ORIGINAL ARTICLE

Intraexaminer and interexaminer reliabilities of landmark identification on digitized lateral cephalograms and formatted 3-dimensional cone-beam computerized tomography images

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Introduction: The purposes of this study were to determine and compare the intraexaminer and interexaminer reliabilities of commonly used cephalometric landmarks identified on digitized lateral cephalograms and formatted cone-beam computerized tomography (CBCT) images. **Methods:** CBCT images from 10 randomly selected adolescent patients were obtained from the orthodontic records of a private practice. Measurement errors, and intraexaminer, and interexaminer reliability correlation coefficients (ICC) were obtained for all landmark coordinates. **Results:** Intraexaminer and interexaminer reliabilities for all coordinates for most landmarks on the digital lateral cephalograms and CBCT images were greater than 0.9 (ICC value). The means of landmark locations differed by approximately 1 mm in most coordinates from the lateral cephalograms and were predominantly higher than 1 mm for all coordinates from the CBCT images. **Conclusions:** Intraexaminer and interexaminer reliabilities were high for most landmarks. Coordinates with greater measurement errors in the lateral cephalograms (condylion, gonion, porion, mandibular incisor apex, and posterior nasal spine) were in structures without clearly defined borders. In the CBCT images, gonion, condylion, and porion were located on surfaces that were flat or curved, making it difficult to recognize a specific reference point. Other less reliable landmarks (anterior nasal spine, posterior nasal spine, mandibular incisor apex) were located in structures with lower densities and could not be visualized with 3-dimensional reconstruction; thus, they had high measurement errors. (Am J Orthod Dentofacial Orthop 2010;137:598-604)

Since the development of cephalometric radiology, several cephalometric analyses have been proposed. They have been useful in describing how individual patients vary from population norms, forecasting and following growth and treatment changes, and establishing descriptive communications between clinicians. Because cephalometric analysis is a 2-dimensional (2D) rendering from 3-dimensional (3D) structures, cephalometric measurements on radiographic images are subject to projection, landmark identification, and measurement errors.[1,2]

Magnification and distortion play important roles in the radiographic projection errors of skeletal and dental structures in cephalometric images. Magnification occurs because the x-ray beams originate from a source that is not parallel to all points of the object examined. Distortion occurs because of unequal magnifications between different planes. Although many landmarks used in cephalometric analysis are located in the midsagittal plane and are not prone to superimposition errors, other landmarks with different paramedial structures are affected by distortion because of their locations at different depth fields.[1,2]

Landmark identification errors are also considered a major source of cephalometric errors. This type of error is influenced by many factors such as quality of the radiographic image, precision of landmark definition, reproducibility of the landmark location, and operator and registration procedures.[1,2] Despite all these potential errors, cephalometric radiographs are still

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widely used and are often essential in a patient's diagnosis and treatment.

Advances in the use of 3D imaging hardware and software have challenged our perception of 3D craniofacial structures and their associated growth. Monitoring of treatment changes is also affected. CBCT is a relatively new technique that allows primary reconstructions (sagittal, coronal, and para-axial cuts) and secondary reconstructions (3D reconstructions and maximum intensity projections) of various craniofacial structures.[3] Compared with traditional cephalometric radiographs, CBCT images are anatomically true (1:1 in size) 3D representations from which slices can be displayed from any angle in any part of the skull and provided digitally on paper or film.[4]

Currently, 3D volumetric imaging provides useful information for clinicians in identifying teeth and other structures for diagnostic and descriptive purposes.[5] Before establishing CBCT as a common orthodontic diagnostic approach, landmark reliability must be assessed. This has been extensively done for traditional lateral cephalograms. However, landmark reliability assessment for CBCT is limited, and additional research is required in this area.[6,7] The purposes of this study were to determine and compare intraexaminer and interexaminer reliabilities of common cephalometric landmarks from digitized lateral cephalograms and formatted 3D CBCT images.

