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Validity and Reliability of a New Edge-based Computerized Method for Identification of Cephalometric Landmarks

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ABSTRACT

Objective: To evaluate the validity and inter- and intraexaminer reliability when on-screen landmarks are digitized manually or when these are computer-assisted by means of a new cephalometric software feature.

Materials and Methods: Twenty radiographs were digitized four times by two experienced orthodontists using a manual method and an edge-based algorithm that helps landmark identification by detecting the edges of anatomical structures.

Results: The computer-assisted method did not agree with manual digitization in 7 of 13 landmarks and 5 of 10 variables. With a tolerance of 0.5 mm or degrees, the two methods did not agree in cephalometric variables. Intraoperator reliability was improved for B point (x-axis), and Menton (x- and y-axis). It got worse for point A (y-axis). Interoperator reliability was improved for B point (x- and y-axis), Soft Labrale Inferior (x- and y-axis), Soft Pogonion (x-axis), and Menton (y-axis). It decreased for point A (y-axis). Intra- and interoperator reliability got better for only one cephalometric variable under study (SNB).

Conclusions: The edge-locking feature seems to be a promising tool for increasing the reliability of on-screen cephalometric analysis. There seem to be difficulties in locating the appropriate edges when artifacts or soft tissue edges are located near the targeted landmark. The existence of very small, but systematic differences between the two digitization methods manifests the need for further improvement.

KEY WORDS: Cephalometric landmark identification, Cephalometric software, Edge-based automatic landmark identification.

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INTRODUCTION Return to TOC

The diagnostic value of cephalometric analysis depends on the accurate and reproducible identification of clearly defined landmarks on cephalometric radiographs.[1–3] The difficulty in identifying these landmarks is compounded by the variability of the patient's hard and soft tissues, the radiographic quality, and the experience of the clinician. This is why landmark identification constitutes the main source of cephalometric analysis error.[4–6] Manual analysis of a cephalometric radiograph is time-consuming, and measuring with a ruler and a protractor can increase significantly the total error of the method.

The introduction of computerized cephalometric analysis gave the possibility of direct digitization of radiographs. This process involves fewer steps, decreases the measurement error because the linear and angular cephalometric variables are automatically calculated, and facilitates the transmission of information between practitioners.[7–10] However, in the clinical environment, time pressures can contribute to decreased reliability when the clinician is asked to subjectively define and digitize the position of a series of cephalometric landmarks.[11] Advances and affordability in digital radiographic imaging have recently seen a demand for medical professions to automate analysis and diagnosis that were once performed manually.

Many studies have attempted to improve computer-aided landmark identification in the past. In general, their aim was to reduce the intra- and interexaminer variability and save valuable clinical time. Automatic landmark identification was first described by Cohen and Linney[12] who applied a computer algorithm to retrieve the landmarks Menton and Sella. Although limited in the number of variables supported, this automatic process was an innovative departure from conventional analysis that relied on subjective decisions. Other studies followed with the same goal to enable the practitioner to scan a radiograph and run software that within seconds could retrieve accurate landmarks.

Implementation of different algorithms, among others, "knowledge-based system,"[13] "pyramid method,"[14] "grey-scale mathematical morphology,"[15] "heuristic image processing,"[16] or "active models shape,"[17] attempted to locate more landmarks, but with limited success. Other models such as "spatial spectroscopy"[11] and "pulse coupled neural networks and genetic programming"[18] showed somewhat better results.

Recently, a new version of a cephalometric program was introduced (Viewbox 3.1.1, dHAL Orthodontic Software, Athens, Greece), which offers an innovative feature that can help landmark identification by detecting the edges of anatomical structures. In contrast to previous attempts, which aimed at a completely automatic landmark identification, the objective of this new feature is perhaps less ambitious but it could prove to be a more realistic and clinically useful alternative to conventional manual landmark digitization.

