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A comparison of manual traced images and corresponding scanned radiographs digitally traced

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SUMMARY The aim of this study was to compare the accuracy of cephalometric measurements made with digital tracing software (FACAD®) with equivalent hand-traced measurements, and to evaluate the reproducibility of each method.

Pre- and post-surgical lateral cephalographs of 30 adult patients (12 males and 18 females, median age = 25 years, standard deviation = 8.7) who had undergone orthognathic treatment were scanned into a computer. One operator identified 25 landmarks digitally on the computer display and manually on acetate paper. Measurements on the 60 radiographs were duplicated, and measurement error of each method was determined with interclass correlation. A paired *t*-test was used to detect differences between the manual and digital methods.

Overall, greater variability in digital cephalometric measurements was found. Differences in Gn′, Li, Si, and Ii–Li measurements between the two methods were statistically ($P < 0.05$), but not clinically significant.

The findings indicate that the results of the two investigated tracing methods are similar and that digital tracing with FACAD® is reliable and can be used routinely.

Introduction

Cephalometric radiography is an important tool in the diagnosis and treatment of dental malocclusions and underlying skeletal discrepancies. With serial cephalometric radiographs, it is possible to study and predict growth, and orthodontic treatment effects can be evaluated from changes between pre- and post-treatment measurements. Cephalometric analysis can also be used to predict surgical outcome, which is important in treating dentofacial deformities (Mills, 1970; Vig and Ellis, 1990).

Traditionally, cephalometric images have been analysed by manually tracing radiographs, which is time consuming and has the disadvantage of being subject to random and systematic error. Cephalometric analysis is subject to error from multiple sources, which include landmark identification, radiographic exposure and development, and technical measurements. Most errors occur in landmark identification, which is based on observer experience, landmark definition, and image density and sharpness (Baumrind and Frantz, 1971; Broch *et al.*, 1981; Cohen, 1984; Cooke and Wei, 1991).

With the development of computer technology, digital tracing has become possible. Two techniques are commonly used to produce digital tracings of radiographs. The first uses a charge-coupled device sensor (direct digitization). The digital image is produced instantaneously, without additional processing. The second method uses storage phosphor plates to capture the image (indirect digitization). The plates store the radiation energy generated by the radiographic apparatus in a latent image which is then transferred by a red laser scanner to the computer in digital format. The computer images from either method consist of a collection of pixels, whose size and colour values produce different colours and shades of grey. The final size of the image is determined by the number and colour values of its pixels (Santoro *et al.*, 2006). With both methods, the landmarks are located manually, and thus, digitization of the traced image increases the risk of error. Furthermore, the quality of digitized images, which is affected by their resolution, pixel size, shades of grey, and compression format, will also affect accuracy. Several studies have reported that direct digitization of radiographs is more reproducible and accurate than indirect digitization, although the difference between the methods is small and statistically significant in only a few instances (Houston *et al.*, 1986; Sandler, 1988; Turner and Weerakone, 2001; Power *et al.*, 2005).

Use of digital radiographic systems is gaining in popularity and offers several advantages over conventional cephalograms; measurements can be performed quickly, treatment plans can be determined easily, chemical and associated environmental hazards are eliminated, the images are easy to store, and communication between providers is facilitated. In addition, rapid superimposition of serial radiographs and cost-efficient duplication of radiographs are possible.

Various computer programs have been developed in recent years for cephalometric analysis. Previous studies have evaluated systems such as the Dentofacial Planner, the Dolphin Imaging, and the Quick Ceph®. The common conclusion of these studies was that although differences between computer prediction and manual tracing are not in some cases statistically significant, they can be clinically significant in others. Some landmark locations and measurements (SNA, Wits, E-plane, soft tissue point B, gonion, points articulare) were more reproducible with manual tracing while other points (e.g. the apex of the upper incisor root) were easier to locate with digital tracing (Gerbo *et al.*, 1997; Csaszar *et al.*, 1994; Loh *et al.*, 2001; Turner and Weerakone, 2001; Ferreira and Telles, 2002; Loh and Yow, 2002; Ongkosuwito *et al.*, 2002; Cousley *et al.*, 2003; Chen *et al.*, 2004a,b; Gossett *et al.*, 2005; Power *et al.*, 2005; Bruntz *et al.*, 2006). Few studies have compared soft tissue angular and linear measurements, mostly because analysis of these measurement reproducibility is more challenging than landmark studies (Ongkosuwito *et al.*, 2002; Power *et al.*, 2005; Bruntz *et al.*, 2006).

