The validity of computer assisted system for lateral cephalometric analysis in comparison to conventional method. I.Viewbox Imaging Software

Masoud Davoudian

Abstract

Introduction: Cephalometric radiographs have become an indispensable tool in the orthognathic setting. Traditionally, cephalometric images have been analyzed by manually tracing the radiograph, which was time-consuming. The development of computer technology has made digital tracing possible. The purpose of this study was to examine and compare the reliability and reproducibility of digitization using Viewbox imaging software (version 3.0) with traditional manual technique.

Materials and methods: The sample consisted of cephalograms from 30 randomly selected patients after orthodontic treatment. Twenty one cephalometric measurements calculated by 1 operator, both manually and with digital tracing software. Measurement error was assessed for each method by duplicating measurements of 15 randomly selected radiographs and by using Pearson's coefficient of determination. A paired t-test was used to detect differences between the manual and the digital method.

Results: An overall greater variability in the digital cephalometric measurements was found. Differences between the two methods for saddle angle, gonial angle, nasolabial angle and upper lip to E line were statistically significant ($P<0.05$), but the last one showed a mean difference lower than two units.

Conclusions: The two tracing methods provide accurate and similar clinical results except for some measurements, especially nasolabial angle; therefore, version 3.0 of this digital cephalometric software can be reliably chosen as a routine diagnostic tool with knowledge of its limited errors.

Key words: Accuracy, conventional tracing, cephalometery, software

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Cephalometric radiography is a vital clinical tool in orthodontics for evaluation of the craniofacial complex, determination of morphology and growth, diagnosis of anomalies, forecasting future relationships, planning treatment, and evaluating the results of growth and the effects of treatment.[1] Cephalometrics remains the only practical quantitative method that permits the investigation and examination of the spatial relationships between both cranial and dental structures. The lateral cephalogram provides information regarding skeletal, dental, and soft tissue morphology as well as relationships between these structures.[2]

[d] Assistant Professor, Department of Orthodontics, School of Dentistry, Kerman University, Kerman, Iran.

Corresponding author:
Dr. Masoud Davoudian
E-mail: masoud_davoudian@yahoo.com

The rapid evolution of digital radiographic systems and digital tracing software have an impact on cephalometrics, slowly replacing traditional hand-tracing methods on hard copies of radiographic films.[3] Manually tracing the radiograph, in addition to being time-consuming, has the disadvantage of being open to random and systematic error when locating landmarks[4].

Digital tracing is either by direct digitization of a previously traced image, or by indirect digitization of the image displayed on the monitor. In both methods, the points are located manually, and so human errors in landmark location remain, and digitization of the traced image actually increases the risk of error. The advantages of digitization include:

Manipulation of the image (enlargement and enhancement), allowing for more accurate

assessment of poorly defined areas (only indirect digitization).
Speed and choice of analysis.
Rapid superimposition of serial radiographs.
Storage and retrieval of multiple records.
Easy comparison of data in studies.[5]
Viewbox imaging software has a low price amongst other softwares and its free unregistered copy is available online that can be used practically but with a little delays between some processes. A search of the literature found no research on the accuracy of the dento-skeletal cephalometric analysis produced by any versions of this software.
The purpose of this study was first to assess the reliability of this imaging software and manual method, and to investigate the reproducibility of software method compared with the manual tracing of the same radiographs.

Materials and Methods
Thirty randomly selected cephalometric radiographs of discharged patients from an orthodontic office with an average age of 11 years and 8 months (range:8.3-14.7 years,11 males and 19 females) were selected according to the following criteria:
Inclusion criteria:
Patients biting in maximum intercostals position.
Acceptable contrast of hard and soft tissues
Exclusion criteria:
TMJ disorders
Cleft lip and/or palate
All of these radiographs were taken by analogue machines. The selected radiographs were of varying qualities and thus ease of landmark identification differed substantially amongst the group. To allow for optimal landmark identification both manually and digitally, all tracings and digitizations were performed in a darkened room and located by the same operator (author).

