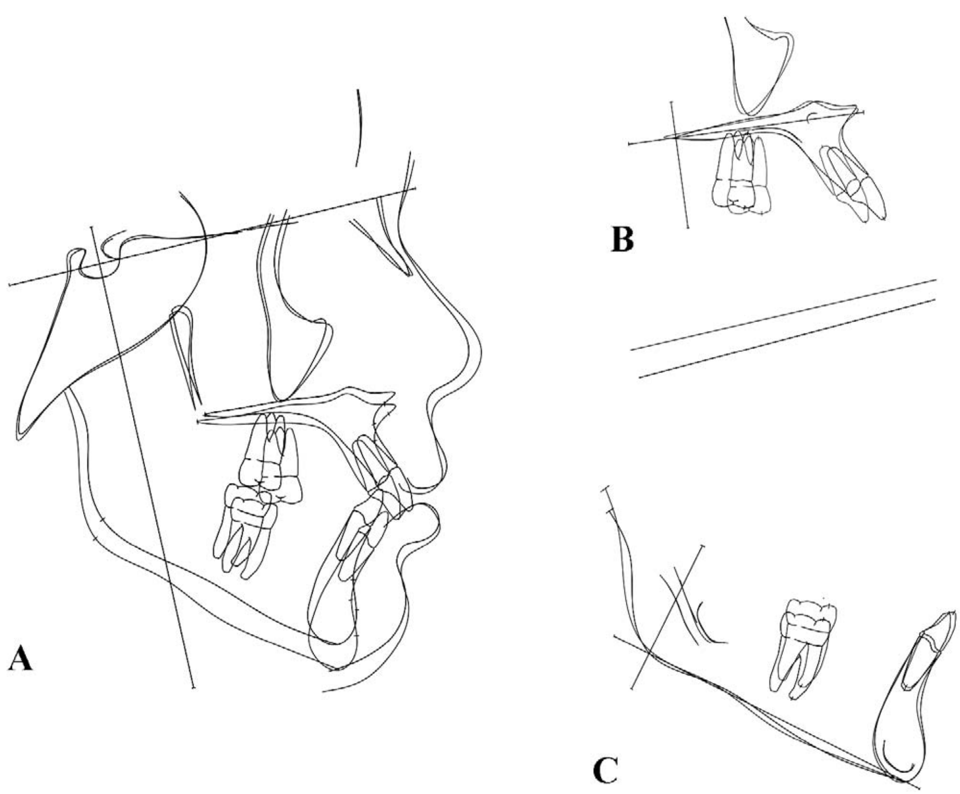

Figure 2. Orthogonal axes in the cranial base (A), maxilla (B), and mandible (C). These axes then provided a point from which differences between the various methods could be quantified.

the hand and the digital method. Cranial base superimpositions were aligned on the best fit of the anterior portion of the sella turcica, the cribriform plate of the ethmoid bone and the internal contour of the frontal bone.[16] Maxillary regional superimpositions were aligned on the best fit of the lower border of the palate and internal cortication of the maxilla.[17,18] Mandibular regional superimpositions were aligned on the best fit of the inner contour of the mandibular symphysis, the mandibular canal, and the apical portion of unerupted third molars if present.[19] Identical methods of superimposition were used for the hand and digital method. For the digital method the custom structures feature was used. Cranial base digital superimpositions were generated using the tracing superimposition free-form feature of the software package. This allowed movement and superimposition of the T_2 time point tracing anywhere onto the T_1 tracing. For the regional superimpositions, Dolphin Imaging 10 does not support the superimposition of custom traced structures unlike cranial base superimpositions. To bypass this software limitation, regional superimpositions were made using the cranial base superimposition feature, but by superimposing on the structures deemed suitable for the regional superimpositions. Then all extraneous landmarks and lines not needed for the regional superimpositions were removed using the delete feature in the custom editor. Therefore, only the structures of interest for the regional superimpositions were visible, but with the ability to superimpose upon any custom structures (Figure 2B,C).

