

Accuracy of Automatic Cephalometric Software on Landmark Identification

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Abstract. This study was to assess the accuracy of an automatic cephalometric analysis software in the identification of cephalometric landmarks. Thirty randomly selected digital lateral cephalograms of patients undergoing orthodontic treatment were used in this study. Thirteen landmarks (S, N, Or, A-point, U1T, U1A, B-point, Gn, Pog, Me, Go, L1T, and L1A) were identified on the digital image by an automatic cephalometric software and on cephalometric tracing by manual method. Superimposition of printed image and manual tracing was done by registration at the soft tissue profiles. The accuracy of landmarks located by the automatic method was compared with that of the manually identified landmarks by measuring the mean differences of distances of each landmark on the Cartesian plane where X and Y coordination axes passed through the center of ear rod. One-Sample T test was used to evaluate the mean differences. Statistically significant mean differences ($p < 0.05$) were found in 5 landmarks (Or, A-point, Me, L1T, and L1A) in horizontal direction and 7 landmarks (Or, A-point, U1T, U1A, B-point, Me, and L1A) in vertical direction. Four landmarks (Or, A-point, Me, and L1A) showed significant ($p < 0.05$) mean differences in both horizontal and vertical directions. Small mean differences ($< 0.5\text{mm}$) were found for S, N, B-point, Gn, and Pog in horizontal direction and N, Gn, Me, and L1T in vertical direction. Large mean differences were found for A-point ($3.0 < 3.5\text{mm}$) in horizontal direction and L1A ($> 4\text{mm}$) in vertical direction. Only 5 of 13 landmarks (38.46%; S, N, Gn, Pog, and Go) showed no significant mean difference between the automatic and manual landmarking methods. It is concluded that if this automatic cephalometric analysis software is used for orthodontic diagnosis, the orthodontist must correct or modify the position of landmarks in order to increase the accuracy of cephalometric analysis.

1. Introduction

Cephalometric radiography is an essential tool in the diagnosis and treatment of malocclusions and skeletal discrepancies. It can be used to diagnose, treatment plan, and evaluate treatment results [1]. Treatment planning decisions are made based on linear and angular measurements called cephalometric analysis using landmarks obtained from lateral skull X-rays. Traditionally, cephalometric analysis has been completed by a manual approach. As radiographs have become progressively digital, computer programs have been developed to aid in cephalometric analysis. More recently, some computer software programs have introduced a fully automatic mode. This mode allows for automatic localization of the landmarks used in these analyses. Automatic identification of



landmarks of these programs has been undertaken in different ways and can be classified into four categories: (1) image filtering plus knowledge-based landmark search, (2) model-based approach, (3) soft-computing or learning approach, and (4) hybrid approach [2]. Different effectiveness in landmark localization by automatic mode have been reported in various studies [3-10]. However, accuracy of the dental imaging software (Carestream Dental, version 6.14) which is a fully automatic cephalometric analysis program available at Mahidol University is not yet reported. Therefore, it was the aim of this study to evaluate the accuracy of this software program in locating the cephalometric landmarks.

2. Materials and Methods

The ethics approval for this study was obtained from the Faculty of Dentistry/Faculty of Pharmacy, Mahidol University, Institutional Review Board. Thirty lateral cephalograms of orthodontic patients were randomly selected from the database of the Oral and Maxillofacial Radiology Clinic, Faculty of Dentistry, Mahidol University.

The criteria for selecting the subjects were as follows: 1) cephalometric radiographs taken with the same x-ray machine (CS9000C); 2) high quality radiographs without artifacts; 3) lateral cephalograms with fully intact permanent central incisors and no craniofacial deformities, such as cleft lip and cleft palate, etc.

Manual cephalometric method was used as a gold standard of which the measurements were compared with the automatic mode. For the manual tracing, an acetate paper was overlaid on the lateral cephalograms and the outline of skull, facial structures and teeth were traced using a sharpened 0.5 mm HB pencil over a light box by one examiner^g. Then, 13 anatomical landmarks (Fig. 1) were identified and a consensus were made between two experienced orthodontists^{a,b}. The thirteen landmarks (Fig. 1) used in this study were Sella (S), Nasion (N), Orbitale (Or), A- point (A-pt), B-point (B-pt), Pogonion (Pog), Gnathion (Gn), Menton (Me), Gonion (Go), Upper incisal tip (UIT), Upper incisal apex (UIA), Lower incisal tip (LIT), and Lower incisal apex (LIA).

