Imaging and Radiation Research (2021) Volume 4 Issue 1
doi:10.24294/irr.v4i1.1733

ORIGINAL RESEARCH ARTICLE

Quantification of the distortion present in the postero-anterior skull radiograph

Janneth Rocío Zúñiga Prado, Elizabeth Peña Tobar, Gloria Patricia Baena-Caldas*

Universidad del Valle, Cali, Colombia. E-mail: gloria.baena@correounivalle.edu.co

ABSTRACT

Introduction: It is universally accepted that the posteroanterior skull radiograph shows a lower degree of distortion than other radiographic images, so that measurements on it are considered reliable. **Objective:** To determine the percentage of distortion in the different facial regions of the postero-anterior skull radiograph. **Methods:** Thirty human skulls with their jaws were divided by three horizontal and four vertical planes into fifteen quadrants; there were ten in the skull and five in the jaw. On each of them a steel wire was placed in vertical and horizontal positions and their length (actual measurement) was measured. Each set was X-rayed in posteroanterior projection and the length of the wires was measured in the image (radiographic measurement). **Results:** It was not possible to measure in the lateral quadrants of the skull. The horizontal measurement in the right and left lower intermediate quadrants of the skull and in the intermediate and lateral quadrants of both sides of the mandible is not reliable; in the median quadrant of the mandible it is minimized; in the right and left upper intermediate and median quadrants of the skull and in the median of the mandible it is magnified. Vertical measurements in all quadrants are reliable; in the right and left upper intermediate and left upper and middle quadrants of the skull and in the right and left middle and lateral quadrants of the mandible it is magnified; in the lower intermediate and upper and lower middle quadrants of the skull and median of the mandible it is minimized. The least distortion for both measurements occurs in the upper median quadrant of the skull. Percentages of distortion are reported for each quadrant. **Conclusions:** Distortion is present in the posteroanterior skull radiograph and varies from one region of the face to another.

Keywords: Dental Radiography; Radiographic Magnification; Cephalometry; Skull

ARTICLE INFO

Received: 4 April 2021
Accepted: 25 May 2021
Available online: 1 June 2021

1. Introduction

Traditionally, in diagnostic imaging, the exact correspondence between the shape and size of the actual anatomical structures and their radiographic projection is known as 1:1 ratio. In contrast, the absence of the 1:1 ratio is known as distortion[1]. In clinical practice, it has been accepted that the postero-anterior skull radiograph shows minimal distortion with respect to the real object, although there may be factors that alter this 1:1 ratio, such as errors due to the radiographic projection technique[1].

Panoramic, lateral and posteroanterior skull radiographs are extremely useful for diagnostic, surgical and forensic measurements[2–4]. Knowing the precise dimensions of a conventional radiographic image or its distortion reduces the risk of injuring vasculo nervous structures, since their location in relation to visible bony structures can be predicted and more precise measurements can be taken prior to surgery[5,6]. On the other hand, conventional radiography is of utmost importance if we take into account that it is one of the most requested diagnostic aids by health professionals, and it is one of the previous steps to prescribe more complex and expensive complementary studies, such as cone beam computed tomography and magnetic resonance imaging[5,7].

An alternative to have greater diagnostic accuracy and to make the procedure more predictable and reliable is the use of tomographic studies. Even so, cone beam computed tomography, universally considered as 1:1, presents some distortion although not significant, as evidenced by the work done by Baena *et al.*[8] in 2013, with the aggravating factor that its high cost makes it unaffordable to many patients. This is why obtaining the maximum possible information from a conventional radiograph is invaluable for the health professional, so different comparative studies have been carried out between conventional radiographs and computed tomography[9,10,11].

According to the literature review conducted for this study, the distortion that can occur in the various existing radiographic projections of the skull has not been quantified or standardized for the different facial regions. For this reason, the aim of this study was to determine the percentage of distortion presented in the different facial regions of the postero-anterior skull radiograph.