Manual tracing
Each radiograph was taped to a lightbox (with LED light). A sheet of semi-matt, fine grade acetate paper was then taped over the radiograph, and landmarks were located, using a sharp HB pencil. Twenty one measurements were used as shown in table I. Angular measurements were rounded to the nearest 0.5 using a Perspex protractor (3M Unitek TM Cephalometric Protractor) and linear measurements were measured and rounded to the nearest 0.5 mm using a Perspex ruler.

Digital tracing
The cephalograms were scanned in using a flatbed scanner (HP Scanjet G4050) at 200 DPI, linked to a Dell Computer (Dell workstation PWS530 running on Microsoft Windows XP). Radiographic images were subsequently imported separately into the software program (Viewbox imaging software, version 3.0). The landmarks were identified on a 19-in. color monitor at a screen resolution of 1280 × 960 pixels via a mouse (circular cursor). In this software scale option did not work correctly so for calibrating radiographs, the real height of each radiograph was entered in the image resize panel (Fig 1). Manipulation and enhancement was used to assist in point identification when difficulty was encountered. (Fig 2) Once digitization was complete, the custom analysis previously recorded including measurements as shown in table I was selected from the analysis toolbar, and then measurements rounded manually to the nearest 0.5 during data collection.

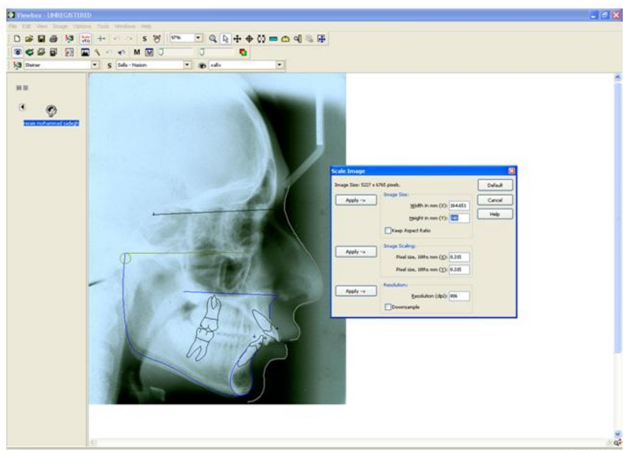

Fig 1: Calibrating of radiograph

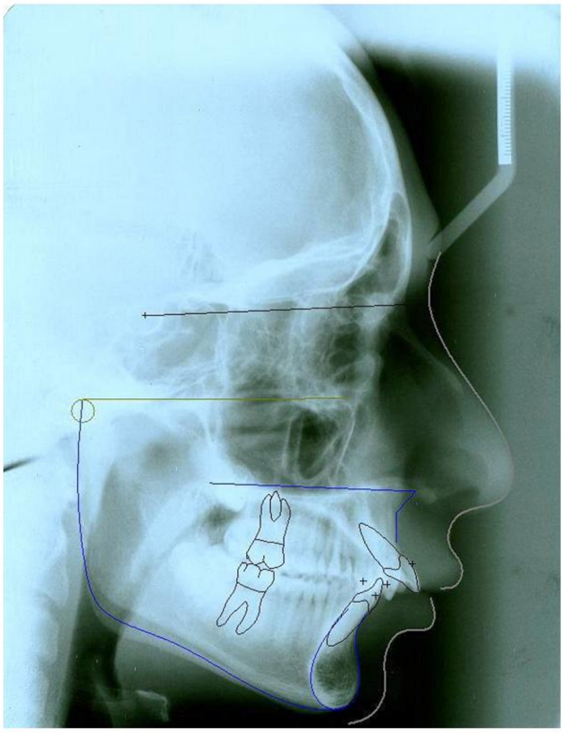

Fig 2: Digitized radiograph

Repeat tracings

In order to determine operator reliability and reproducibility, and to establish reproducibility of both methods, 15 randomly selected radiographs were retraced by both methods, with a two-week interval between each recording. To avoid any errors that could be encountered in the digital methods when capturing the image, the same saved image was digitized on both the first and second occasions.