Table I. Definitions of landmarks

Nasion (N): most anterior point of the frontonasal suture in the median plane
Orbitale (Or): lowest point in the inferior margin of the orbit
A-point (A): point at the deepest midline concavity on the maxilla between ANS and prosthion
B-point (B): point at the deepest midline concavity on the mandibular symphysis between infradentale and pogonion
Pogonion (Pg): most anterior point of the bony chin in the median plane
Gnathion (Gn): most anteroinferior point on the symphysis of the chin, constructed by intersecting a line drawn perpendicular to the line connecting menton and pogonion
Menton (Me): most inferior midline point on the mandibular symphysis
Gonion (Go): constructed point of intersection of the ramus plane and the mandibular plane
Porion (Po): superior point of the external auditory meatus
Sella (S): midpoint of the pituitary fossa (sella turcica)
Basion (Ba): median point of the anterior margin of the foramen magnum
Anterior nasal spine (ANS): tip of the anterior nasal spine
Posterior nasal spine (PNS): tip of the posterior nasal spine
Condylion (Co): most superior point on the condylar head
Upper central incisor tip (U1T): point on the tip of the maxillary central incisor crown
Upper central incisor root apex (U1R): point on the apex of the maxillary central incisor root
Lower central incisor tip (L1T): point on the tip of the mandibular central incisor crown
Lower central incisor root apex (L1R): point on the apex of the mandibular central incisor root

MATERIAL AND METHODS

Digitized lateral cephalograms (Planmeca, Roselle, Ill) and CBCT scans (NewTom 3G volumetric scanner, Aperio Services, Verona, Italy) from 10 adolescent patients were randomly selected from the orthodontic records previously taken at a private practice orthodontic clinic in Calgary, Alberta, Canada. The sample size was based on a statistical power of 0.90 with $\alpha = 0.05$.[8] This study was approved by the Human Research Ethics Board at the University of Alberta.

After obtaining the CBCT images (by using a 12-in field of view with 8-mm aluminum filtration at 110 kV and 6.19 mAs, and slice thickness of 0.5 mm) in raw study data, they were converted into DICOM format. Commercially available third-party software (AMIRA, Mercury Computer Systems, Berlin, Germany) was used to obtain primary reconstructed images (axial, coronal, and sagittal) and the 3D reconstructions of the images for landmark recognition and location. Lateral cephalograms (obtained at 68 kV and 12 mA, and image size with approximately a 12-in field of view) were uploaded into the AMIRA software, and landmark locations were calculated.

AMIRA software has a predetermined fiduciary coordinate axis system for each image. The center of the coordinate axis system is outside the image of interest. This predetermined coordinate axis system is always the same when the same image is uploaded in the software. Since the purpose of this study was not to compare images, determining a common reference plane on every image was not necessary.

The landmarks used in this study are described in Table I. For the coordinates obtained from CBCT, the AMIRA software gave values in millimeters. The CBCT data had no magnification (1:1 image size), and, to allow true comparison, magnification of the lateral cephalogram images was corrected with the calibration ruler imbedded in each image at its acquisition.

Landmark coordinates for each image set were obtained by 1 investigator (M.O.L.) 3 times, and 1 time by 2 investigators (C.F. and R.C.). All examiners were previously trained in the use of AMIRA software and orthodontic landmark identification. For investigator blinding, the images were identified by code and analyzed in random order. Intraexaminer reliability was

Table II. Intraexaminer mean differences of coordinates of the landmarks from lateral cephalograms (mm)