2. Methods

Thirty dry human skulls with their respective mandibles, well preserved and without trauma, belonging to the Department of Morphology of the Universidad del Valle in Cali, Colombia, were used. The calvaria and the mandible were fixed to the skull; in the edentulous skulls, an intercrestal space of approximately 15 mm was left between the edges of the alveolar bone crests of the maxilla and the mandible. The calculation of this value was based on the fact that normally, the upper central incisors have an approximate length of 9–11 mm, the lower central incisors 8–10 mm and that the “overbite” or vertical overbite presents normal values between 0 and 4 mm[12]; additionally, bone resorption was included, which can be 1–3 mm[13]. Therefore, in order to simulate the space that the teeth would occupy and maintain it in the skulls, a thick, non-deformable foam block of the appropriate dimensions was placed in the intercrestal space. Similarly, 5 mm thick soft foam blocks were placed in the temporomandibular joints to recreate the joint space.

To fulfill the objective of determining the distortion presented by the posteroanterior skull radiograph in different regions of the skull, the skull and mandible were divided into 15 quadrants, for which three horizontal planes and four vertical planes were drawn, and a rectangular stainless steel wire of different lengths and in vertical and horizontal positions was placed in each quadrant as an anatomical and radiographic reference; a posteroanterior skull radiograph was taken in each quadrant.

Figures 1 and **2** show the horizontal planes A, B and C and vertical planes I, I', II and II' in which the skull and mandible were divided (**Figure 1**), as well as the radiographic images (**Figure 2**). The horizontal planes divide into upper, middle and lower craniofacial thirds, while the vertical planes delimit the median and intermediate and right and left lateral regions. Plane A passes through the steepest part of the infraorbital rims, plane B passes through the occlusal plane and extends only to the anterior border of each ramus of the mandible, and plane C is parallel to the inferior border of the chin. The occlusal plane is the plane drawn between the incisal edges of the lower incisor teeth and the tips of the buccal cusps of the lower molars; it is not normally a plane, however, it is considered the midplane of the curvature of these surfaces[14]. Since the present work had edentulous skulls and mandibles, but a 15 mm intercrestal space was preserved, and the occlusal plane was traced through the middle of this space. In the upper third are essentially the orbits, the upper part of the nasal cavity and the upper part of the skull up to its apex. The middle third contains mainly the lower part of the nasal cavity and most of the maxillae. The lower third basically corresponds to the mandible with its body and branches.

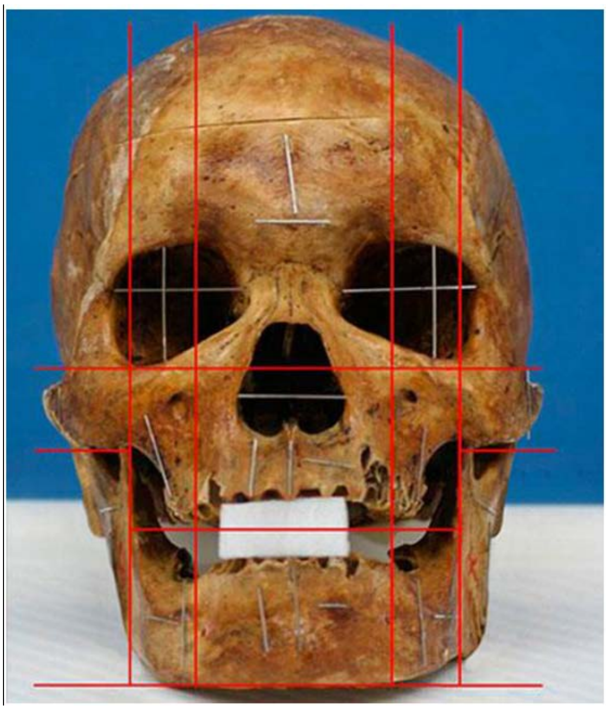

Figure 1. Frontal view of one of the dry skulls used in the study, showing the foam placed in the intercrestal space to simulate the space that the teeth would occupy. Also shown are the three horizontal and four vertical planes drawn to delimit the 15 quadrants in the skull and jaw, as well as the location of rectangular stainless-steel wires of different lengths, positioned vertically and horizontally.