Statistical analysis

Examiner error (reliability) was evaluated by duplicating tracings of 15 radiographs (performed a minimum of 2 weeks apart) and using the Pearson correlation coefficient as a measure of standardized covariance. (Table II) Systematic error (reproducibility) was calculated by paired measurement comparisons of the 30 digital and manual tracings by using paired t-tests based on equality of variance between the 2 samples. A P-value of 0.05 was used as the minimal level of statistical significance.[3,6] (Table III)

Accuracy is difficult to ascertain in cephalometrics, that is because of modes of image capture and measurement techniques. If the manually traced conventional cephalogram is used as a gold standard, then comparison can be made among the groups so in this study the mean difference between the manual tracings as gold standard and the digital tracings was determined for each parameter. Because a difference of 2° or 2 mm in means does not appear to cause a clinical difference in classification or treatment decisions in most of the parameters,[3,7] any difference less than 2 units was considered to be clinically acceptable.

Table I. Selected cephalometric measurements.

Measurement	Unit	Definition
SNA	o	Angle between SN and NA
SNB	o	Angle between SN and NB
ANB	o	Angle between NA and NB
Wits	mm	Linear distance between Points A and B parallel to occlusal plane
A-N.perp	mm	Linear distance between Point A and perpendicular line from point N to Frankfort horizontal plane(Po-Or)*
Pg- N.perp	o	Linear distance between Point Pog and perpendicular line from point N to Frankfort horizontal plane
Saddle Angle	o	Angle between SN and NAr
Articular Angle	o	Angle between NAr and ArGo
Gonial Angle	o	Angle between ArGo and MeGo
Sum of posterior Angles	o	Sum of three above angles
PP-MeGo	o	Angle between ANA-PNS and MeGo
SN-MeGo	o	Angle between SN and MeGo
S-Go	mm	Linear distance between Points S and Go
N-Me	mm	Linear distance between Points N and Me
S-Go/N-Me	ratio	Linear distance S-Go over linear distance N-Me
L1-MeGo	o	Angle between Me-Go and line joining crown tip and apex of lower incisor
U1-SN	o	Angle between SN and line joining crown tip and apex of upper incisor
U1-L1	o	Internal angle between upper and lower incisors
Nasolabial Angle	o	Angle between a line tangent to the base of the nose and a line tangent to the upper lip
Upper lip to E plane	mm	Linear distance between Point Ls and Pn'-Pg'
Lower lip to E plane	mm	Linear distance between Point Li and Pn'-Pg'

*For more accurate identification in this study we used Co point instead of Po.8

Table II. Differences in Paired measurements for digital and conventional radiographs (reliablity).

Measurement	Manual method			Digital method		
	Difference Mean	Difference SD	Coefficient of determination	Difference Mean	Difference SD	Coefficient of determination
SNA	0.00	0.66	0.98	0.07	1.62	0.88
SNB	0.67	0.70	0.98	0.07	1.03	0.96
ANB	-0.07	0.80	0.77	-0.27	1.28	0.74
Wits	-0.47	1.30	0.83	-0.53	2.30	0.76
A-N.perp	0.47	1.41	0.87	-0.47	2.53	0.64
Pg- N.perp	0.53	3.02	0.87	-2.00†	4.74	0.71
Saddle Angle	1.27	3.62	0.79	2.00†	2.01	0.96
Articular Angle	-1.53	3.44	0.87	-0.27	2.28	0.92
Gonial Angle	0.33	1.35	0.96	0.33	2.02	0.88
Sum of posterior Angles	0.07	1.28	0.96	0.27	1.28	0.96
PP-MeGo	0.07	1.03	0.98	-0.73	1.91	0.94
SN-MeGo	-0.27	0.80	0.98	-0.13	1.25	0.98
S-Go	0.53	1.27	0.72	1.53	7.10	0.64
N-Me	-0.47	1.06	0.98	2.33†	10.53	0.53
S-Go/N-Me	0.27	1.07	0.87	-0.13	1.64	0.94
L1-MeGo	-0.20	1.37	0.96	-2.13†	3.09	0.96
U1-SN	-0.13	2.07	0.96	1.07	3.59	0.90
U1-L1	0.53	2.30	0.96	1.53	4.09	0.90
Nasolabial Angle	-2.8†	6.52	0.28*	4.00†	5.48	0.28*
Upper lip to E plane	-0.13	0.52	0.92	0.40	0.99	0.67
Lower lip to E plane	0.07	1.10	0.72	0.13	1.41	0.37*

