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Evaluation of Ricketts Frontal Analysis Reference Points on Cone-beam Computed Tomography Images

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AJR and OVV designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Authors AJR, LGS and LASC managed the analyses of the study. Authors BSV and ATSM managed the literature searches. Authors AJR, BSV, ATSM and OVV revised the manuscript for intellectual content. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this study was to evaluate the reliability of Ricketts frontal analysis reference points when viewed by three-dimensional images.
Methodology: The points related to the Ricketts frontal analysis were identified at multiplanar reconstructions (MPR) and three-dimensional reconstructions (Rec 3D) obtained from cone-beam computed tomography. The cephalometric landmarks, following the author's definition, were located by three operators: an orthodontist, a radiologist, and a student coursing the eighth period of the graduation course in dentistry. After two weeks, the landmarks were repeated. The values of

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X, Y, and Z were obtained for each point, and the intraclass correlation coefficient was calculated.
Results: The intraclass correlation coefficient values were less than 0.45 (poor reliability) at 15 points viewed from the three-dimensional reconstructions and 8 points for the multiplanar reconstructions, including the intra and interobserver assessments. It was not possible to identify the J point on the CBCT images.
Conclusion: The multiplanar reconstructions allow greater reliability in the identification of the anatomical landmarks for both intra and interobserver assessments. To improve its reliability, Ricketts frontal analysis reference points must be defined in the three planes of space before transfer to three-dimensional images, or new anatomical references can be adopted.

Keywords: Anatomic landmarks; cephalometry; cone-beam computed tomography; orthodontics; three-dimensional image; ricketts frontal analysis.

1. INTRODUCTION

Radiographs are the most commonly used imaging studies for diagnosis and orthodontic treatment planning. Due to the two-dimensional (2D) representation of three-dimensional (3D) structures, this method presents well-known limitations: overlapping of anatomical structures, distortion, and magnification [1-3]. Moreover, an incorrect positioning of the head during the acquisition of the image results in other diagnostic problems [4].

Two-dimensional images are traditionally preferred for marking skeletal and dental points and making tracings and measurements [4]. However, it is common for operators to make mistakes when scoring some points due to the overlapping of anatomical structures in an assessed region, which is also influenced by the quality and resolution of the image. Points often erroneously marked are the porion, condyle, orbital, basion, gonion, anterior and posterior nasal spine, and lower incisor apex [1,5].

Cone-Beam Computed Tomography (CBCT) provides a high-resolution image and brings together in a single exposure all traditional orthodontic images [6]. It allows the structures' visualization in tomographic images, facilitating the analysis of a desired region, produces less artifacts when there are metallic restorations in the mouth, and enables the digital removal of the overlapping structures, such as the vertebral spine. Those features facilitate the identification and marking of the cephalometric points.

The development of a 3D cephalometric analysis requires the selection of reference points in the three spatial planes (axial, sagittal, and coronal) that are easy to identify and reproduce [7-9]. The reconstructed images from the tomographic slices are considered reliable in relation to the cephalometric points and the measurement of distances between them [10,11]. However, the data obtained may be affected by the anatomical reference structure, the anatomical plane used, and the operator's level of training [12].

Posteroranterior (PA) radiographs enable the evaluation of the transverse dimension and asymmetries that would not be identified by a lateral view. Among the various analyses proposed, the Ricketts analysis [13,14]. Is the most widely used. Its greater acceptance is due to the understandable standard rules and appropriate value suggestions according to age [15,16]. However, there are only a few studies that have evaluated the PA radiograph and points of the frontal analysis in tomographic images.

The points used on Ricketts [13,14] frontal analysis, when marked over 3D images, have not yet been studied. Therefore, the aim of this study is to determine if these points have the reliability needed to be located in this kind of image.