The purpose of this study was to evaluate the validity and the inter- and intraexaminer reliability when on-screen landmark digitization is performed manually or it is computer-assisted by means of the aforementioned cephalometric software feature. The null hypothesis was that there is no difference in both validity and reliability between the two methods.

MATERIALS AND METHODS Return to TOC

Twenty lateral cephalographs were selected from the records of 30 consecutive patients treated at a university postgraduate orthodontic clinic. Exclusion criteria were substandard radiographic quality or the presence of unerupted or partially erupted teeth that could hinder landmark identification. The quality of the cephalographs selected was considered to be sufficient for landmark identification rather than excellent, in an attempt to stay close to the clinical reality.

The radiographs were scanned at a resolution of 300 dpi (Epson Expression 1600 Pro, Epson Deutschland GmbH, Meerbusch, Germany), and a recently introduced version of the software Viewbox™ was used to digitize them. This software is provided with one featu of particular interest called Auto Edge Locking™. This feature provides a cursor that automatically locates the edge between hard and soft tissues. The operator must guide the cursor in the vicinity of the targeted landmark to allow the software to snap the cursor onto the existing edge between structures (Figure 1).

All radiographs were digitized four times by two experienced orthodontists using two different methods: conventional on-screen digitization and computer-assisted digitization. A complete set of measurements was performed every week.

The computer-assisted method applies only to those landmarks that lie on the edge of anatomical structures. It was used for the identification of 13 commonly used cephalometric landmarks (Table 1). The position of each of the landmarks was defined with the help of a horizontal (x) and vertical (y) coordinate system (in pixels). However, the mean differences between methods were subsequently expressed in millimeters. Three more landmarks, Sella (S), Nasion (N), and Articulare (Ar), were manually digitized for each radiograph only once at the beginning of the experiment. Their exact position was then transferred (copied) to all subsequent digitization series of the same radiograph. This allowed the calculation of more commonly used cephalometric variables. All 16 landmarks were used to calculate a total of 10 variables: SNA, SNB, Upper incisor to NA, Lower incisor to NB, SN mandibular plane angle, SN Pog, Jarabak ratio, Lower lip to E Line, Lower lip to H Plane, and Subnasale to H Plane. Because of the methodological procedure used, the position of the landmarks S, N, and Ar was identical with repeated digitization of the same radiograph and therefore did not increase the observed variation of the cephalometric variables they codefine.

Statistical analysis

The validity of the edge-based computerized method was investigated by comparing it to the results obtained manually. A mixed model analysis of variance was used where "method" was the fixed factor and "radiograph" and "operator" were random factors. This was done because we wanted to draw conclusions for all possible radiographs and operators and not for the specific ones that made up the sample of our study. Both landmark position and cephalometric variables were investigated.

To estimate the intra- and interoperator reliability, the mean and variance were calculated for each group of four measurement repetitions per radiograph, operator, and method. For intraoperator reliability, the variances were then used to compare the manual and the computer-assisted methods by performing a paired *t*-test. This was performed for all radiographs, both operators, and each of the 36 variables independently. The variances were transformed into standard deviations to describe the existing differences in the tables. For the interoperator reliability, the means of four repetitions were used to calculate the differences between operators using the manual and the computer-assisted methods for all radiographs and each of the 36 variables independently. These differences were then compared by means of a paired *t*-test. The mean differences between operators were used to quantify the degree of agreement between operators using both methods.

RESULTS Return to TOC

The computer-assisted method did not agree with manual digitization in 7 of 13 landmarks under investigation. Intraoperator reliability was improved by using the computer-assisted method for B point (x-axis; $P < .05$) and Menton (x- and y-axis; $P < .05$ and $P < .001$, respectively).