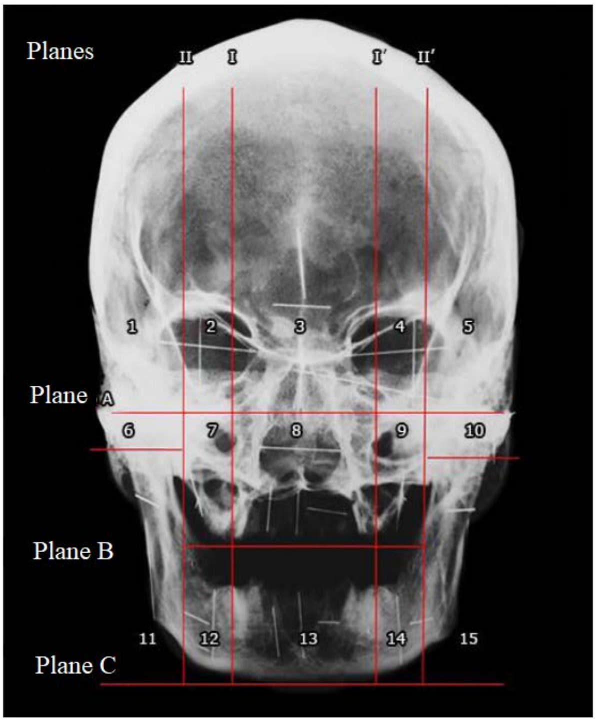

Figure 2. Postero-anterior radiograph of the skull with horizontal planes A, B and C and vertical planes I, I', II and II' used to delimit the 15 quadrants into which the skull and mandible were divided. The radiological image of the rectangular wires of different lengths placed vertically and horizontally in each of the 15 quadrants is also shown.

Planes I and I' pass through the most medial border of the right and left infraorbital foramina respectively, and planes II and II' pass through the anterior border of each ramus of the mandible. The median region located between planes I and I', the right and left intermediate regions located between planes I and II and planes I' and II' respectively, and the right and left lateral regions located laterally to planes II and II' respectively, were thus delimited. With the thirds and regions thus delimited, 15 quadrants were demarcated and numbered from 1 to 15, successively from top to bottom and from right to left. It is pertinent to clarify that, since plane B only extends to the anterior border of each branch of the mandible, in the right and left lateral regions a small horizontal plane was drawn at the level of the inferior border of the zygomatic arch in order to delimit middle and inferior right and left lateral quadrants; so that quadrants 6 and 10 corresponded to the zygomatic arch on each side and quadrants 11 and 15 covered the entire branch of the mandible on both sides. This is because in clinical practice, the mandibular ramus is considered as a single unit when measurements are taken on it.

The anatomical and radiographic reference that was placed in each quadrant to take the horizontal and vertical measurements is a rectangular stainless-steel wire of 0.019 mm high × 0.025 mm wide, but of different lengths, as shown in **Figure 1**. The set of skulls and their jaws with the wires positioned, were taken to a radiological center in the city of Cali to take the corresponding posteroanterior skull radiograph, simulating that of a patient. Bilaterally, a 1 cm^3 thick, non-deformable foam block was placed at the level of the pterion to support the radiographic equipment. The equipment warheads were introduced in both external auditory canals in order to place the skull with the Frankfort plane[15] parallel to the floor and to center the midline, to avoid possible rotations of the skull. A posteroanterior radiograph was taken of each skull, at a distance of 1.8 m from the specimen, using 20.3 cm × 25.4 cm plates, with Orthophos Plus Ceph equipment (Dentsply Sirona, New York, USA). Due to the absence of soft tissues, the radiographs were taken with a tube voltage and current of 60 kV and

9 mA respectively. To achieve a better contrast between the bone and the radiopaque material used as a reference, two veiled radiographs were placed inside the chassis, one in front of and one behind the radiographic plate that was to be hit by the X-rays. Likewise, the plate had to be passed very quickly through the developing liquid (60 s).