*Low correlation between repeated measures.

†Differences of mean measurements exceeding 2 units(clinically significant).

Table III. Measurement differences between digital and manual tracings.

Measurement	Difference		P value
	Mean (Digital – Manual)	SE	
SNA(°)	0.17	0.99	0.88
SNB(°)	0.4	0.98.	0.69
ANB(°)	-0.4	0.42	0.35
Wits(mm)	0.23	0.92	0.8
A-N.perp(mm)	-0.23	0.62	0.71
Pg- N.perp(mm)	-0.6	1.38	0.67*
Saddle Angle(°)	-2.87†	1.23	0.03
Articular Angle(°)	-1.57	1.46	0.29
Gonial Angle(°)	3.27†	0.59	0.00*
Sum of posterior Angles(°)	-1.17	1.02	0.26
PP-MeGo(°)	-0.83	0.9	0.37
SN-MeGo(°)	0.67	1.08	0.54
S-Go(mm)	2.47†	1.43	0.1
N-Me(mm)	1.5	1.3	0.26
S-Go/N-Me(%)	1.3	0.84	0.14
L1-MeGo(°)	-0.57	1.17	0.63
U1-SN(°)	-0.43	2.07	0.84
U1-L1(°)	-0.67	2.41	0.78
Nasolabial Angle(°)	10.83†	2.4	0.00*
Upper lip to E plane(mm)	0.83	0.35	0.03*
Lower lip to E plane(mm)	0.17	0.5	0.74

*Statistically significant difference between two methods (*P*<0.05).
†Differences of mean measurements exceeding 2 units (clinically significant).

Results

Table II indicates the reliability of repeated measurements by a single operator for two methods investigated. The differences between the means of the 2 samples are also shown. Greater differences were detected for repeated measurements performed with the digital method. Differences between the first and second tracings varied between 0.00 and 2.8 units (millimeters, degrees or percent according to the measurements) for manual tracings and between 0.07 and 4.00 for digital ones. Variability of the differences was reflected in the coefficients of determination (r^2) that if more than 0.5, means good reproducibility of the variable (good reliability). For manual tracings, the coefficients of determination of all variables were above 0.5 with the exception of nasolabial angle (0.28). For the digital method, we obtained 2 measurements with an r2 below 0.5, including nasolabial angle (0.28) and lower lip to E-line (0.37) that the latter had a mean difference lower than 2 units (0.13). Although the mean differences of 4 other variables were 2 or a little more than 2 units but their r^2 were statistically acceptable. The coefficient of determination for nasolabial angle (0.28) was lower than the other values in both methods. Overall, the comparison between r^2 values showed good reliability and a small error of the operator for all measurements except nasolabial angle.

Table III gives the measurement differences between the 2 methods. In general, the magnitude of the difference between sample means was small, with only 4 measurements (saddle angle, gonial angle, S-Go, nasolabial angle) having values above 2 units (millimeter, degree or percent). Statistically significant differences were detected for saddle angle, gonial angle, nasolabial angle and upper lip to E-line.