	X				Y			
	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
N	0.29	0.13	0.09	0.52	0.47	0.20	0.28	0.77
Or	0.78	0.79	0.15	2.83	0.42	0.24	0.14	0.90
A	0.62	0.61	0.13	1.94	0.77	0.60	0.07	1.88
B	0.29	0.18	0.05	0.60	0.68	0.47	0.18	1.66
Pg	0.26	0.18	0.02	0.60	0.54	0.26	0.10	0.90
Gn	0.32	0.21	0.03	0.84	0.39	0.27	0.07	0.84
Me	0.55	0.17	0.31	0.78	0.47	0.20	0.08	0.74
Go	0.90	0.63	0.07	1.87	0.58	0.29	0.21	1.16
Po	0.78	0.60	0.20	1.91	1.00	0.50	0.43	2.24
S	0.30	0.23	0.05	0.67	0.39	0.18	0.15	0.67
Ba	0.93	0.94	0.29	3.52	1.64	1.26	0.46	3.77
ANS	0.65	0.23	0.33	1.10	0.47	0.19	0.20	0.78
PNS	1.52	0.94	0.49	3.20	0.55	0.39	0.25	1.44
Co	1.38	0.83	0.32	2.53	1.36	0.48	0.54	2.00
U1T	0.31	0.21	0.11	0.81	0.25	0.11	0.14	0.45
U1R	0.85	0.48	0.22	2.00	0.87	0.63	0.23	2.17
L1T	0.29	0.13	0.18	0.60	0.42	0.22	0.14	0.87
L1R	0.95	0.47	0.36	1.69	1.23	0.51	0.69	2.34

assessed by using intraclass correlation coefficients (ICC) for the first investigator's 3 measurements. ICC was also used to calculate interexaminer reliability by comparing his second trial with the measurements of the other 2 investigators. Measurement errors (average of the mean differences between measurement trials) for all coordinates (x, y, and z for CBCT; x and y for digital lateral cephalograms) were also determined.

RESULTS

Intraexaminer and interexaminer reliabilities for the x and y coordinates of most landmarks in the lateral cephalograms were greater than 0.9. Only porion, basion, and condylion had moderate intraexaminer reliabilty for the y-axis (0.81, 0.57, and 0.67, respectively) and mild interexaminer reliability for the y-axis (0.46, 0.46, and 0.38, respectively).

Mean differences from repeated landmark identification by the same examiner in the x-axis were less than 1 mm with the exception of posterior nasal spine (1.52 mm) and condylion (1.38 mm). For the y-axis, the mean differences were equal to or less than 1 mm with the exception of basion (1.64 mm), condylion (1.36 mm), and mandibular incisor root apex (1.23 mm). When the 3 examiners were compared, their mean differences in the x-axis were less than 1 mm in 50% of the landmarks, with gonion (2.81 mm), basion (1.46 mm), anterior nasal spine (1.58 mm), maxillary incisor root apex (1.66 mm), mandibular incisor root apex (1.38 mm), and posterior nasal spine (2.26 mm) all greater than 1 mm. In the y-axis, the greatest differences were in gonion (2.28 mm), basion (2.45 mm), porion (1.96 mm), condylion (2.12 mm), maxillary incisor root apex (2.59 mm), and mandibular incisor apex (2.36 mm) (Tables II and III).

Intraexaminer and interexaminer reliabilities for the x, y, and z coordinates for all landmarks in CBCT were greater than 0.9.

Mean differences from the same examiner's trials were generally less than 1.0 mm. In the x-axis, orbitale left, sella, basion, anterior nasal spine, posterior nasal spine, and condylion right had values between 1.0 and 2.0 mm. Porion right and left had the highest differences in this axis (2.62 and 3.37 mm, respectively). In the y-axis, gonion right and left, porion left, and posterior nasal spine had mean differences between 1.0 and 2.0 mm. In the z-axis, only B-point and mandibular incisor root apex left had mean differences between 1.0 and 2.0 mm.

For the mean differences between the 3 examiners in the x-axis, they were predominantly higher than 1.0 mm. Orbitale right and left (3.25 and 2.57 mm, respectively), porion right and left (2.7 and 2.94 mm, respectively), and condylion right and left (3.48 and 3.08 mm, respectively) all had mean differences greater than 2.0 mm. In the y-axis, half of the landmarks had errors higher than 1.0 mm. Gonion right and left (5.5 and 3.9 mm, respectively) and anterior nasal spine (2.51 mm) had mean differences greater than 2.0 mm. In the z-axis, about 40% of the landmarks had errors higher than 1.0 mm. Gonion right and left (3.5 and 2.66 mm, respectively) and

Table III. Interexaminer mean differences of coordinates of the landmarks from lateral cephalograms (mm)