Measurements of the wires placed on the skulls (**Figure 1**) and of these on the radiographs (**Figure 2**) were taken with a Bulltools electronic digital caliper (Bulltools, Maxwell, San Diego, USA), with a resolution of 0.01 mm/0.0005", precision of ±0.02 mm/0.001" and repeatability 0.01 mm/0.0005". After every fifth measurement, it was calibrated with a KLS MARTIN compass (Karl Leibinger Medizintechnik, Tuttlingen, Germany) with extra-fine and straight tips. All measurements, both real and radiographic, were performed by the same researcher (Zúñiga) but the cutting of the wires and their placement in the skulls and jaws were performed by the other two (Peña and Baena). The data were recorded in a format specially designed by the researchers for this work and the only variable considered in the study was the length of the wires, which was measured both in the dry skulls and jaws (real measurement) and in the radiological images of the wires (radiographic measurement).

For the statistical analysis of the data, which consists of comparing the real measurements with the radiological measurements and obtaining the difference between the two, an electronic spreadsheet in Excel (Microsoft Corporation, Redmond WA, USA) was used, designed especially for this work by Professor Hugo Hurtado, Master in Public Health and Biostatistics of the Universidad del Valle, in Cali, Colombia. Taking into account that the objective of this study was to measure the concordance or discordance between the real measurement and the radiographic measurement, it was considered that the test best suited to achieve this purpose was the concordance correlation coefficient (CCC); likewise, the confidence interval of the concordance correlation coefficient (ICccc) was calculated and the mean of the differences and the radiographic measurement *versus* the real measurement were plotted. These graphs are not published in the current text for space reasons, but can be consulted with the principal investigator (Zúñiga).

The aforementioned analysis was applied in each of the 30 skulls to each of the vertical and horizontal measurements in the quadrants in which it was possible to take them. The analysis of the results was performed based on a scale of values, according to which CCC values close to 1 indicate that the concordance between the two measurements is maximum, i.e. the difference between them is close to zero (0); CCC values between 0 and 0.10 are considered very low, between 0.11 and 0.39 low, between 0.40 and 0.79 moderate, between 0.80 and 0.89 high and above 0.90 very high[8]. Only the CCC values whose confidence intervals (CI) had a lower limit equal to or greater than 0.80 were considered high or very high and the measurements taken in the quadrants that had such values were considered reliable. The present work was endorsed by the Human Ethics Committee of the Universidad del Valle.

3. Results

Due to the lateral position, in quadrants 1 and 5, it was not possible to determine the location of the ends of the wires to measure their length and they were eliminated. It was also impossible to obtain the CCC in quadrants 6 and 10 because there is a great overlapping of the anatomical structures, which generates very radiopaque images that do not allow to differentiate well the wires placed in them to measure them.

The results obtained for the vertical and horizontal measurements are shown in **Tables 1** and **2** respectively. For reasons of space, only the results obtained in one of the reliable quadrants are explained, quadrant 2 for the vertical measurements: the CCC for this quadrant is 0.9634, with an ICccc between 0.9421 and 0.9846, which indicates that the agreement between the real and radiographic measurements is very high and the mean of the differences (δ) between these measurements is reliable, with an average value of 0.59 mm and a 95% CI of 0.49 mm–0.69 mm. In this quadrant the radiographic measurement is higher than the real one, which represents a magnification percentage of 1.70%, where the upper and lower limits expressed in percentages are 1.99% and 1.41% respectively.

Figure 3 shows the percentages of distortion presented in each of the quadrants for the vertical and horizontal measurements.

Table 1. Vertical measurement by quadrant for postero-anterior skull radiographs

Square	**Confidence interval**			**Limits of difference**			**Concept**
	Superior	**Medium**	**Lower**	**Superior**	**Medium**	**Lower**	
2	0.9846	0.963	0.9421	1.99	1.70	1.41	Reliable
3	0.9982	0.993	0.9884	0.75	–0.48	-1.72	Reliable
4	0.9880	0.972	0.9565	1.54	1.36	1.17	Reliable
7	0.9936	0.977	0.9618	0.40	–0.92	-2.24	Reliable
8	0.9965	0.987	0.9782	–0.12	–1.58	-3.04	Reliable
9	0.9951	0.981	0.9685	–0.07	–1.20	-2.34	Reliable
11	0.9930	0.979	0.9669	4.85	3.48	2.11	Reliable
12	0.9943	0.983	0.9730	2.51	0.35	-1.82	Reliable
13	0.9965	0.987	0.9786	1.54	–0.10	-1.75	Reliable
14	0.9933	0.982	0.9726	2.69	0.84	-1.02	Reliable
15	0.9876	0.964	0.9411	5.12	3.47	1.81	Reliable

* Negative values indicate minimization, others magnification.