2. MATERIALS AND METHODS

From a total of 142 orthodontic pretreatment CBCT exams from the institution`s archive, those that were indicated for retreatment, lacked incisors or first permanent molars, or presented with supernumerary teeth or severe asymmetries were excluded. Exams with poor-quality images were also excluded. From the 98 remaining exams, three CBCT images (one male and two females, aged between 21 and 23 years) were randomly selected. The research protocol was approved by the institutional review board in 2016, under the number 1.717.953.

All file exams were obtained with ai-CAT 3D scanner (Imaging Sciences International, Hatfield, PA, USA). The acquisition parameters used were 120 kV, 3-7mA, and 40s of exposure.

The voxel size was 0.4 mm and the FOV (field of view) was 220 mm. Patients were advised to maintain the natural position of the head and the teeth in centric occlusion. The base images or raw data were exported to a DICOM (Digital Imaging and Communication in Medicine) file type.

2.1 Landmarks Identification

The anatomic reference points were marked using two different visualization modes available in the In Vivo Dental 5.1 software (Anatomage, San Jose, CA, USA) — a multiplanar reconstruction (MPR) of axial, coronal, and sagittal slices and a 3D virtual image model (Rec 3D) — according to the methodology adopted in a previous study [17].

Three operators (an orthodontist, a radiologist, and a student coursing the eighth period of the graduation course in dentistry) were trained and calibrated to identify the reference points using a CBCT scan that was not included in the sample. Subsequently, they marked the points on the three scans of the sample and repeated the procedure after a two-week interval. The operators initially carried out the marking of points in the MPR, automatically obtaining the values of the X (axial), Y (coronal), and Z (sagittal) coordinates by clicking on the image with the marking tool. Next, the evaluation was performed in the Rec 3D (Fig. 1).

The reference points are described in Table 1.

2.2 Statistical Analysis

The intraclass correlation coefficient (ICC) was obtained comparing the X, Y, and Z values that corresponded to the exact location of each point on axial, coronal, and sagittal axes to assess the reliability of the measurements. The ICC values were classified as highly reliable, if the result was greater than or equal to 0.90; reliable, between 0.75 and 0.90; acceptable, between 0.45 and 0.75; and poor, if less than or equal to 0.45.The SPSS v20.0 software (Chicago, IL, USA) was used to calculate the ICC. It was considered the mixed two-way model, with absolute agreement and a 0.95 confidence interval.

3. RESULTS

The frequency results of the intra and interobserver reliability for the MPR and Rec 3D are shown in Tables 2 to 6. The frequency of highly reliable values was higher in intraobserver assessment than in the interobserver assessment in the two types of visualization.

Table 2 shows the frequency of intraobserver reliability for the X, Y, Z, and total values to MPR. The ICC value was greater or equal to 0.90 on 51 assessments (77.27%), with higher frequency for the X coordinate (95.45%).

Table 1. Cephalometric landmarks

Crista galli (Cg)	Upper point of crista galli apophysis
Anterior nasal spine (ANS)	Most anterior point of the anterior nasal spine
Pogonion (Pog)	Point located on the center of the radiopaque image representing the chin's protuberance
Upper incisor (A1)	Median point over the upper interincisal papilla, on the crown-gingiva junction
Lower incisor (B1)	Median point over the lower interincisal papilla, on the crown-gingiva junction
Zygomatic (Z)	The most internal point of the frontozygomatic suture (left and right)
Zygomatic arch (Za)	Point at the most lateral border of the centre of the zygomatic arch (left and right)
Jugal (J)	Intersection of the maxillar tuberosity (lateral contour) with the zygomatic process contour (left and right)
Nasal Cavity (NC)	The most external point of the nasal cavity (left and right)
Antegonion (Ag)	Highest point in the antegonial notch (left and right)
Upper canine (A3)	Top of the upper canine's cusp (left and right)
Lower canine (B3)	Top of the lower canine's cusp (left and right)
Upper molar (A6)	The most prominent lateral point on the buccal surface of the first upper molar (left and right)
Lower molar (B6)	The most prominent lateral point on the buccal surface of the first lower molar (left and right)