Calculation of T_2 Landmark Distance

To allow for comparison of the superimposition methods, hand superimpositions were scanned using an Epson Expression 1680 Professional transparency scanner at 400 dpi color scale and saved as JPEG images. All digital superimpositions were copied directly from the software and saved, along with the scanned hand superimpositions, in Publisher (Microsoft 2003, Redmond, Wash) as JPEG images. These JPEG files for the hand and digital superimpositions were imported into the GetData 2.21 (GetData Graph Digitizer, S. Fedorov, Moscow, Russia) digitizing program. Linearity and accuracy of this digitizing program were checked by digitizing points on a coordinate grid. Hand and digital superimpositions were digitized onto the T_1 coordinate axis for each sample. From the coordinate locations of the T_2 cephalometric landmarks, distances between corresponding (hand and digital) T_2 landmarks were calculated (Figure 3). This linear measurement was the main outcome variable of the study and was defined as the T_2 landmark distance (T_2 LD). If the location of the T_2 landmarks for the hand and

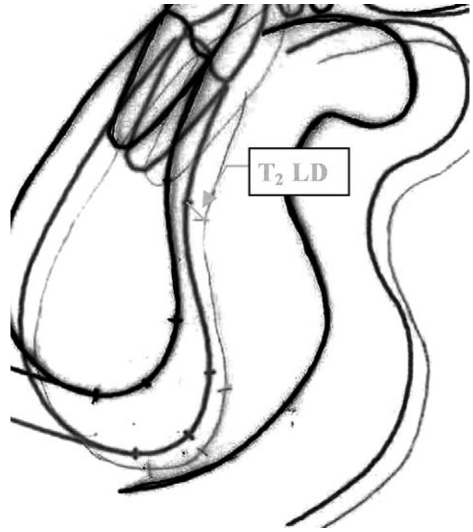

Figure 3. Online version: The B point region of the mandible is used to demonstrate the T_2 LD. The black is the pretreatment tracing, the thick red the digital T_2 tracing, and the thin red is the hand T_2 tracing. The green line depicts the difference in B point position in the digital vs the hand T_2 tracing and is the difference between the two methods of interest.

Figure 3. Paper version: The B point region of the mandible is used to demonstrate the T_2 LD. The first black line (left to right) is the digital pre-treatment tracing, and the second black line is the digital post-treatment tracing. The third line, depicting the outline of the symphysis, is the hand post-treatment tracing. Arrow indicates T_2 LD.

digital superimpositions were coincident (T_2 LD $= 0$), it would mean that the hand and digital superimpositions were identical. At a later date, 20 sets of radiographs were randomly selected for error analysis.

Comparison of Best-Fit and S-N Digital Superimpositions

Using the methods described earlier, the digital best-fit cranial base superimpositions were compared with the digital S-N superimposition. In 3 of the 64 patient records, the agreement between the hand and digital best-fit cranial base superimpositions was large ($>$1 mm). Thus, 61 patient records, with treatment time ranging from 6 months to 5.5 years, were compared. In addition, these records were further divided into three groups based on the length of the T_1 to T_2 time period. Group I consisted of 15 subjects and treatment time was 0–2 years, Group II had 29 subjects and treatment time was 2–3 years, and finally, Group III had 17 subjects and treatment time of $>$3 years. Age was not controlled for in the three groups, just the effect of duration of treatment.

Statistical Methods

Descriptive statistics, including 95% confidence intervals, were calculated for the linear distance be-

Table 2. Descriptive statistics for T_2 LD Between Multiple Paired Hand and Digital Superimpositions

Landmark	N	Mean T_2 LD (mm)	SD	5% CL for Mean	95% CL for Mean	Minimum	Maximum	Median
PNS	64	0.68	0.44	0.57	0.79	0.08	1.94	0.56
ANS	64	0.71	0.51	0.58	0.84	0.04	2.04	0.56
A point	64	0.72	0.50	0.60	0.85	0.10	2.19	0.56
B point	64	0.76	0.55	0.62	0.89	0.11	2.42	0.61
Pogion	64	0.75	0.59	0.61	0.90	0.03	2.24	0.56
Gonion	64	0.73	0.51	0.60	0.86	0.04	3.07	0.58
U1 tip	64	0.92	0.67	0.75	1.09	0.06	3.00	0.76
U1 apex	64	0.92	0.71	0.74	1.09	0.12	3.67	0.71
U6 tip	64	0.85	0.58	0.70	0.99	0.10	2.90	0.68
U6 apex	64	0.81	0.59	0.66	0.96	0.06	3.04	0.72
L1 tip	64	0.69	0.66	0.53	0.86	0.04	3.44	0.54
L1 apex	64	0.66	0.58	0.51	0.80	0.03	3.35	0.54
L6 tip	64	0.69	0.55	0.55	0.82	0.13	3.22	0.55
L6 apex	64	0.67	0.51	0.54	0.80	0.03	2.67	0.56

Table 3. Descriptive Statistics for T_2 LD for the Repeated Hand and Digital Superimpositions