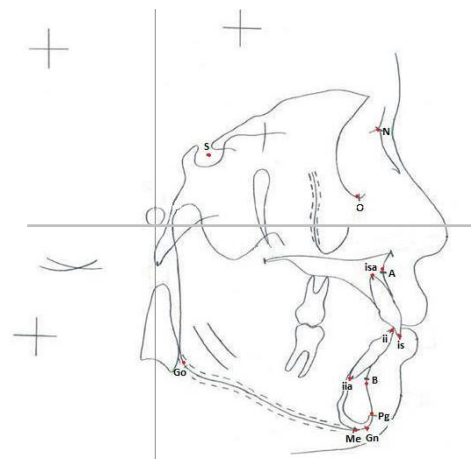


Fig. 1 The thirteen landmarks used in this study.

For the automatic software, all cephalograms were automatically analyzed by the software. Then, the printouts (1:1 ratio) which included tracing lines and landmarks were used for superimposition with the tracings from the manual method. Superimposition of each subject was obtained by registration at the soft tissue profile. The bisecting line from the image of the cephalostat through the center of the machine ear rod was defined as y-axis, and the line perpendicular to the y-axis through the center of the ear rod was defined as x-axis [9]. This coordinate was used for distance measurements of all the 13 landmarks for both manual and automatic methods.

All measurements were done by 2 examiners^{e,f} with the same cephalometric protractor. Mean of the measurements by 2 examiners was calculated and used for statistical analysis.

Mean distances in x- and y-axes of each landmark in the manual tracing were used as a baseline to compare with those obtained from the automatic method. Descriptive statistics was used for each

variable and the mean different distances of each landmark in horizontal and vertical direction were evaluated for significant differences by One-Sample T test.

3. Results

The accuracy of the automatic software program in locating the landmarks is described as the distance the automatic software's estimate is from the clinicians' estimate. Mean differences for automatic and manual landmark identification in horizontal (x-axis) and vertical (y-axis) directions are shown in Tables 1 and 2. There were no statistically significant difference ($p < 0.05$) between manual and automatic methods in 8 of 13 landmarks (61.54%: S, N, U1T, U1A, B, Gn, Pog, and Go) in horizontal direction, 6 of 13 landmarks (46.15%: S, N, Gn, Pog, Go, and L1T) in vertical direction and 5 of 13 landmarks (38.46%: S, N, Gn, Pog, and Go) in both directions. Statistically significant differences ($p < 0.05$) were found in mean differences of 5 of 13 landmarks (38.46%: Or, A-point, Me, L1T, and L1A) in horizontal direction, 7 of 13 landmarks (53.85%: Or, A-point, U1T, U1A, B-point, Me, and L1A) in vertical direction and 4 of 13 landmarks (30.77%: Or, A-point, Me, and L1A) in both directions. The S, N, B-pt, Gn, and Pog in horizontal direction and N, Gn, Me, and L1T in vertical direction were the most accurately identified landmark because the landmark location discrepancy was found to be < 0.5 mm. The A-pt in horizontal direction (location discrepancy of $3.0 < 3.5$ mm) and the L1A in vertical direction (location discrepancy of > 4.0 mm) were the least accurately identified landmarks (Table 3).

Table 1. Comparison of the means differences for automatic and manual landmark identification in horizontal direction (x-axis)

Land marks	Horizontal (x-axis)						
	Software		Manual		Differences		Sig
	Mean(mm)	SD(mm)	Mean(mm)	SD(mm)	Mean(mm)	SD(mm)	
S	19.40	3.44	19.38	3.46	0.02	1.14	0.96
N	82.01	5.75	82.0	5.78	0.01	0.98	0.96
Or	71.0	5.04	72.48	5.43	-1.48	2.55	0.003*
A	87.05	5.46	83.72	5.88	3.33	1.77	<0.001*
U1T	91.53	5.85	92.11	5.69	-0.58	1.71	0.76
U1A	80.16	5.21	79.58	5.92	0.58	2.09	0.14
B	81.27	5.61	81.25	5.77	0.017	0.77	0.91
Gn	79.13	5.67	78.96	6.05	0.18	1.37	0.49
Pog	81.47	5.81	81.5	6.08	-0.03	0.76	0.81
Me	75.33	5.65	73.78	5.95	1.54	1.44	<0.001*
Go	14.41	2.91	13.89	3.48	0.52	1.95	0.16
L1T	87.96	5.49	88.83	5.42	-0.87	1.92	0.02*
L1A	75.6	5.57	78.06	5.69	-2.46	2.13	<0.001*
Total mean difference					0.89	1.58	

*Significant difference at $p < 0.05$

Table 2. Comparison of the means differences for automatic and manual landmark identification in vertical direction (y-axis).