Discussion

Reliability is an important aspect of measurement. If a measure cannot be reproduced consistently, then the value (cost, time and patient treatment decisions) of the methodology is questionable.[3] In a clinical situation such as orthodontics, a reproducibility that is within 2° or 2 mm will probably not make a difference in treatment.[3,6] The analysis of the error (Coefficient of determination, Table II) on the conventional tracing showed a high correlation of repeated measures, meaning that the operator had no difficulty in correctly reproducing measurements on traditional procedure and that the landmarks were readily identifiable. Subjective assessment of image quality can predict reliability of landmark location.[9] A low value of the coefficient of determination (0.28) for the nasolabial angle measurement was found in this method. The nasolabial angle is formed by drawing a line tangent to the base of the nose and a line tangent to the upper lip.[8] Since radiographic images with better contrast used in this research were taken by analogue machines, in spite of efort to select better contrast images, however; it was possible to have some cases with undetectable borderes of soft tissues. Another factor is that the definition of the landmark relates to anatomical variability of the landmark location. A sharp incisal edge would likely have less error associated with its identification than a landmark location associated with a more gradual curve such as Sn point. Errors in the latter would be influenced by the vertical or horizontal orientation of the curve.[2] In addition, based on author experience, drawing the tangent line from Sn point to the base of the nose in manual method is not so accurate and reliable.

Landmark identification is greatly affected by the operator's experience, which might be as important as the tracing method itself. Inter-examiner error has been found in general to be greater than intra-observer error, so that, to minimize errors, all measurements in this study were made by 1 examiner.[6] Our data on reliability of hand-traced measurements were similar to those obtained in other studies.[10-12]

Landmark identification from digital images can be affected by several factors such as spatial and contrast resolution of the display device, background luminance level, and luminance range of the display system, brightness uniformity, extraneous light in the reading room, displayed field size, viewing distance, image motion and monitor flickering, signal-to-noise ratio of the displayed image, magnification functions, and user interface.[13] In regard to the digital measurements in our study, reliability was also generally satisfactory, with only the nasolabial angle(0.28) and lower lip to E-line (0.37) having significant mean differences. The same landmark-location difficulties previously discussed for the hand-traced nasolabial measurement apply to the digital one, and because the 2 values of the nasolabial angle (0.28) are similar, we can consider the digital, if not perfect, at least equivalent to the manually traced one. The lower lip to E-line value (0.37) was lower than the hand-traced one(0.72). The E-line in our upper lip to E-line measurements did not generate a major reliability problem (r^2 = 0.67), so that we could safely assume that locating the labiale inferius(Li) is the major factor in producing the problem. However, the mean difference of this measurement was very small (0.18) and not clinically significant. In the other way, Eppley and Sadove[14] reported that, although both digitally enhanced and standard cephalometric radiographs have comparable accuracy for bony landmark identification, digital enhancement is consistently superior at delineating soft-tissue relationships. Four measurements including Pg-N.prp, saddle angle, N.Me and L1-MeGo showed mean differences even or a little more than 2 units but their r^2 were statistically acceptable.

Our results indicate that the reliability of repeated measurements appears to be acceptable in both methods except for nasolabial angle and that it is slightly better with conventional tracing than with digital tracing software, corroborating the findings of previous studies. For example, Geelen et al[10] compared the reproducibility of landmark identification of conventional cephalometric radiographs, monitor-displayed images obtained by the storage phosphor technique, and printed hard copies. The authors found the greatest overall variability in landmark location to be associated with monitor-displayed images, with minimal differences between the other 2 methods. Chen et al [11] compared the consistency of landmark location of 10 conventional films and scanned digital images performed by 7 different examiners, and also reported a greater error in landmark reproducibility with monitor displayed images and digital tracings. They concluded that, because the magnitude of the differences was small with both methods, as confirmed in our study for most of measuements, the differences had little clinical significance. Santoro et al[3] in their study on the accuracy of digital and analogue cephalometric measurements analyzed by 1 operator, found slightly better reproducibility of the measurements in the digital method.