FACAD® (Ilexis AB, Linköping, Sweden) is a cephalometric digitization program used for cephalometric analysis and to predict hard and soft tissue changes in orthognathic surgery. No published data on the accuracy and the reproducibility of cephalometric analysis using this program have been found in the literature.

The aim of this study was to compare the accuracy of cephalogram tracings made manually with tracings made using the FACAD® program, and to evaluate the reproducibility of each method.

Materials and methods

The study was registered according to the Swedish Law of Personal Integrity (PUL).

The radiographs of 30 adult patients (12 males and 18 females) who had undergone orthognathic treatment with vertical ramus osteotomies due to mandibular prognathism at the Department of Maxillofacial Surgery and Jaw Orthopaedics at Malmö University Hospital, Sweden, were randomly selected. The age of the patients at the time of surgery ranged from 17 to 46 years [median = 25 years, standard deviation (SD) = 8.7]. All patients underwent pre- and post-surgical fixed orthodontic treatment and were surgically stabilized with intermaxillary fixation. The cephalograms had been taken with the patient in an upright standing position, adopting a natural position of the head, and keeping the teeth in centric occlusion with the lips relaxed. The radiographs were reproduced with a linear enlargement of 9 per cent. Two cephalometric radiographs of each patient were used: a pre-surgical cephalograph taken 2–8 months (median 3.5 months) before surgery and a post-surgical cephalograph taken 12–19 months (median 14.6 months) after surgery. In total, 60 radiographs were analysed. To optimize landmark identification, the same operator (JN) undertook all manual and digital tracings in a darkened room. Hard and soft tissue measurements and measurements of angles in the *x*-axis were assessed. No more than 10 radiographs were traced regardless of the method at any one time to avoid operator fatigue.

Manual tracing

Acetate paper (3M Unitek GmbH, Seefeld, Germany) was taped over each radiograph, and landmarks commonly used to assess dentofacial relationships were identified with a 4H pencil using the Frankfort plane as the horizontal reference plane. The midpoint of bilateral structures and double images was chosen by construction. Measurements were obtained using a ruler and protractor. Table 1 lists the cephalometric landmark and measurement definitions used in both methods of tracing. Cephalometric analysis comprised five skeletal and two dental measurements together with measurements of seven soft tissue parameters

Table 1 Cephalometric landmark and measurement definitions used in the manual and digital cephalometric analyses.

Landmark	Definition
SNA	Angle between points S-N-A
SNB	Angle between points S-N-B
ANB	Angle between points A-N-B
SNPg	Angle between points S-N-Pg
G	Glabella: most anterior point on the forehead
S	Sella: the centre of sella turcica
N	Nasion: the most anterior point of the frontonasal suture
x-axis	The horizontal plane at a 7 degree slope to the Sella-Nasion (SN) plane
y-axis	The plane that passes through Sella perpendicular to the *x*-axis
Cm	Columella point: the midpoint of the columella of the nose
Sn	Subnasale: the point at which the columella (nasal septum) merges with the upper lip in the midsagittal plane
A	Point A: the innermost point on the contour of the maxilla between anterior nasal spine and the incisor
Ls	Labrale superius: the most anterior point of the upper lip
Is	Incision superior incisal: the midpoint of the incisal edge of the most prominent maxillary central incisor
Ii	Incision inferior: the midpoint of the incisal edge of the most prominent mandibular central incisor
Li	Labrale inferius: the most anterior point of the lower lip
Si	Mentolabial sulcus: the point of greatest concavity in the midline between Li and chin (Pg')
B	Point B: most posterior point in the concavity along the anterior border of the symphysis
Pg	Pogonion: the most anterior point on the midsagittal symphysis
Pg'	Soft tissue pogonion: the most anterior point of the soft tissue chin
Gn	Gnathion: point midway between pogonion and menton on outline of symphysis
Gn'	Soft tissue gnathion: the most anteroinferior point of the soft tissue chin
Me	Menton: the most inferior point of the chin on the outline of the symphysis
Me'	Soft tissue menton: the lowest point on the contour of the soft tissue chin
Cm-Sn-Ls	Nasolabial angle: the angle made by the points Cm-Sn-Ls
G-Sn-Pg'	Facial convexity: the angle made by the points G-Sn-Pg'
Ii–Li ⌉ B–Si ú|⇒ P–Pg'⌋	Soft tissue thickness: the distance from point Ii to Li, from B to Si, and from P to Pg'