		Repeated Hand Superimpositions			Repeated Digital Superimpositions		
Landmark	N	Mean T_2 LD (mm)	SD	Median	Mean T_2 LD (mm)	SD	Median
PNS	20	0.7438	0.4276	0.7672	0.7400	0.4010	0.7552
ANS	20	0.7671	0.5191	0.6799	0.7667	0.4543	0.8096
A point	20	0.7924	0.4392	0.8245	0.7825	0.4726	0.7872
B point	20	0.8176	0.4991	0.6795	0.7447	0.6220	0.6466
Pogion	20	0.8233	0.5437	0.9370	0.8324	0.5511	0.7222
Gonion	20	0.7835	0.4683	0.6234	0.7822	0.4913	0.6503
U1 tip	20	0.9265	0.4430	1.0710	0.9092	0.5835	0.8919
U1 apex	20	0.8920	0.5701	0.7597	0.8558	0.4083	0.8481
U6 tip	20	0.9643	0.5947	0.9119	0.9502	0.5749	0.8130
U6 apex	20	0.8272	0.4579	0.7366	0.7702	0.5212	0.6948
L1 tip	20	0.7891	0.4959	0.7021	0.7357	0.5370	0.6141
L1 apex	20	0.7845	0.4260	0.6186	0.6910	0.4642	0.5102
L6 tip	20	0.7593	0.5824	0.7352	0.7814	0.4528	0.8511
L6 apex	20	0.7056	0.5958	0.5619	0.7412	0.5205	0.5748

tween multiple corresponding cephalometric landmarks between the hand and the digital superimpositions (T_2 LDs). A Friedman test was applied to examine the differences between the T_2 LDs of the repeated hand superimpositions, the repeated digital superimpositions, the hand compared to the digital superimpositions, and the digital best fit cranial base to S-N superimpositions.

RESULTS

Descriptive statistics for the T_2 LD are listed in Table 2. The upper 95% confidence limit for the mean of the T_2 LD was <1 mm for all landmarks except maxillary incisor tip and apex (both 1.09 mm). Results of the means and medians for the 20 repeated hand and digital superimpositions are listed in Table 3. The Friedman test indicated no statistically significant differences for the reproducibility of the hand and digital methods and between superimposition methods based on $P < .05$ significance for any of the landmarks tested.

Table 4 lists the descriptive statistics for the T_2 LD for the 61 samples comparing the digital best-fit and S-N methods. For all landmarks except PNS, the upper 95% confidence interval was >1 mm. Table 5 demonstrates the value for each landmark at the varying treatment lengths. The upper 95% confidence intervals for Group III (>3 years between T_1 and T_2 records) were larger (range = 1.27–3.72 mm) than those for Group I (0–2 years between T_1 and T_2 records).

DISCUSSION

The principle finding of this study is that the mean T_2 LD for the hand and digital superimpositions were not equal to zero. However, the differences were small (<1 mm) and can be considered clinically insignificant. Thus, the digital superimposition method can accu-

Table 4. Descriptive Statistics for T_2 LD for Best-fit vs S-N Superimpositions

Landmark	N	Mean T_2 LD (mm)	SD	5% CL for Mean	95% CL for Mean	Median
PNS	61	0.87	0.62	0.56	0.90	0.69
ANS	61	1.17	1.01	0.63	1.22	0.89
A point	61	1.19	1.02	0.86	1.14	0.86
B point	61	1.53	1.33	0.85	1.45	1.17
Pogion	61	1.65	1.49	0.88	1.68	1.13
Gonion	61	1.30	0.98	0.86	1.27	1.04
Gnathion	61	1.71	1.54	0.85	1.80	1.20
Menton	61	1.64	1.54	0.82	1.54	1.05

rately replicate and replace the traditional hand superimposition method for both cranial base and regional superimpositions. However, when digital best-fit cranial base was compared with computer-generated S-N superimposition, there were differences, especially with increasing time between these two digital methods.

When comparing the hand and digital superimpositions, the upper 95% confidence limit of the mean was $<$1 mm for all of the variables except for the maxillary incisor tip and apex (1.09 mm). This T_2 LD distribution for the sample is represented graphically in Figure 4. This figure illustrates a hand-traced superimposition with scatter plots of all of the T_2 digital landmark positions for all 64 subjects with the origin (marked by orthogonal lines) of the plot representing the location of the T_2 hand landmark. The differences were small and would therefore be unlikely to alter the clinical interpretation of the superimpositions.