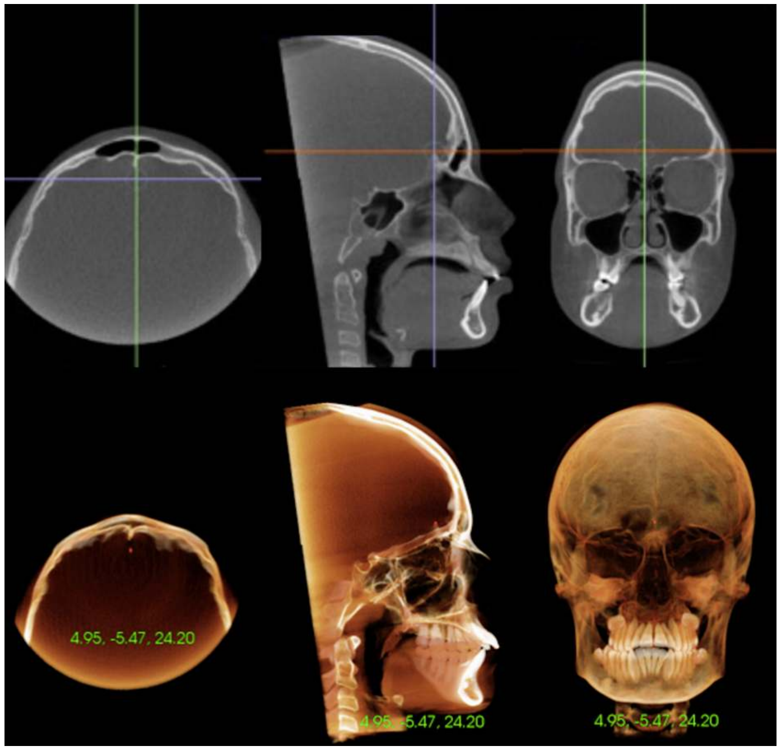

Fig. 1. Identification of the Crista galli (Cg) point, one of the landmarks used in the study. Multiplanar (upper; X, Y, and Z coordinates) and 3D reconstruction (lower) view

The Y and Z coordinates showed lower reliability (ICC ≤0.45) for two variables (9.09%), which represented four assessments in the total (6.06%).

The frequency of interobserver reliability for the MPR view is shown in Table 3. The ICC was greater or equal to 0.90 in 22 assessments (33.33%), with the highest frequency for the X coordinate (77.27%). The Z coordinate presented the lowest reliability, with 5 assessments in a total of 12 (18.18%).

Table 4 shows the frequency of intraobserver reliability for the Rec 3D. From 66 assessments, 54 (81.81%) presented the ICC ≥ 0.90. The Y coordinate showed the highest frequency (90.90%). There were five assessments (7.57%) with the ICC ≤ 0.45. X and Z coordinates contributed with two assessments in each one (9.09%).

The frequencies of interobserver reliability for the Rec 3Dshowed that all 19 assessments (28.78%) with ICC ≥ 0.90 belonged to the X coordinate (Table 5). From a total of 16 assessments (24.24%) that presented ICC ≤ 0.45, 14 (63.63%) belonged to the Z coordinate.

The estimated intra and interobserver reliability by ICC for each landmark evaluated with their respective X, Y, and Z coordinates for the MPR and Rec 3D can be seen in Table 6. In the same table, the clinical reliability is presented, following the criteria by the ICC range. Measurements with low reliability (ICC ≤ 0.45).

The points B1, A3(*l*), B3(*r*), B3(*l*), and A6(*l*) showed reliable performance (ICC> 0.75) when viewed through the MPR.

Values considered acceptable (0.45<ICC ≤0.75) in both types of view have been checked for points Cg, A6(*r*), B6(*r*), and B6(*l*). When the MPR view was separately analyzed, the points considered acceptable were ANS, Pog, Me, A1, and A3(*r*). For the Rec 3D, only the Ag(*r*) point was considered acceptable.