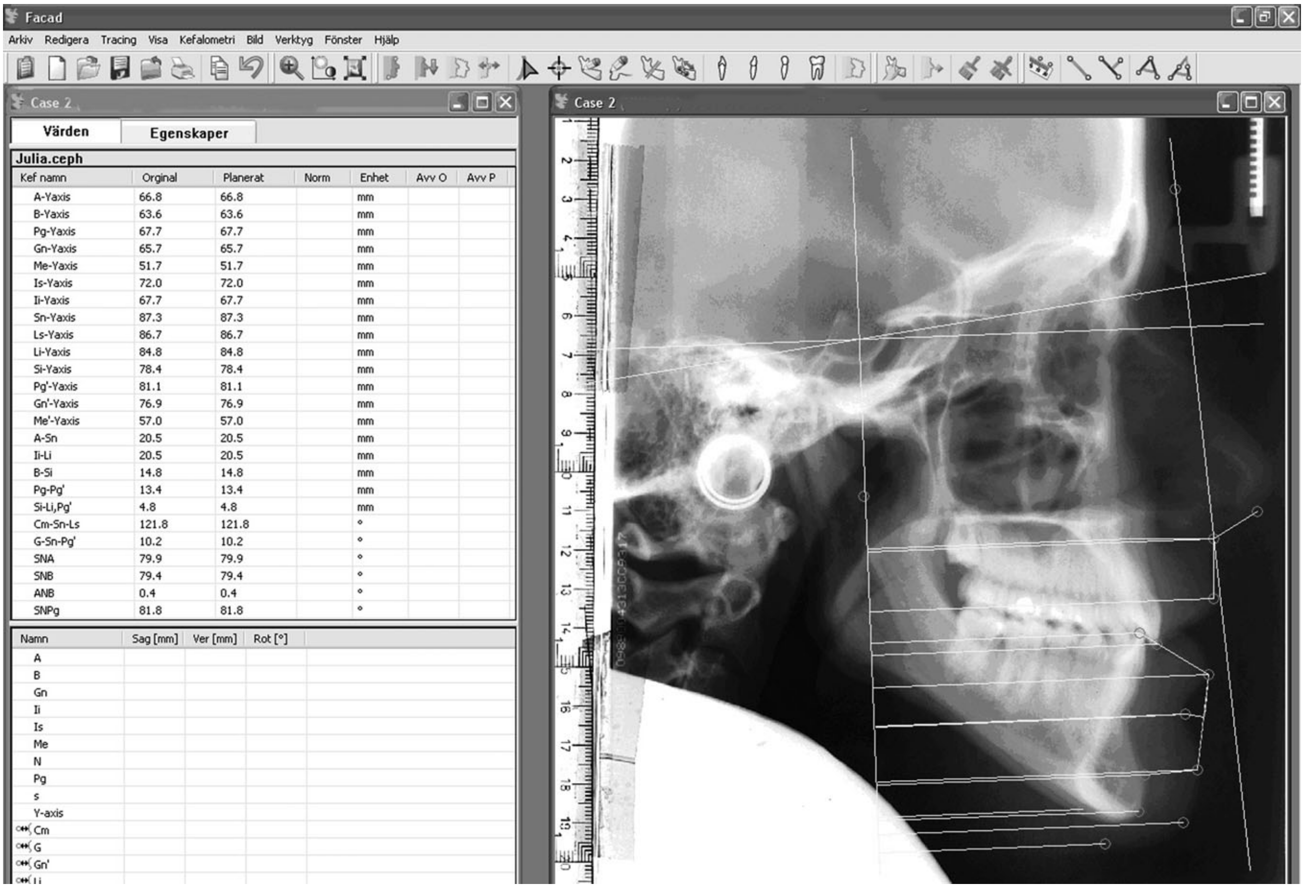

Figure 1 The dental, skeletal, and soft tissue landmarks used in this study.

and six angles (Figure 1). These were calculated and rounded to the nearest 0.5 mm/degree.