	X				*Y*			
	Mean	*SD*	*Minimum*	*Maximum*	*Mean*	*SD*	*Minimum*	*Maximum*
N	0.42	0.15	0.23	0.66	0.76	0.41	0.24	1.49
Or	1.13	0.85	0.15	2.86	1.07	0.82	0.32	2.65
A	0.75	0.80	0.18	2.46	1.21	1.01	0.14	3.21
B	0.34	0.23	0.09	0.83	1.61	0.89	0.48	3.36
Pg	0.37	0.22	0.09	0.67	0.85	0.56	0.17	2.03
Gn	0.83	0.42	0.26	1.54	0.98	0.59	0.33	1.91
Me	1.45	1.06	0.26	3.29	0.68	0.47	0.08	1.48
Go	2.81	1.21	1.21	4.64	2.28	1.86	0.53	5.46
Po	1.53	0.56	0.82	2.43	1.96	1.51	0.40	4.76
S	0.57	0.19	0.36	0.91	0.77	0.22	0.47	1.22
Ba	1.46	0.97	0.21	3.47	2.45	1.54	0.63	4.60
ANS	1.58	1.59	0.39	5.56	0.38	0.20	0.11	0.71
PNS	2.26	1.45	0.70	5.09	0.90	0.62	0.09	2.15
Co	1.15	0.61	0.20	1.99	2.12	1.34	0.46	4.94
U1T	0.28	0.16	0.05	0.52	0.54	0.16	0.36	0.74
U1R	1.66	0.75	0.24	2.51	2.59	1.08	1.29	4.38
L1T	0.30	0.13	0.05	0.43	0.55	0.33	0.12	1.26
L1R	1.38	0.78	0.68	3.36	2.36	1.30	0.87	5.35

mandibular incisor root apex left (2.05 mm) all had mean differences greater than 2.0 mm (Tables IV and V).

DISCUSSION

The error involved in landmark identification is an important issue in cephalometric analysis.[9] Chen et al[10] stated that it is impossible to estimate landmark positions without errors. Efforts should be made to minimize the effect of errors in landmark identification in cephalometric measurements, since they are the major source of tracing errors.[11,12] Several factors contribute to the reliability of landmark identification: nature of the cephalometric landmarks, density and sharpness of the images, anatomic complexity and superimposition of hard and soft tissues, definition of the landmark, and training level or experience of the observers.[12-14] McWilliam and Welander[13] added that landmark identification might be related to pattern recognition, which is more applicable to experienced observers.

Intraobserver landmark identification errors are generally lower than interobserver errors.[11] Intraobserver differences could be due to the nature of the cephalometric landmark, image quality, and blurring of anatomic structures, whereas interobserver differences might be caused by variations in the observer's training and experience.[15,16] Chen et al[17] stated that the major influence on the reliability of a landmark is interobserver variation; this was seen in our study.

Intraexaminer and interexaminer cephalometric landmark identification errors in this study were similar or slightly smaller than those reported in previous studies.[9,17] The digital cephalograms we used were high quality; this facilitated landmark identification. Furthermore, the AMIRA software helped locate the landmarks by allowing the operator to change gray scales and zoom in or out of the image.

CBCT in dentistry has provided an imaging solution with no projection errors associated with magnification and no superimposition problems associated with traditional cephalometric imaging and analysis.[18] Also, CBCT has a wide range of tools such as 3D reconstructions and ortho slices in any direction to permit location of landmarks correctly. Studies have reported excellent accuracy of 3D computed tomography (CT) with phantoms and metallic markers.[19,20] This approach demonstrates the accuracy of the imaging but does not simulate the clinical situation, in which precision is influenced by the difficulty in identifying landmarks.[6] Since, in our study, neither markers nor phantoms were used, identification of landmarks reflected a real clinical situation, and discrepancies in landmark identification were more likely. CBCT images were not converted to lateral cephalogram projections because it was thought that changing a 3D image to 2D would defeat the purpose of taking CBCT images.