The differences between the superimpositions are due to error derived from several sources. Many investigators have illustrated that the process of landmark identification represents the largest source of error in cephalometric analyses.[20,21] To prevent landmark identification error between the hand and digital samples, all landmarks were identified on the original radiographs from which the hand and digital tracing were generated and thus greatly reduced or eliminated this source of error. It is interesting to note that the mean repeatability error (Table 3) was not more 0.2 mm different from the T_2 LD in the superimposition study.[22]

Another source of error would be associated with superimposition. The range of error of cranial base and regional superimposition varies in the literature.[23–26] The method errors found in this study are similar to the errors found in the literature for the reproducibility of superimpositions. However, it is difficult to quantitatively compare superimposition error studies because of the many different methods used to calculate and describe the errors.[27]

Few studies have reported the accuracy of digitally produced superimpositions. Two other studies agree

Table 5. Descriptive Statistics for T_2 LD for Best-fit vs S-N Superimpositions Comparing Treatment Length

Landmark	N	Mean T_2 LD (mm)	SD	5% CL for Mean	95% CL for Mean	Median
Group I						
PNS	15	0.67	0.37	0.43	0.90	0.57
ANS	15	0.68	0.47	0.22	0.97	0.47
A point	15	0.72	0.43	0.40	0.92	0.54
B point	15	0.90	0.52	0.38	1.38	0.87
Pogion	15	0.88	0.55	0.47	1.31	0.82
Gonion	15	0.80	0.39	0.52	0.98	0.78
Gnathion	15	0.91	0.56	0.47	1.36	0.87
Menton	15	0.87	0.53	0.42	1.12	0.85
Group II						
PNS	29	0.80	0.60	0.49	1.03	0.57
ANS	29	1.05	0.87	0.50	1.50	0.79
A point	29	1.06	0.88	0.54	1.53	0.74
B point	29	1.36	1.13	0.59	1.84	1.13
Pogion	29	1.49	1.23	0.63	1.86	1.13
Gonion	29	1.23	0.90	0.76	1.42	1.04
Gnathion	29	1.56	1.29	0.67	1.86	1.21
Menton	29	1.44	1.27	0.57	1.54	0.99
Group III						
PNS	17	1.17	0.73	0.69	1.27	0.92
ANS	17	1.79	1.28	0.89	2.71	1.47
A point	17	1.82	1.32	0.82	2.68	1.54
B point	17	2.37	1.72	0.96	3.35	1.85
Pogion	17	2.60	1.96	1.03	3.68	2.06
Gonion	17	1.84	1.21	1.09	2.37	1.58
Gnathion	17	2.67	2.02	0.88	3.79	2.18
Menton	17	2.66	2.01	0.94	3.72	2.14

with the results of our study in finding that digital superimpositions produced by computer-based programs are similar to those produced by hand. One study examined the analysis of superimposition on reference lines using Dolphin Imaging version 9.[13] No custom structures were traced and the free-form superimposition feature in Dolphin Imaging was not used. The ability to superimpose with Quick Ceph 2000 (Quick Ceph Systems, Inc, San Diego, Calif) has also been examined.[12] Superimpositions were completed as described by the American Board of Orthodontics clinical exam.[5] No significant differences were found between the hand and digital superimpositions.

The T_2 LD calculations were not equal to zero when comparing the digital best-fit cranial base superimposition to the S-N superimposition. However, when considering a 95% confidence interval, the interval is either $<$1 or includes 1 for all landmarks under consideration. Of interest is the evaluation of the treatment length groups. All landmarks for Group I (treatment time 0–2 years) have a 95% confidence interval that was $<$1 or includes 1. Group II (treatment time 2–3 years) also had all landmarks with a 95% confidence interval that includes or is $<$1. However, Group III (treatment time 3 or more years) have landmarks