Digital tracing

The cephalograms were digitized at 300 dpi (dots per inch) with an 8 bit grey scale, using Umax Mirage II SE, a flatbed scanner (Techville Inc., Dallas, Texas, USA; optical resolution maximum: ×800 1600 dpi, maximum grey scale output 8 bits per pixel) linked to a computer (300 MHz). The images were imported into Adobe® Photoshop 5.01®, saved as JPEG files on compression rate 8 (1 is full compression and 10 no compression), and then transferred into FACAD® (version 3.0.0.8) in accordance with the manufacturer's instructions, where the images were enhanced with an on-screen digitizer set at an average resolution of 96 dpi. Once enhancement was complete, the dentofacial relationships and landmarks that had been identified on the manual tracing were determined using tools from FACAD®'s analysis toolbar. When point identification was difficult, the image was manipulated and further enhanced. Measurements obtained from the digital tracing were rounded to the nearest 0.1 mm/degree.

Repeat tracings

To determine intraoperator error and the reproducibility for the manual and digital methods, all 60 radiographs were retraced manually and digitally by the same operator (JN) after a 1 month interval. To avoid operator fatigue, no more than 10 radiographs were digitized at any one time. The same scanned image was analysed on both occasions to avoid errors in scanning and orientation on the Frankfort horizontal, which would interfere with reliability and reproducibility calculations of the cephalometric measurements.

Statistical analysis

Data were analysed with the Statistical Package for Social Sciences (SPSS Inc., Chicago, Illinois, USA), version 13.0. The mean and SD of the differences in landmark location between the two methods and between the first and second measurement for each method were calculated. Intraoperator error was determined using Pearson's correlation coefficient (r) to measure standardized covariance of the duplicate measurements. These levels were used to interpret correlation: $r \geq 0.8$ = good; $0.5 \leq r \leq 0.80$ = moderate; $r < 0.5$ = poor. Systematic error was calculated by paired measurement comparisons with a *t*-test. The level of statistical significance was set at $P \leq 0.05$.

Results

Table 2 shows the reproducibility of duplicate measurements by a single operator and the means of each sample pair for both methods. Differences between the first and second tracings varied between −0.49 and 0.34 (mm or degrees, according to measurement) for digital tracings and between −0.13 and 0.46 for manual tracing. This variability in the correlation coefficients (r) is shown in Table 3. For manual tracing, correlation coefficients of all variables were above 0.95, and for the digital method, the r of eight measurements was below 0.95 while the r of the remaining values was mainly good ($r \geq 0.8$). The correlation coefficients for Ii–Li, B–Si, and Si to Li–Pg' were lower than those for the other measurements but only for digital tracing. Overall, as indicated by the correlation coefficients, reproducibility was good and intraoperator error was small.

The differences between the measurements with the manual and digital methods are shown in Table 4. In general, magnitudes of the differences between sample means were small, with differences below 1 unit (mm or degree) for all variables. Statistically significant differences between the methods were detected for Gn, Li, Si, and Ii–Li.

Discussion

The accuracy of cephalometric analysis is important for treatment planning so that the clinician can accurately assess

Table 2 Differences and standard deviations (SD) in duplicate measurements for manual and digital tracing.