Intraoperator reliability was decreased for point A (y-axis; $P < .05$). Interoperator reliability was found to be improved by using the computer-assisted method for B point (x- and y-axis; $P < .05$ and $P < .001$, respectively), Soft Labrale Inferior (x- and y-axis; $P < .01$ and $P < .05$, respectively), Soft Pogonion (x-axis; $P < .05$), and Menton (y-axis; $P < .001$) (Table 2). It was found to be decreased for point A (y-axis; $P < .1$).

The differences observed between the manual and the computer-assisted methods as far as the cephalometric variables are concerned were very small. The two methods did not agree in 5 of 10 variables. However, if a difference of 0.5 mm or degrees is allowed, the two methods agreed for all but one variable (Upper incisor to NA). Both intra- and interoperator reliability was improved in the case of only one variable (SNB, $P < .05$) (Table 3).

DISCUSSION Return to TOC

This study evaluated the validity and reliability of a new edge-based computerized method of cephalometric landmark identification and digitization. This method comes as a new feature (Auto Edge Locking™) of commercially available cephalometric software.

Both cephalometric landmarks and variables were evaluated in this study. Although there was an improvement of the reliability of some landmarks and variables, the measurements performed using this feature were not found to agree in some of the cases with those performed after manual on-screen digitization of the cephalometric radiographs under investigation. These differences were very small, and probably clinically insignificant, but it seems that this promising tool may need improvement. Our study showed, as well, that the edge-based algorithm may be influenced by the individual radiographic image characteristics.

Most cephalometric points lie at the edge of skeletal structures. Although the human eye can determine the edge of a skeletal structure with precision, it is not always easy to trace the intended target with sufficient accuracy. The idea behind the software feature investigated in this study was that an edge-locking cursor could facilitate this hand to eye coordination during on-screen landmark digitization. Using a special algorithm, the software locks on an edge as the operator slides the cursor to the desired point. Therefore, it is not an automatic landmark identification system but provides a computer-assisted digitization feature that aims at increasing reproducibility. Average quality radiographs were used for this study with no particular problems. Although there has been an effort to address the problem of double structure identification using a special double directional cursor, edge-locking did not function in 2 of the 20 radiographs under study for the landmark mandibular tangent posterior.

Mandibular tangent posterior

Edge-based image recognition relies on special algorithms that are generally complex and require a lot of computational power.[19] Various algorithms have been used for the computer-assisted identification of cephalometric landmarks in the recent past. A success rate of only 80% was reported in the automatic recognition of the cephalometric points A and B.[20] Another study investigated the identification of eight commonly used cephalometric landmarks and concluded that there was an 87% success rate when a tolerance of 1 mm is allowed.[21] In this study the success rate was 54%, but it would rise to 77% with a tolerance of 1 mm. It has to be mentioned that in this study we considered as failure even the case when landmark identification failed only in one of the two coordinate axes.

The algorithms used in computer-assisted landmark identification locate any differences between edges even if these are due to artifacts or soft tissue delimitations. This can be a significant problem when various edges lie close to the targeted landmark. The cephalometric software used in this study gives the possibility to override the feature of Auto Edge Lock™ by right-clicking with the mouse when the identification of a landmark is obviously erroneous. The differences found in this study as far as the cephalometric variables are concerned were systematic and statistically significant in 50% of the cases but remained, however, very small. A difference of 0.07° in measuring SNB is statistically very significant when systematically present, but it is probably rather insignificant from a clinical point of view. With a tolerance of 0.5 mm or degree the software feature under investigation showed a success rate of 90% as far as the cephalometric variables are concerned.

Intraoperator reliability improved in the following landmarks: B point (x-axis) and Menton (x- and y-axis). It was decreased for point A (y-axis). The improvement was sometimes observed only in one of the coordinates x and y. Interoperator reliability was improved in the following landmarks: B point (x- and y-axis), Soft Labrale Inferior (x- and y-axis), Soft Pogonion (x-axis), and Menton (y-axis). It was decreased for point A (y-axis). The clinical relevance of these results was investigated using some common cephalometric variables based on these landmarks. Only one variable (SNB) showed less variability using the edge-based software feature. We assume that the reliability improvement in landmark identification was not so important to have a significant effect on the cephalometric variables under study.