Kragskov et al[6] indirectly compared landmark reliability through linear and angular measurements from traditional cephalometric analyses in lateral and posteroanterior cephalometric radiographs with the same measurements from 3D spiral CT. Their findings suggest that landmarks and measurements were less

Table IV. Intraexaminer mean differences of coordinates of the landmarks from CBCT (mm)

	X				*Y*				*Z*			
	Mean	*SD*	*Minimum*	*Maximum*	*Mean*	*SD*	*Minimum*	*Maximum*	*Mean*	*SD*	*Minimum*	*Maximum*
N	0.37	0.19	0.07	0.64	0.11	0.08	0.01	0.30	0.54	0.47	0.09	1.53
Or right	0.89	0.62	0.31	2.31	0.53	0.36	0.12	1.20	0.47	0.25	0.19	0.85
Or left	1.17	0.58	0.12	1.98	0.72	0.39	0.07	1.35	0.32	0.24	0.07	0.77
A	0.43	0.27	0.22	1.07	0.29	0.43	0.01	1.45	0.74	0.48	0.20	1.77
B	0.65	0.42	0.16	1.44	0.22	0.13	0.01	0.36	1.42	0.71	0.24	2.70
Pg	0.47	0.23	0.10	0.71	0.20	0.13	0.03	0.41	0.74	0.37	0.21	1.55
Gn	0.47	0.28	0.12	0.87	0.39	0.26	0.03	0.73	0.42	0.21	0.06	0.73
Me	0.61	0.27	0.30	1.05	0.67	0.31	0.19	1.08	0.16	0.08	0.04	0.23
Go right	0.50	0.19	0.27	0.82	1.41	0.65	0.53	2.17	0.56	0.32	0.24	1.20
Go left	0.63	0.37	0.18	1.46	1.41	0.89	0.28	2.76	0.58	0.41	0.09	1.37
Po right	2.62	1.67	0.83	5.69	0.92	0.61	0.27	2.08	0.82	0.83	0.17	2.99
Po left	3.27	1.60	0.81	6.23	1.53	0.78	0.38	2.55	0.76	0.58	0.11	1.78
S	1.47	0.92	0.56	2.80	0.63	0.21	0.24	0.98	0.59	0.21	0.35	1.06
Ba	1.47	0.92	0.56	2.80	0.50	0.28	0.09	1.06	0.47	0.19	0.21	0.70
ANS	1.06	0.70	0.28	2.52	0.81	0.84	0.03	2.90	0.70	0.47	0.34	1.61
PNS	1.17	0.75	0.28	2.52	1.06	0.52	0.43	2.15	0.66	0.26	0.24	1.09
Co right	1.55	0.83	0.84	3.36	0.72	0.26	0.36	1.02	0.51	0.23	0.12	0.92
U1T right	0.34	0.22	0.00	0.56	0.40	0.28	0.07	0.84	0.54	0.32	0.11	1.01
U1R right	0.34	0.22	0.00	0.56	0.48	0.21	0.12	0.90	0.63	0.38	0.15	1.51
L1T right	0.34	0.22	0.00	0.56	0.44	0.28	0.08	0.82	0.50	0.31	0.09	1.05
L1R right	0.34	0.22	0.00	0.56	0.76	0.45	0.30	1.59	0.89	0.55	0.24	1.69
U1T left	0.53	0.33	0.00	1.12	0.42	0.18	0.19	0.67	0.31	0.21	0.03	0.62
U1R left	0.53	0.33	0.00	1.12	0.53	0.30	0.24	1.10	0.55	0.24	0.07	0.79
L1T left	0.69	0.28	0.28	1.12	0.40	0.18	0.12	0.68	0.44	0.37	0.05	1.28
L1R left	0.53	0.33	0.00	1.12	0.79	0.38	0.22	1.36	1.11	0.84	0.13	3.11
Co left	0.74	0.55	0.00	1.96	0.64	0.28	0.16	1.03	0.43	0.28	0.18	1.06

reliable in 3D CT image analysis. It was argued that the reason behind these findings was that distances calculated between landmarks on 2D cephalograms only have x and y coordinates, whereas 3D CT images have x, y, and z coordinates, thus adding an extra deviation.[6] Hildebolt et al[21] showed that 2D CT measurements are inferior to 3D CT measurements when landmarks were located on different CT slices, but measurements made on the same slice have been reported to be accurate and reliable.[18,22,23] Another aspect to consider is locating points outside scanner planes. For example, A-point lies outside the scan plane on a normal transverse CT scan, but it is easy to locate in 3D CT image reconstructions.[6]