Variable	Manual tracing (ΔM1–M2), $n=60$*			Digital tracing (ΔD1–D2), $n=60$†		
		95% CI‡			95% CI‡	
	Difference (mean ± SD)	Upper bound	Lower bound	Difference (mean ± SD)	Upper bound	Lower bound
Skeletal (mm)						
A	0.12 ± 0.64	0.29	−0.04	0.35 ± 1.54	0.75	−0.05
B	0.36 ± 0.65	0.52	0.19	0.19 ± 1.71	0.63	−0.25
Pg	0.46 ± 0.77	0.66	0.26	0.31 ± 1.49	0.69	−0.07
Gn	0.31 ± 0.96	0.56	0.06	0.17 ± 1.77	0.64	−0.28
Me	0.12 ± 1.28	0.45	−0.21	−0.49 ± 2.32	0.10	−1.98
Dental (mm)						
Is	0.25 ± 0.79	0.45	0.04	0.16 ± 1.45	0.53	−0.22
Ii	0.43 ± 0.60	0.5	0.28	0.29 ± 1.57	0.70	−0.11
Soft tissue (mm)						
Sn	0.19 ± 0.68	0.37	0.01	0.34 ± 1.58	0.75	−0.06
Pg'	0.41 ± 0.78	0.48	0.10	−0.29 ± 2.69	0.47	−0.98
Gn'	0.28 ± 0.91	0.52	0.04	−0.49 ± 2.02	0.03	−1.01
Me	0.17 ± 1.37	0.52	−0.18	−0.16 ± 1.55	0.24	−0.56
Ls	0.22 ± 0.72	0.40	0.03	0.20 ± 1.84	0.67	−0.28
Li	0.22 ± 0.71	0.41	0.04	−0.26 ± 1.68	0.18	−0.68
Si	0.29 ± 0.73	0.48	0.10	−0.38 ± 1.38	−0.03	−0.74
Soft tissue thickness (mm)						
Ii–Li	0.03 ± 0.60	0.19	−0.12	0.13 ± 1.08	0.41	−0.15
B–Si	0.23 ± 0.60	0.38	0.06	0.28 ± 0.99	0.54	0.02
Pg'–Pg	0.28 ± 0.60	0.43	0.12	0.05 ± 1.06	0.32	−0.28
Si to Li–Pg'	0.04 ± 0.51	0.17	−0.09	0.12 ± 0.77	0.31	−0.08
Sn–A	−0.13 ± 2.32	0.47	−0.73	−0.32 ± 4.76	0.90	−1.55
Angular (degree)						
G-Sn-Pg'	0.09 ± 0.82	0.32	−0.11	0.05 ± 1.33	0.39	−0.29
Cm-Sn-Ls	0.30 ± 1.42	0.66	−0.06	0.01 ± 1.76	0.47	−0.44
SNA	−0.02 ± 0.77	0.17	−0.22	0.15 ± 1.77	0.61	−0.31
SNB	0.03 ± 0.56	0.17	−0.11	−0.77 ± 1.38	0.28	−0.43
ANB	−0.01 ± 0.70	0.16	−0.19	0.04 ± 1.06	0.31	−0.23
SNPg	−0.08 ± 0.56	0.06	−0.23	0.17 ± 1.19	0.47	−0.13

*(ΔM1–M2): the difference between the first and second manual measurement.
†(D1–D2): the difference between the first and second digital measurements. Negative values: negative mean difference. Positive values: positive mean difference.
‡95% confidence interval (CI) of the difference.

Table 3 Correlation for manual and digital tracing.

Variable	Correlation coefficient	
	Manual tracing, $n=60$	Digital tracing, $n=60$
Skeletal (mm)		
A	0.99	0.97
B	0.99	0.98
Pg	0.99	0.98
Gn	0.99	0.99
Me	0.99	0.98
Dental (mm)		
Is	0.99	0.98
Ii	0.99	0.98
Soft tissue (mm)		
Sn	0.99	0.97
Pg’	0.99	0.95
Gn’	0.99	0.98
Me	0.99	0.97
Ls	0.99	0.98
Li	0.99	0.98
Si	0.97	0.98
Soft tissue thickness (mm)		
Ii–Li	0.97	0.87
B–Si	0.95	0.87
Pg’–Pg	0.99	0.91
Si to Li–Pg’	0.95	0.88
Sn–A	0.98	0.92
Angular (degree)		
G–Sn–Pg’	0.98	0.91
Cm–Sn–Ls	0.99	0.99
SNA	0.98	0.89
SNB	0.99	0.95
ANB	0.97	0.95
SNPg	0.99	0.92

Pearson’s correlation coefficient (r): $r \geq 0.8$ = good; $0.5 \leq r \leq 0.80$ = moderate; $r < 0.5$ = poor.

various treatment options and provide the patient with a more realistic image of treatment outcome. Rapid advances in computer science have led to the wide application of computers in cephalometry. The focus of interest in this study was therefore to compare the accuracy of lateral cephalograms traced manually and with the FACAD® program.

Landmark identification is greatly affected by operator experience, which might be as important as the tracing method itself. Because interoperator error has in general been found to be greater than intraoperator error (Sayinsu *et al.*, 2007), all measurements in this study were carried out by one examiner to minimize error.

Intraoperator error in hard and soft tissue landmark and angular measurements was assessed on the x-axis on manual and digital tracings of radiographs by determining reproducibility with a test–retest method. Error analysis (Table 3) of the manual tracings showed a high correlation between duplicate measurements: the operator had no difficulty in correctly reproducing measurements on traditional films, and the landmarks were easily identifiable. For digital tracings, low correlation coefficients were found for Ii–Li, B–Si, and Si to Li–Pg’ measurements. The results

Table 4 Differences between sample pair means of measurements made on manual and digital tracings.