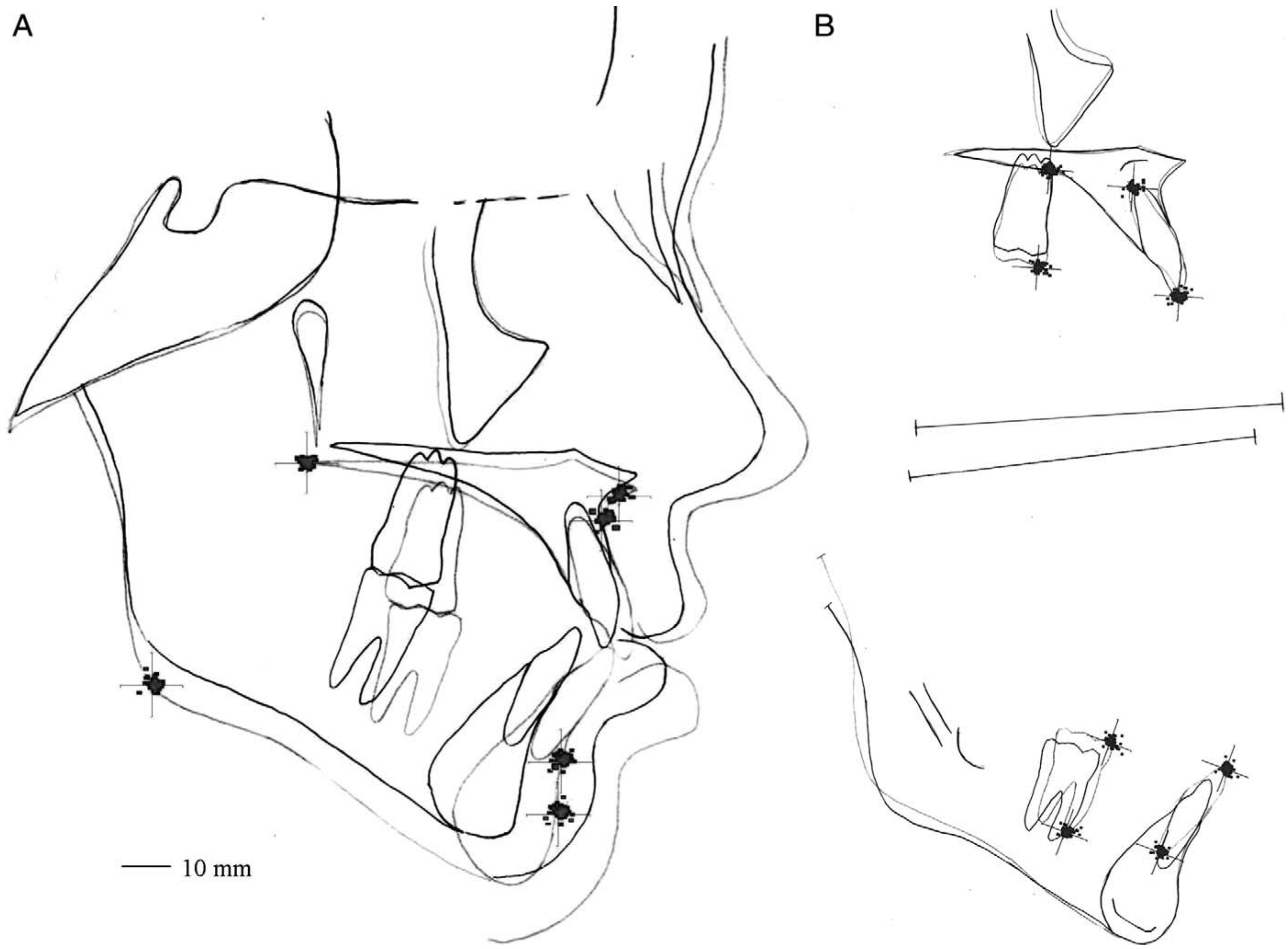

Figure 4. Scatterplots for the T_2 LD for the repeated hand and digital superimpositions. Landmarks representing the deviation of the digital and hand superimpositions from zero for each of the 64 patients in the (A) cranial base, (B) maxillary, and (C) mandibular region.

where the 95% confidence interval is >1 (Table 5). This difference can be attributed to method error. In growing patients there is change in the frontonasal area of the cranial base. This growth may account for the discrepancy that was noticed in subjects whose treatment time lasted longer than 3 years. Because growth is occurring in the frontonasal area, and the S-N alignment is based on the sella and nasion landmarks, the discrepancy that is occurring may be attributed to the nasion landmark. The best-fit cranial base superimposition is based on aligning three relatively stable landmarks in the cranial base; however, these landmarks do not include nasion.

Although Dolphin Imaging version 10 is a powerful cephalometric analysis program, the software does not support the superimposition of custom structures for regional superimpositions. This feature is only currently available for cranial base superimpositions. We overcame this limitation by a tedious process for this research, but it is not practical for the orthodontic practitioner. Although three-dimensional cephalometry will become increasingly important, it is likely that two-dimensional superimpositions will still be used effectively by the practicing orthodontists.

CONCLUSIONS

- There are no differences between cranial base and regional superimpositions produced by Dolphin Imaging version 10 and those completed by hand when using the described methods.
- Given that the differences were within measurement error, accurate interpretations of growth and changes produced by orthodontic therapy are possible.
- Additionally, there is little difference of clinical relevance between best-fit cranial base and S-N superimpositions; however, as treatment time exceeds 3 years in growing patients the S-N superimposition may provide a less accurate representation of growth in growing patients.

- This research provides support for transition from hand to digital superimposition methods.

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