The magnitude of the landmark identification errors depends on the position of the landmark and is expected to be smaller with clear borders with high-density contrast and greater in blurred areas of craniofacial structures.[15,24] Baumrind and Frantz[15] stated that landmarks that are placed on anatomically formed edges or crests are easy to identify, but those on curves with wide radii show greater errors of measurement. Although these 2 statements were made with respect to 2D imaging, they also apply to 3D imaging. Some landmarks were more difficult to locate in CBCT than on lateral cephalograms. Gonion, condylion, and porion are difficult to define in a 3D projection because of their location on 3 dimensionally flat surfaces or widely curved bone structures. Curved and flat surfaces in traditional lateral cephalograms appear as curved lines that would only involve location variations in 2 dimensions, whereas, in CBCT, a third dimension is added, increasing the variation of the respective landmarks.[6] Other points in areas of low density are more difficult to identify in CBCT images than on 2D lateral cephalograms. Root apexes also can be difficult to locate, since a clear division between the end of the root apex and the surrounding cortical bone is not easily identified. Two dense structures such as root and cortical bone can create some error when trying to view solely the root in 3D reconstructions, since software categorizes some of its density similar to bone.

Mean measurement errors in landmarks identified in CBCT varied between 0.1 and 4 mm in all 3 axes. Some landmarks had higher variations in 1 axis but lower variations in the other 2. Values obtained in this study, although important, are still not enough to determine or designate which landmarks are clinically acceptable

Table V. Interexaminer mean differences of coordinates of the landmarks from CBCT (mm)

	X				*Y*				*Z*			
	Mean	*SD*	*Minimum*	*Maximum*	*Mean*	*SD*	*Minimum*	*Maximum*	*Mean*	*SD*	*Minimum*	*Maximum*
N	0.68	0.48	0.12	1.50	0.86	0.72	0.23	2.38	1.78	1.15	0.42	3.41
Or right	3.25	2.25	0.17	7.92	1.63	0.72	0.68	3.21	0.61	0.42	0.04	1.57
Or left	2.57	2.13	0.74	8.21	1.20	0.45	0.51	1.96	0.64	0.47	0.07	1.68
A	0.92	0.24	0.56	1.26	0.80	0.35	0.07	1.18	0.77	0.60	0.19	1.92
B	1.51	1.03	0.56	3.76	0.54	0.32	0.10	1.09	1.81	1.69	0.15	5.29
Pg	1.44	1.03	0.56	3.43	0.71	0.33	0.25	1.21	1.22	0.74	0.36	2.70
Gn	1.42	1.05	0.27	3.24	0.93	0.75	0.20	2.74	0.73	0.84	0.10	3.05
Me	1.51	0.94	0.10	2.80	1.21	1.10	0.32	3.67	0.55	0.46	0.07	1.54
Go right	1.54	0.55	1.08	2.67	5.50	1.62	3.63	8.17	3.50	0.61	2.58	4.47
Go left	1.57	0.75	0.29	2.56	3.90	1.65	2.02	6.64	2.66	0.92	1.24	4.44
Po right	2.70	1.56	0.59	6.33	0.90	0.54	0.27	2.08	0.73	0.45	0.05	1.44
Po left	2.94	1.91	0.21	5.40	1.65	2.18	0.14	7.62	0.59	0.29	0.26	1.20
S	1.21	0.80	0.28	3.08	0.41	0.31	0.06	0.91	0.57	0.25	0.07	1.05
Ba	1.23	0.78	0.28	3.08	0.97	0.60	0.25	2.46	1.03	0.33	0.44	1.43
ANS	1.93	1.44	0.47	4.76	2.51	1.65	0.63	6.51	1.13	0.90	0.23	3.03
PNS	1.56	1.11	0.47	3.08	1.03	0.84	0.11	2.66	0.47	0.21	0.12	0.79
Co right	3.48	1.62	1.40	5.63	1.36	0.97	0.50	3.32	0.37	0.22	0.09	0.87
U1T right	0.61	0.29	0.28	1.03	0.53	0.30	0.06	0.93	0.53	0.35	0.03	1.02
U1R right	0.52	0.29	0.00	0.84	0.98	0.87	0.08	2.73	1.24	1.16	0.30	4.20
L1T right	1.53	1.06	0.56	3.08	0.72	0.45	0.16	1.70	0.65	0.58	0.19	2.12
L1R right	1.30	0.95	0.28	3.08	1.30	0.90	0.29	2.52	1.38	0.64	0.11	2.20
U1T left	0.78	0.60	0.00	1.68	0.44	0.12	0.21	0.57	0.58	0.34	0.02	1.31
U1R left	1.11	1.07	0.00	3.64	0.79	0.72	0.04	2.08	1.21	0.97	0.18	3.65
L1T left	1.11	0.72	0.19	2.24	0.43	0.25	0.13	0.81	0.49	0.26	0.11	0.90
L1R left	1.04	0.69	0.28	2.24	1.06	0.46	0.06	1.70	2.05	0.83	0.87	3.24
Co left	3.08	1.47	1.40	6.18	1.28	0.61	0.39	2.37	0.78	0.35	0.22	1.47