The points Z(*r*), Z(*l*), Za(*r*), Za(*l*), NC(*r*), NC(*l*), and Ag(*l*) showed low reliability (ICC ≤ 0.45) in both view modes. The points ANS, Pog, Me, A1, B1, A3(*r*), A3(*l*), B3(*r*), B3(*l*), and A6(*l*) had low reliability for the Rec 3D.

Table 2. Frequency of the intraobserver reliability estimated for the X, Y, and Z coordinates in the visualization of multiplanar reconstructions (MPR)

Range	Coordinates							
	X		Y		Z		Total	
	n	%	n	%	n	%	n	%
ICC≥0.90	21	95.45	18	81.81	12	54.54	51	77.27
0.75< ICC< 0.90	1	4.54	2	9.09	3	13.63	6	9.09
0.45< ICC ≤ 0.75	0	0.00	0	0.00	5	22.72	5	7.57
ICC ≤ 0.45	0	0.00	2	9.09	2	9.09	4	6.06
Total	22	100.0	22	100.0	22	100.0	66	100.0

Table 3. Frequency of the interobserver reliability estimated for the X, Y, and Z coordinates in the visualization of multiplanar reconstructions (MPR)

Range	Coordinates							
	X		Y		Z		Total	
	n	%	n	%	n	%	n	%
ICC≥0.90	17	77.27	0	0.00	5	22.72	22	33.33
0.75< ICC< 0.90	1	4.54	10	45.45	7	31.81	18	27.27
0.45< ICC ≤ 0.75	1	4.54	8	36.36	5	22.72	14	21.21
ICC ≤ 0.45	3	13.63	4	18.18	5	22.72	12	18.18
Total	22	100.0	22	100.0	22	100.0	66	100.0

Table 4. Frequency of the intraobserver reliability estimated for the X, Y, and Z coordinates in the visualization of 3D reconstructions (Rec 3D)

Range	Coordinates							
	X		Y		Z		Total	
	n	%	n	%	n	%	n	%
ICC ≥ 0.90	18	81.81	20	90.90	16	72.72	54	81.81
0.75< ICC< 0.90	1	4.54	0	0.00	3	13.63	4	6.06
0.45< ICC ≤ 0.75	1	4.54	1	4.54	1	4.54	3	4.54
ICC ≤ 0.45	2	9.09	1	4.54	2	9.09	5	7.57
Total	22	100.0	22	100.0	22	100.0	66	100.0

Table 5. Frequency of the interobserver reliability estimated for the X, Y, and Z coordinates in the visualization of 3D reconstructions (Rec 3D)

Range	Coordinates							
	X		Y		Z		Total	
	n	%	n	%	n	%	n	%
ICC ≥ 0.90	19	86.36	0	0.00	0	0.00	19	28.78
0.75< ICC< 0.90	3	13.63	2	9.09	2	9.09	7	10.60
0.45< ICC ≤ 0.75	0	0.00	18	81.81	6	27.27	24	36.36
ICC ≤ 0.45	0	0.00	2	9.09	14	63.63	16	24.24
Total	22	100.0	22	100.0	22	100.0	66	100.0

4. DISCUSSION

Several authors were concerned to validate marking cephalometric landmarks in 3D images [5,10,12,17-21]. Some studies have assessed the reliability and reproducibility of landmarks viewed preferably in cephalometric radiographs obtained in the lateral view. This study aimed to evaluate the points originally used by Ricketts [13,14] in radiographic images obtained in the posteroanterior view.