Variable	Difference (mean ± standard error)	*P* value (*t*-test)
Skeletal (mm)		
A	0.16 ± 0.19	0.426
B	0.17 ± 0.23	0.468
Pg	−0.17 ± 0.21	0.418
Gn	−0.17 ± 0.28	0.541
Me	0.44 ± 0.27	0.105
Dental (mm)		
Is	−0.09 ± 1.83	0.594
Ii	0.20 ± 0.20	0.324
Soft tissue (mm)		
Sn	0.18 ± 0.21	0.376
Pg’	−0.39 ± 0.24	0.116
Gn’	0.63 ± 0.23	0.007**
Me	−0.29 ± 0.25	0.254
Ls	0.01 ± 0.21	0.943
Li	−0.51 ± 0.21	0.017**
Si	0.67 ± 0.20	0.001***
Soft tissue thickness (mm)		
Ii–Li	0.09 ± 0.17	0.058*
B–Si	−0.05 ± 0.14	0.698
Pg’–Pg	−0.23 ± 0.16	0.179
Si to Li–Pg’	−0.07 ± 0.12	0.518
Sn–A	−0.35 ± 0.34	0.306
Angular (degree)		
G–Sn–Pg’	0.03 ± 0.20	0.860
Cm–Sn–Ls	−0.35 ± 0.29	0.243
SNA	0.16 ± 0.21	0.462
SNB	0.11 ± 0.19	0.578
ANB	0.05 ± 0.14	0.706
SNPg	−0.25 ± 0.16	0.114

Negative values: negative mean difference. Positive values: positive mean difference.
$^*P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$.

indicate that the reproducibility of duplicate measurements also appears to be slightly better with the manual than with the digital method since larger differences were observed between the duplicate digital tracings than between the manual tracings (Table 2). Other authors have also found greater errors in landmark reproducibility with digital tracing than with manual tracing, but because the magnitude of differences in duplicate measurements were small with both methods, the main conclusions were that the differences were clinically significant (Cooke and Wei, 1991; Chen *et al.*, 2000; Loh *et al.*, 2001; Gossett *et al.*, 2005; Santoro *et al.*, 2006). Greater error with the digital technique can result from poor quality analogue cephalometric radiographs that often appear even poorer on screen. Other possible explanations for greater errors with the digital method can be: using digital photographs with unknown format and lower quality parameters (Oliver, 1991), unknown grey shades (Macrì and Wenzel, 1993), or unknown parameters (Nimkarn and Miles, 1995). Image quality of a cephalogram scanned in standard resolution (300 dpi) has been reported to be comparable with analogue cephalograms and that high resolution (600 dpi) did not show better results (Ongkosuwito *et al.*, 2002). In the present study, radiographs in standard resolution with an 8 bit grey scale were used. Grey scale is another important factor since the identification of landmarks is based on evaluation of grey shades. Less than a 7 bit grey scale may lead to unreliable decisions on reproducibility of measurements (Thijssen, 1993). The compression technique could also affect the grey scale or the number of pixels. In this study, JPEG format was used, which has been shown by previous authors (MacMahon *et al.*, 1991; Goldberg *et al.*, 1994) not to significantly affect the diagnostic quality of the image when standard compression settings are used.

The direct digital cephalogram can totally eliminate the need for scanning the traditional radiographic film which not only requires an additional time-consuming step but also can introduce magnification errors (Santoro *et al.*, 2006). Recently, the digital storage phosphor plate has been developed which has demonstrated improved subjective image quality than traditional cephalometric images (Gijbels *et al.*, 2001; Santoro *et al.*, 2006). In comparison with the traditional screen–film system, a substantial reduction in radiation exposure could be achieved without detrimental effects on the determination of the cephalometric landmarks (Seki and Okano, 1993).

Comparison of the means of the measurements of the cephalometric landmarks and angles on the *x*-axis on the duplicate manual tracings with those on the duplicate digital tracings (Table 3) showed that the accuracy of dental and skeletal measurements was high between the two methods. This is in agreement with several other studies (Gerbo *et al.*, 1997; Turner and Weerakone, 2001; Santoro *et al.*, 2006).

The statistically significant between-method differences for four of the 25 cephalometric variables (Gn', Li, Si, and Ii–Li) were within 1 standard error ($P<0.05$). Most of the landmarks that tended to be less reliable were for the soft tissue points, which is similar to Nimkam and Miles (2005) who found Si and E-plane to be the measurements with the least accuracy in the digital method.

Conclusion

Digital tracing with FACAD® is sufficient for clinical purposes and comparable with manual cephalometric tracings.

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