Table 2. Horizontal measurement per quadrant for postero-anterior skull radiography

	Confidence interval			**Limits of difference**			**Concept**
	Superior	**Medium**	**Lower**	**Superio**	**Medium**	**Lower**	
2	0.9858	0.9646	0.9433	1.17	0.98	0.79	Reliable
3	0.9960	0.9898	0.9836	3.01	2.51	2.02	Reliable
4	0.9830	0.9599	0.9368	1.40	1.21	1.01	Reliable
7	0.1724	0.1012	0.0301	-58.33	-	-73.42	No
8	0.9901	0.9696	0.9491	1.84	1.36	0.87	Reliable
9	0.1219	0.0535	-0.0149	-59.43	-	-78.96	No
11	0.0860	0.0513	0.0166	-58.70	-	-68.03	No
12	0.5717	0.4161	0.2604	-26.10	-	-35.57	No
13	0.9939	0.9805	0.9671	-2.80	-4.50	-6.21	Reliable
14	0.5844	0.4318	0.2792	-27.95	-	-37.74	No
15	0.0611	0.0294	-0.0022	-55.01	-	-67.07	No

* Negative values indicate minimization, others magnification.

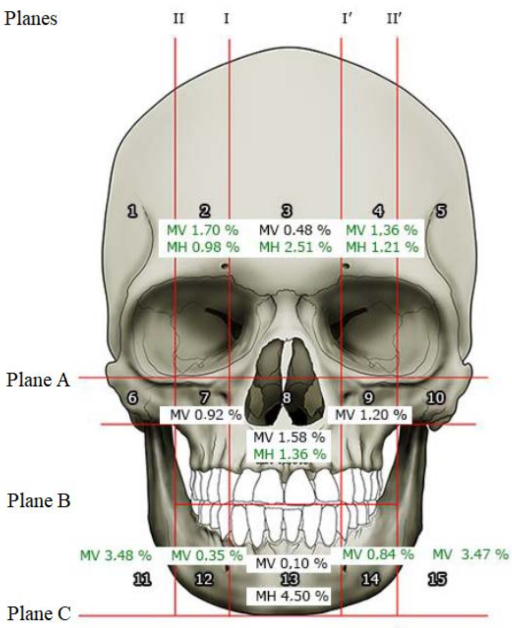

Figure 3. Scheme made based on the data in tables 1 and 2, showing the percentage of distortion present in each of the 15 quadrants.

Note: The vertical measurements (MV) in quadrants 3, 7, 8, 8, 9 and 13 are of minimization and in the others are of magnification. The horizontal measurement in quadrant 13 is of minimization and in the others is of magnification.

4. Discussion

Given that in quadrants 7, 9, 11, 12, 14 and 15 the CCC for horizontal measurements is less than 0.80, indicating that the agreement in them is null, low or moderate, and that the mean of the differences between real and radiographic measurements (δ) is not reliable, it is advisable not to take reference measurements in these quadrants. Horizontal measurements in paramedian quadrants 7, 9, 12 and 14 and lateral quadrants 1, 5, 6, 10, 11 and 15 are also unreliable. This may be due to the variable direction with which the X-rays emitted by the source contact the bony structures of the skull. In structures such as the maxillomolar pillar, the region of the tuberosity of the maxilla or the body of the mandible, where initially a posterior curve is generated and then, from the mandibular angle, it turns upwards to form the ramus, the direction in which the rays strike them is not always perpendicular and in some parts they do so tangentially, with varying degrees of angulation, greatly affecting the horizontal measurement. The same does not occur with the vertical measurement, since all the wire is on the same plane and the rays strike in a similar way along the whole length of it; this is why in the vertical measurements taken in all the quadrants considered, the CCC is higher than 0.90, which indicates that the concordance is very high and the Mean Difference between the radiographic and real measurements (δ) is reliable, with a confidence interval of 95%.