Landmark identification is always associated with an error, which follows a certain pattern or envelope. The identification of A or B points, for example, is much more prone to an error in the perpendicular than in the horizontal plane.[22] It is clear that any improvement due to the edge-locking feature could only take place in the direction of the interface between two structures. The cursor ensures that the digitized point will stay on this interface, but its exact location along this interface depends entirely on the decision of the operator. This probably explains why interoperator reliability did not change substantially, especially in the case of the cephalometric variables. In both manual and computer-assisted methods, the calculation of the cephalometric variables was automatically performed by the software. This means that any differences in reliability can only be due to landmark identification. It should be mentioned again that the operator has the option to turn the automatic feature off at any moment during the digitizing process. Both operators participating in this investigation had the impression that landmark identification and digitization was significantly easier and faster using the computer-assisted method.

CONCLUSIONS Return to TOC

- Computer-assisted cephalometric landmark identification led to some improvement of intraoperator reliability compared with manual digitization.
- The edge-based logarithm seems to be a promising tool to facilitate and increase the reliability of on-screen cephalometric analysis for both clinical and research purposes.
- There are difficulties in locating the appropriate edge when artifacts or soft tissue edges are located near the targeted landmark.
- The existence of small but systematic differences between the two digitization methods manifests the need for further improvement of the edge-based algorithm in order.

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Table 1. Cephalometric Landmark Definitions

Cephalometric Landmarks	Definition
A point	Point at the deepest concavity on the maxilla between the anterior nasal spine and prosthion
B point	Point at the deepest concavity on the mandibular symphysis between infradentale and pogonion
Upper incisor facial	The most labial point on the crown of the maxillary central incisor
Lower incisor facial	The most labial point on the crown of the mandibular central incisor
Pogonion	The most anterior point of the bony chin
Menton	The most inferior point on the mandibular symphysis
Mandibular tangent posterior	The tangential point on the lower border of the mandible between menton and antegonial notch
Ramus tangent	The tangential point on the posterior border of the ramus between gonion and articulare
Soft Pronasale	The most prominent point of the nose
Soft Subnasale	The point where the lower border of the nose meets the outer contour of the upper lip
Soft Labrale Superior	The point in the upper margin of the upper membranous lip
Soft Labrale Inferior	The point in the lower margin of the lower membranous lip
Soft Pogonion	The most prominent point on the soft tissue contour of the chin

Table 2. Validity and Reliability in Digitizing the Cephalometric Landmarks Under Study Using the Manual and the Computer-assisted Methods. The Position of Each Landmark is Given Relative to the x and y Coordinate Reference System Used in this Study. All Values are in Millimeters[a]