It seems obvious that accuracy in the identification of anatomical landmarks is related to greater or lesser experience of the operators. Selecting a graduate student in dentistry,

Table 6. Reliability estimated by intraclass correlation (ICC) for each landmark and each coordinate in the visualization of multiplanar (MPR) and three-dimensional (Rec 3D) reconstructions, and recommendation for clinical use

Landmark	MPR intraobserver			MPR interobserver			Rec 3D intraobserver			Rec 3D interobserver			Clinical reliability
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	
Cg	1.000	0.999	0.992	0.984	0.702	0.727	0.999	0.915	0.995	0.995	0.618	0.541	Acceptable both
ANS	0.993	0.997	0.962	0.968	0.774	0.587	0.976	0.986	0.746	0.975	0.783	-0.038	Acceptable MPR
Pog	0.991	1.000	0.837	0.903	0.787	0.563	0.809	0.964	0.996	0.878	0.308	0.547	Acceptable MPR
Me	0.993	0.998	0.976	0.913	0.734	0.936	0.907	0.693	0.972	0.909	0.403	0.035	Acceptable MPR
A1	0.999	0.999	0.934	0.978	0.707	0.765	0.961	0.986	0.993	0.967	0.737	0.314	Acceptable MPR
B1	0.999	0.998	0.971	0.970	0.780	0.971	0.957	0.975	0.973	0.962	0.671	0.138	Reliable MPR
Z(*r*)	0.988	0.969	0.107	0.980	0.815	0.800	0.992	0.998	0.966	0.996	0.706	0.022	Poor
Z(*l*)	0.997	0.976	0.498	0.990	0.790	0.061	0.995	0.980	0.970	0.995	0.715	0.243	Poor
Za(*r*)	0.835	0.849	0.789	0.240	0.189	0.242	0.997	0.982	0.898	0.992	0.726	0.320	Poor
Za(*l*)	0.926	0.862	0.569	0.673	0.181	-0.023	0.999	0.966	0.964	0.996	0.588	0.327	Poor
J	-	-	-	-	-	-	-	-	-	-	-	-	-------
NC(*r*)	0.977	0.979	0.674	0.990	0.695	0.196	0.992	0.977	0.841	0.990	0.689	0.252	Poor
NC(*l*)	0.981	0.986	0.544	0.957	0.704	0.159	0.963	0.966	0.852	0.969	0.691	0.281	Poor
Ag(*r*)	0.945	0.391	0.834	0.107	0.193	0.762	0.921	0.944	0.914	0.873	0.537	0.863	Reliable Rec 3D
Ag(*l*)	0.956	-0.316	0.411	-0.172	0.438	0.753	0.971	-0.302	-0.447	0.785	0.452	0.681	Poor
A3(*r*)	0.998	1.000	0.981	0.974	0.735	0.815	0.049	0.980	0.990	0.983	0.656	0.284	Acceptable MPR
A3(*l*)	0.999	0.999	0.994	0.968	0.782	0.907	0.493	0.986	0.955	0.939	0.698	0.193	Reliable MPR
B3(*r*)	0.960	0.987	0.975	0.891	0.804	0.860	0.949	0.972	0.985	0.954	0.738	0.126	Reliable MPR
B3(*l*)	0.975	0.987	0.992	0.929	0.839	0.900	0.970	0.973	0.979	0.980	0.768	0.172	Reliable MPR
A6(*r*)	0.998	0.975	0.976	0.961	0.689	0.974	0.985	0.974	0.945	0.987	0.740	0.756	Acceptable both
A6(*l*)	0.996	0.994	0.942	0.974	0.774	0.807	0.057	0.970	-0.015	0.957	0.668	0.637	Reliable MPR
B6(*r*)	0.999	0.999	0.976	0.949	0.739	0.665	0.968	0.977	0.955	0.962	0.710	0.497	Acceptable both
B6(*l*)	0.998	0.997	0.668	0.978	0.770	0.557	0.954	0.977	0.986	0.967	0.735	0.627	Acceptable both

r= right; l= left side

a specialist in orthodontics, and a radiologist, we tried to conduct the study with operators from different levels of training, similar to De Oliveira et al. [12].

As the localization of J point is established by image superimposition of two anatomical structures (maxillary tuberosity and zygomatic apophysis), it was not possible to mark this reference point in the MPR or the Rec 3D. Therefore, 22 anatomical landmarks were identified in each image generated by the three CBCT exams. The marking was repeated after a two-week interval. It is valid to assume that the greater the time interval between the markings, the more reliable the results will be, because the operators will landmarks be less able to remember their previous choices of landmark positions.