Given that in quadrant 13 the horizontal measurement is minimized, while in quadrants 2, 3, 4 and 8 it is magnified and that the vertical measurement in quadrants 3, 7, 8, 9 and 13 is minimized and in quadrants 2, 4, 11, 12, 14 and 15 it is magnified, it is possible to affirm that in the posteroanterior skull radiographs the ratio of the real versus the radiographic measurements is not 1:1 in all the extension of the plate, as is generally accepted. Therefore, it is evident that distortion exists and, even if it is not significant in some quadrants, there is not a single quadrant in which it is not present. Although the distortion in the quadrants is variable, when comparing those on the right side with the corresponding ones on the left side, for example, quadrant 2 with quadrant 4, quadrant 7 with quadrant 9, quadrant 12 with quadrant 14, etc., it is evident that the distortion, whether due to magnification or minimization, is similar and this supports the use of this radiograph to evaluate facial asymmetries. The greatest distortion in the horizontal measurements was in quadrant 13 (4.50% of minimization), while in the vertical measurements it was in quadrants 11 and 15 (3.48% and 3.47% of magnification, respectively).

Performing measurements in quadrants of high or very high reliability, taking into account the percentage of magnification or minimization, can be very useful, such as those taken in the aditus of the orbit, frontal region, frontomalar pillar, supraorbital, infraorbital and mental foramina, ethmoidal and maxillary sinuses, pyriform opening of the nasal cavity and nasal conchae, among others. In this regard, Ghorai *et al.*[16] were able to determine the sex of the skulls using radiographs with the Caldwell projection technique to measure the opening or aditus of the orbits and the distance between the medial wall of the orbits.

It should be emphasized that improper positioning of the patient, especially when the head is rotated, generates extreme alterations in the size and shape of the anatomical structures, producing greater distortion in each quadrant[17,18]. In this regard, Damastra *et al.*[19] compared postero-anterior skull radiographs with cone beam computed tomography to detect mandibular asymmetries, and found that the tomographic images were more reliable and accurate; therefore, it is inferred that if surgical correction is required, it would not be advisable to use only postero-anterior skull radiography for its planning.

Standardizing the distortion for each quadrant of the skull and jaw is very important to ensure that the images of postero-anterior skull radiographs are used in a more reliable and safe way, and that treatments can be planned in a more predictable way and with less possibility of error. To date, no published work has been found that reports in detail the percentage of distortion, either magnification or minimization, that is present in the different regions of the skull and mandible, with data for vertical and horizontal measurements, as the present work does. Since the highest percentage of distortion occurs in the lateral quadrants of the skull, it is recommended to use a more precise radiological method when working in these regions, such as cone beam computed tomography. Finally, it is advisable to divide the skull and mandible into the quadrants postulated in this study and apply the necessary corrections to the horizontal and vertical measurements taken in them, taking into account the percentages of magnification or minimization provided by this study.

5. Conclusions

The postero-anterior skull radiograph is not a

1:1 image because distortion was present in all facial regions, which varied for vertical and horizontal measurements, being more reliable those of the central and paramedian regions of the upper third of the skull. On the other hand, the percentage of distortion for vertical and horizontal measurements is relatively small and is similar in the corresponding quadrants of each side of the skull.

Acknowledgments

The authors would like to thank Mr. Fabián Cabrera for processing and editing the images, and Professor Hugo Hurtado for his contribution to the statistical analysis of the data.

Conflict of interest

No conflict of interest is declared by the authors.