Land marks	Vertical (y-axis)						Sig
	Software		Manual		Differences		
	Mean(mm)	SD(mm)	Mean(mm)	SD(mm)	M(mm)	SD(mm)	
S	27.91	4.06	27.04	4.39	0.87	2.03	0.27
N	35.73	4.98	35.93	5.89	0.19	2.37	0.661
Or	7.67	4.13	10.18	5.07	2.51	2.89	<0.001*
A	20.96	4.58	20.04	4.77	0.92	1.89	0.013*
U1T	42.09	4.99	41.35	4.68	0.74	1.45	0.009*
U1A	19.79	4.43	21.66	4.68	1.87	2.09	<0.001*
B	59.66	5.21	57.48	5.18	2.18	1.90	<0.001*

Gn	74.93	5.51	75.19	5.67	0.26	1.24	0.264
Pog	69.13	5.43	70.24	6.12	1.11	2.26	0.12
Me	76.43	5.54	76.01	5.37	0.43	0.69	0.002*
Go	45.69	3.55	47.0	4.52	1.31	3.75	0.66
L1T	38.61	5.17	38.76	4.94	-0.15	2.03	0.688
L1A	60.55	5.1	55.83	4.92	4.73	1.93	<0.001*
Total mean difference					1.32	2.04	

*Significant difference at $p < 0.05$

Table 3. Landmark location discrepancy between automatic and manual method in horizontal and vertical directions.

Degree of discrepancy (mm)	Landmarks	
	Horizontal	Vertical
$x < 0.5$	S, N, B-pt, Gn, Pog	N, Gn, Me, L1T
$0.5 \leq x < 1.0$	U1T, U1A, Go, L1T	S, A-pt, U1T
$1.0 \leq x < 1.5$	Or, Me	Pog, Go
$1.5 \leq x < 2.0$	-	U1A
$2.0 \leq x < 2.5$	L1A	Or, B-pt
$2.5 \leq x < 3.0$	-	-
$3.0 \leq x < 3.5$	A-pt	-
$3.5 \leq x < 4.0$	-	-
$x > 4.0$	-	L1A

4. Discussion

Manual cephalometric analysis is a well established traditional method used as a quality standard and reference [11, 12]. In our study, two experienced orthodontists manually identified landmarks with a consensus in order to avoid professional bias. These landmarks were then used as baseline landmarks and compared with those located by the automatic system.

According to statistical analysis, significant mean differences ($p < 0.05$) on the x- and y-axes for each landmark would represent the error of the automatic system in locating the landmarks. The results in this study showed that errors between manual and automatic systems were not significantly different ($p < 0.05$) for 5 of 13 landmarks (S, N, Gn, Pog, and Go). This is consistent with the study of Liu et al [9] who also reported that 5 of 13 landmarks (S, N, Po, Or, and Gn) showed no significant difference in landmarking. One of the contributing factors for the insignificant difference may arise from the reason that these landmarks were in clear border of the craniofacial structure. However, if the landmark is in a blurred area of the craniofacial structures, the error will be large [13, 14].

Regarding the magnitude of cephalometric landmarks identification error, Trpkova et al [15] recommended that 0.59 mm of total error for the x-coordinate and 0.56 mm for the y-coordinate are within acceptable levels of accuracy. In our study, total mean differences in x-axis and y-axis were 0.89 and 1.32 mm, respectively. The results suggested that computerized landmarking of this software was not accurate enough to allow its use for clinical purpose. Variation in magnitude of error in automatic landmarking were reported in other previous studies [3-6,9,10]. Factors influencing the magnitude of error could be summarized as: (1) errors associated with the automatic system techniques, (2) quality of the digital images, and (3) superimposition of the nearby anatomic structures. In this study, some cephalometric points showed less error on the horizontal plane (S, N, B-pt, Gn, and Pog) and some showed better results on the vertical plane (N, Gn, Me, and L1T). This is in accordance with the statement that the distribution of errors for many landmarks is systematic and follows a typical pattern (non-circular envelop). In fact, it has been reported that some cephalometric landmarks are more reliable in the horizontal dimension whereas others are more reliable in the vertical dimension [15]. The results in this study revealed that B-pt could be identified with a higher degree of accuracy in horizontal plane than vertical plane, whereas A-pt showed a higher degree of accuracy in the vertical plane than horizontal plane.

Regarding the pattern of error, landmarks lying on horizontal edges or planes were more accurately located in the vertical dimension. Similarly, landmarks lying on vertical edges were more accurately located in the horizontal dimension. It was also noted that there were large mean errors (discrepancy of > 2 mm.) in some landmarks (U1A, L1A, Or, B-pt, and A-pt). The possible reason may be because those landmarks were located on poorly defined structures or were overlapped with surrounding structures.

More accurate algorithms of automated landmarking are needed for the improvement of the software so that it can be reliably used in orthodontics. The error of automatic landmark identification must be less than or close to that of manual identification.

5. Conclusion

The automatic cephalometric analysis software in this study was unable to compete with manual identification of radiographs in terms of accuracy of landmark identification. In fact, the ability to automatically identify landmarks is fair for many landmarks, but overall, the software was not accurate enough for routine clinical use. The orthodontist must use the fully automatic cephalometric analysis system with caution.

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