for analysis. If a landmark is used to measure angles or distances similar to cephalometric analysis, only 2 dimensions would have an impact on the final values, and a third dimension would have no influence. Linear measurements will be influenced by all 3 dimensions. Furthermore, the tolerance for landmark identification differences depends on how the craniofacial measurements will be used. Intraexaminer landmark identification reliability is important in research, whereas interexaminer landmark reliability is important in clinical diagnosis and treatment planning. It is reasonable that mean differences in landmark identification less than 1 mm are clinically acceptable. It is also reasonable that mean differences between 1 and 2 mm are useful in most analyses, and landmarks with mean diffences greater than 2 mm should be used with caution.

Traditional landmarks used in lateral cephalometric analysis have been defined and used based on what can be visualized on 2D images. In 3D imaging with CBCT, these traditional landmarks might not represent useful anatomic structures. Important structures that could not be visualized in 2D imaging because of superimpositions are now available for analysis. New landmarks should be defined and evaluated. These can now be located on osseous and dental surfaces or inside bones and teeth depending on the objective to be analyzed. Ideal locations for landmarks in CBCT would be edges, foramina, apices, and other structures that are easily pinpointed with the tools available in 3D imaging. Landmarks that can be easily viewed by using 3D reconstruction and verified with 2D slices should be preferred. Other good locations for landmarks would be between structures with different densities to eliminate the possibility of loss during thresholding or distinguishing the limits between anatomic structures. Furthermore, 3D landmarks in the cranial base are relatively unaffected by growth and allow superimposition of image sets taken over time independent of patient positioning.[25] This will allow 3D assessment of craniofacial growth and treatment effects. CBCT also provides new opportunities for soft-tissue landmarks.

In 2D analysis, landmarks have been used to represent structures with the limitations of that type of imaging. With 3D imaging, 1 landmark might not represent how a whole anatomic structure would react to growth or treatment. For this reason, thought should be given to considering several landmarks in a structure of interest. For example, landmarks in various parts of a tooth will allow measurement of movement in all planes of space, including rotational movement.

CBCT as a routine orthodontic diagnostic and treatment evaluation tool still needs development. Secondary software applications such as AMIRA require a significant learning curve for a typical clinician. There is also a learning curve of understanding craniofacial anatomy from 3D imaging, and experience is needed to gain confidence when identifying landmarks.

CONCLUSIONS

Intraexaminer and interexaminer reliabilities (ICC) of landmarks were high for all CBCT landmarks and most 2D lateral cephalometric landmarks. Although CBCT landmarks were statistically reliable, clinicians and researchers should be aware of the circle of identification errors for each landmark.

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