References

1. Méndez JA. Evaluación de la distorsión en las radiografías laterales cefalométricas tomadas en nuestro medio (Spanish) [Evaluation of distortion in cephalometric lateral radiographs taken in our environment]. Revista Odonto Ciencia 2002; 11: 15–30.
2. Kim JY, Jung HD, Jung YS, *et al*. A simple classification of facial asymmetry by TML system. Journal of Cranio-Maxillofacial Surgery 2014; 42(4): 313–320.
3. Perez I, Chavez AK, Ponce D. Applicability of the Ricketts' postero-anterior cephalometry for sex determination using logistic regression analysis in Hispano American Peruvians. Journal of Forensic Dental Sciences 2016; 8(2): 111.
4. Verma K, Nahar P, Singh MP, *et al*. Use of frontal sinus and nasal septum pattern as an aid in personal identification and determination of gender: A radiographic study. Journal of Clinical and Diagnostic Research 2017; 11(1): ZC71–ZC74.
5. Verma P, Verma K, Khosa R, *et al*. Combined use of frontal sinus and nasal septum patterns as an aid in forensics: A digital radiographic study. North American Journal of Medical Sciences 2015; 7(2): 47–52.
6. Su N, van Wijk A, Berkhout E, *et al*. Predictive value of panoramic radiography for injury of inferior alveolar nerve after mandibular third molar surgery. Journal of Oral and Maxillofacial Surgery 2017; 75(4): 663–679.
7. Sanders DA, Chandhoke TK, Uribe FA, *et al*. Quantification of skeletal asymmetries in normal adolescents: Cone-beam computed tomography analysis. Progress in Orthodontics 2014; 15(1): 26.
8. Baena G, Zúñiga J, Peña E. Distorsión en imágenes obtenidas mediante tomografía computarizada de cono (Spanish) [Distortion in images obtained by cone computed tomography]. Revista Española de Cirugía Oral y Maxilofacial 2013; 35(2): 51–58.
9. Pittayapat P, Bornstein MM, Imada TSN, *et al*. Accuracy of linear measurements using three imaging modalities: Two lateral cephalograms and one 3D model from CBCT data. European Journal of Orthodontics 2014; 37(2): 202–208.
10. Lee HJ, Lee S, Lee EJ, *et al*. A comparative study of the deviation of the chin on postero-anterior cephalograms and three-dimensional computed tomography. Imaging Science in Dentistry 2016; 46(1): 33–38.
11. Park HY, Lee JS, Cho JH, *et al*. Accuracy of three-dimensional cephalograms generated using a biplanar imaging system. Korean Journal of Orthodontics 2018; 48(5): 292–303.
12. Choi SH, Kim JS, Kim CS, *et al*. Cone-beam computed tomography for the assessment of root-crown ratios of the maxillary and mandibular incisors in a Korean population. Korean Journal of Orthodontics 2016; 47(1): 39–49.
13. Carranza N, Bonta H, Gualtieri AF, *et al*. Alveolar dimensional changes relevant to implant placement after minimally traumatic tooth extraction with primary closure. Acta Odontologica Latinoamericana 2016; 29(2): 105–114.
14. Shaikh SA, Lekha K, Mathur G. Relationship between occlusal plane and three levels of ala tragus line in edentulous and partially edentulous patients in different age groups: A pilot study. Journal of Clinical and Diagnostic Research 2015; 9(2): ZC39–42.
15. Huh YJ, Huh KH, Kim HK, *et al*. Constancy of the angle between the Frankfort horizontal plane and the sella-nasion line: A nine-year longitudinal study. Angle Orthodontist 2014; 84(2): 286–291.
16. Ghorai L, Asha M, Lekshmy J, *et al*. Orbital aperture morphometry in Indian population: A digital radiographic study. Journal of Forensic Dental Sciences 2017; 9(2): 61–64.
17. Gaddam R, Shashikumar HC, Lokesh NK, *et al*. Assessment of image distortion from head rotation in lateral cephalometry. Journal of International Oral Health 2015; 7(6): 35–40.
18. Shokri A, Miresmaeili A, Farhadian N, *et al*. Effect of changing the head position on accuracy of transverse measurements of the maxillofacial region made on cone beam computed tomography and conventional posterior-anterior cephalograms. Dentomaxillofacial Radiology 2017; 46(5): 1–12.
19. Damstra J, Fourie Z, Ren Y. Evaluation and comparison of posteroanterior cephalograms and cone-beam computed tomography images for the detection of mandibular asymmetry. European Journal of Orthodontics 2013; 35(1): 45–50.