The ICC values were $\leq$0.45 for 15 landmarks in the 3D Rec visualization, while there were 8 landmarks for the MPR. In the present study, the correlation in marking the anatomical points is similar to the results reported by Da Neiva et al. [17]. Thus, the MPR were more reliable than the Rec 3Dconcerning landmark identification. Definitions adopted for the reference points were originally developed for 2D images related to cephalometric radiographs taken in the posteroanterior view. The greatest similarity between radiographic images and the multiplanar view could explain this result. In the multiplanar view the internal structures can be better evaluated, as in the radiographic images. It is also likely that some structures are less visible in the Rec 3D, unlike those completed by Couceiro and Vilella [9]. However, these authors used printed images, which may have influenced the results. In the present study, the images were evaluated directly on the screen. Furthermore, the evaluated points were not the same in both studies.

As occurred in previous studies, [12,17] the frequency of reliable values was higher in the intraobserver assessment than in the interobserver assessment in the two types of visualization. The frequency of ICC values in the MPR view was greater than 0.75 in 86.36% of intraobserver assessments, reaching 100% for the X coordinate, whereas the frequency for interobserver assessment was 60.6% (81.81% for the X coordinate).

When the 3D images were analyzed, it was observed that values higher than 0.75% occurred in 87.87% of the intraobserver assessments, against 39.38% of interobserver assessments. The poor results related to interobserver assessments were due to the low values found for the Y and Z coordinates (both 9.09%), in contrast to the results presented by Da Neiva et al. [17] in whose study the ICC values for the Y and Z coordinates were greater than 0.75%, representing 63.3% and 70.0%, respectively. Da Neiva et al. [17] redefined the points in 3 planes, whereas in the present research the definitions proposed by Ricketts in a single plan were used.

The variation between intra and interobserver assessments was higher for the Rec 3D (48.49%) than for the MPR visualization (25.76%). This result suggests that there should be an association between both visualization types to increase the reliability of marking the anatomical landmarks, as emphasized by Hassan et al. [20].

The points related to dental structures showed reliable [B1, A3(*l*), B3(*r*), B3(*l*), and A6(*l*)] or acceptable [A1, A3(*r*), A6(*r*), B6(*r*) and B6(*l*)] ICC values for the MPR. Regarding the Rec 3D, the A6(*r*), B6(*r*), and B6(*l*) points proved to be acceptable. The results for the MPR were similar to those found by other authors [12,17,19] who evaluated the points related to central incisors and first molars. With respect to the Rec 3D, the values were lower.

The Cg point showed acceptable values for the two visualization types. The ANS, Pog, and Me landmarks were acceptable only for MPR views. De Oliveira et al. [12] and Da Neiva et al. [17] found higher ICC values when evaluating these points. The results suggest that points located on the sagittal plane are more easily identifiable due to the similarity between the sagittal slice and the cephalometric lateral radiograph [21]. This reasoning can also be applied with respect to the Cg point, due to the similarity between the coronal slice and the posteroanterior cephalometric radiograph.

Regarding the landmarks located on both sides of the skull, only the Ag(*r*) point presented acceptable values for the Rec 3D. The points Z(*r*), Z(*l*), Za(*r*), Za(*l*), NC(*r*), NC(*l*), and Ag(*l*) showed poor reliability. The fact that the authors of this study adopted the radiographic definition may have contributed to this result, because some points developed for 2D frontal projection do not seem to be useful for 3D visualization. In a future study, it would be interesting if the landmarks could be defined in the three planes of space or new anatomical references could be adopted.

5. CONCLUSION

The multiplanar reconstructions allow for greater reliability in the identification of anatomical landmarks related to the Ricketts frontal analysis, both in the intra and in the interobserver evaluations.

CONSENT

It is not applicable.

ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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