Utilization of Software aided cephalometric analysis can be justified only through the repetitive examination of outcome measurements showing at least comparable or preferably improved accuracy when compared with that of the traditional manual technique. Table III reprents the results of the comparison, via paired t-test, between the digital and the manual methods. The statistically significant differences detected for 4 of the 21 cephalometric variables (saddle angle, gonial angle, nasolabial angle and upper lip to E-line) that had means above 2 units, with the exception of the upper lip to E-line (Mean=-0.83). Although linear measurement S-Go mean was above 2 units (2.47 mm) did not show significant difference, statistically. This maybe because of not enough sample volume to define this clinically significant difference. The problems encountered for the gonial angle and S-Go can be explained by the difficulty in locating gonion. This point corresponds to a poorly defined outline associated with bilateral anatomic structures, located away from the midsagittal plane and often projecting as a double image on the film.[2] It is difficult to define the bilateral landmarks.[15] Identification of this landmark can be facilitated by constructing the point and using the bisecting angle to a tangent to the posterior border of the ramus and the mandibular plane; unfortunately, this could not be done with Viewbox (version 3.0) tracing software.

In our investigation, saddle angle (N.S.Ar) measured by software was smaller than manual method(2.87°) where as gonial angle measured by software was larger than manual method (3.87) so that, sum of posterior angles showed insignificant difference between the two methods. One geometrical reason for the systematicly larger calculation of gonial angle measurement in digital method could be using anatomic Go in Viewbox(version 3.0) software instead of constructed Go, so that a wider angle would be created. In one report[2] on the accuracy of landmark locating with manual and digital methods, Ar was imprecise in the vertical for film identification and Go in both x- and y-coordinates for both methods. Baumrind and Frantz [16] showed, Go was imprecise along both axes, too. Software's calculation of nasolabial angle measurement resulted in measurements approximately 11° larger than manual techniques, a difference which is rather clinically significant. It is not clear how this measurement is calculated in this software. Upper lip to E-line showed statistically significant difference between the two methods, but its magnitude was not clinically significant (mean=0.83). The error of the operator for this measurement is low in both methods (r^2 = 0.67); this means that, if the measurement was consistently reproduced, the landmark location must have been relatively uncomplicated. The noncorrespondence between hand-traced and digital values can only be attributed to a real difference in the reading of the image when projected on screen. The operator perceives some anatomic structures differently in a digital setting, even if he or she can reproduce them consistently in each setting. 3 In this case, the Ar and the Go landmarks seem to have been affected, too. Other variables that could have influenced landmark identification included the type of registration pointer used in the different software programs. Viewbox uses a circular cursor while some programs like vistadent (version 7.33 and 8.01) use a conventional pointer that obscured the landmark. Other authors [7, 17] related the same difficulties in landmark identification with the cursor obscuring landmarks, so that it can be one reason of good reliability and reproducibility of most of measurements in this study by Viewbox imaging software.

As technology progresses, it becomes increasingly difficult to determine if there is adequate evidence to assess the efficacy of the technology before it becomes commercially available. Although a multitude of cephalometric analysis software programs are available on market for several years, there are few studies [18] comparing their reliability and the similarity of measures across the programs. There are also few studies determining if there are differences between different versions of cephalometric analysis software. It can be difficult for the practitioner to select technology that is reliable and accurate unless appropriate studies are available.[7] This study provides a basis for evaluation of the software programs. Further studies in this area will, no doubt, improve our knowledge about the risks and limitations of other softwares. But, for the time being, the orthodontic office can depend on Viewbox imaging software (versio 3.0) for lateral cephalomtric analysis and diganosis with knowledge of its little deficiencies.

Conclusions

Greater variability in repeated cephalometric measurements was found in digital method compared with manually traced images. The differences, however, were clinically insignificant, because for most values, the mean differences were near or lower than 2 units. Both the hand-traced and the digital method therefore can be safely regarded as reliable except for nasolabial angle.

When comparing the 2 methods, the difference between means in individual measurements was rarely above 2 mm, 2°, or 2%, except only some measurements of difficult-to-locate landmarks, especially nasolabial angle. The data suggest that Viewbox tracing software can be used instead of the time consuming conventional method for lateral cephalometric analysis with knowledge of its limited errors.

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