	Validity Agreement Between Methods[b]		Reliability					
			Intraoperator Expressed As SD[c]			Interoperator Expressed As Mean Difference Between Operators[c]		
Cephalometric Landmarks	Mean Difference	*P*	Manual	Computer Assisted	*P*	Manual	Computer Assisted	*P*
x-axis								
A point	0.81	*	1.07	1.03	NS	0.88	1.06	NS
B point	0.13	NS	0.52	0.37	*	0.39	0.25	*
Upper incisor facial	0.25	*	0.32	0.55	NS	0.22	0.22	NS
Lower incisor facial	0.88	NS	0.51	0.88	NS	0.36	0.36	NS
Pogonion	0.26	NS	0.38	0.53	NS	0.24	0.32	NS
Menton	0.20	NS	0.91	0.70	*	0.66	0.96	NS
Mandibular tangent posterior	1.09	*	2.39	2.23	NS	1.69	2.54	NS
Ramus tangent	0.67	NS	1.76	1.52	NS	1.21	1.12	NS
Soft Pronasale	0.52	NS	0.32	0.76	NS	0.26	0.31	NS
Soft Subnasale	1.02	NS	0.76	1.10	NS	0.59	0.91	NS
Soft Labrale Superior	0.76	***	0.35	0.51	NS	0.26	0.28	NS
Soft Labrale Inferior	0.70	*	0.42	0.34	NS	0.33	0.14	**
Soft Pogonion	0.65	***	0.32	0.24	NS	0.27	0.18	*
y-axis								
A point	0.22	NS	1.38	1.69	*	1.44	2.91	**
B point	0.78	NS	2.26	2.18	NS	5.02	1.26	***
Upper incisor facial	1.12	NS	1.25	8.83	NS	0.85	0.98	NS
Lower incisor facial	0.08	NS	1.86	2.61	NS	1.96	1.89	NS
Pogonion	0.92	NS	1.27	7.16	NS	1.06	1.17	NS
Menton	0.48	NS	0.36	0.18	***	0.42	0.13	***
Mandibular tangent posterior	0.67	NS	1.22	1.22	NS	1.08	1.27	NS
Ramus tangent	0.61	NS	3.94	4.31	NS	4.77	5.14	NS
Soft Pronasale	0.41	NS	0.74	0.75	NS	0.57	0.66	NS
Soft Subnasale	1.46	*	0.94	2.70	NS	0.65	0.64	NS
Soft Labrale Superior	0.99	**	0.63	2.21	NS	0.73	0.68	NS
Soft Labrale Inferior	0.33	NS	1.01	4.27	NS	0.87	0.47	*
Soft Pogonion	0.39	NS	1.57	1.60	NS	0.98	1.31	NS

[a] NS indicates not significant.
[b] Mixed model analysis of variance.
[c] Paired *t*-test.
*, **, ***, statistically significant at $P < .05$, $P < .01$, and $P < .001$, respectively.

Table 3. Validity and Reliability for the Cephalometric Variables Under Study Using the Manual and the Computer-assisted Method. All Values are in Millimeters[a]

Cephalometric Variables	Validity Agreement Between Methods[b]		Reliability: Intraoperator Expressed As SD[c]			Reliability: Interoperator Expressed As Mean Difference Between Operators[c]		
	Mean Difference	*P*	Manual	Computer Assisted	*P*	Manual	Computer Assisted	*P*
SNA (°)	0.42	**	0.46	0.43	NS	0.39	0.43	NS
SNB (°)	0.07	*	0.15	0.11	*	0.09	0.06	*
Upper incisor to NA (mm)	0.52	**	0.88	1.05	NS	0.66	0.71	NS
Lower incisor to NB (mm)	0.13	NS	0.39	0.64	NS	0.29	0.32	NS
SN-Mandibular plane (°)	0.11	NS	0.25	0.29	NS	0.28	0.22	NS
SNPog (°)	0.13	**	0.09	0.18	NS	0.04	0.05	NS
Lower lip to E plane (mm)	0.24	**	0.34	0.37	NS	0.31	0.27	NS
Jarabak ratio	0.00	NS	0.01	0.01	NS	0.01	0.01	NS
Lower lip to H plane (mm)	0.23	NS	0.31	0.39	NS	0.35	0.33	NS
Subnasale to H plane (mm)	0.27	NS	0.55	0.92	NS	0.44	0.51	NS

[a] NS indicates not significant.
[b] Mixed model analysis of variance.
[c] Paired *t*-test.
* and ** statistically significant at $P < .05$ and $P < .01$, respectively.

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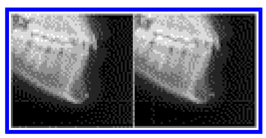

Click on thumbnail for full-sized image.

FIGURE 1. (A) Manual digitization: the cursor must be positioned exactly on the landmark. (B) Computer-assisted digitization: the operator must guide the cursor in the vicinity of the targeted landmark to allow the software to snap the cursor onto the existing edge between structures

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