

Orthodontists Reproducibility and Accuracy in Linear and Angular Measurement on 2d Digital and 3d Cbct Radiographic Examination

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Abstract

The use of Cone Beam Computed Tomography (CBCT) in orthodontic is evolving. Orthodontists' ability in using the CBCT radiographic images as a diagnostic aid remains to be investigated. The aim of this research is to compare the orthodontist reproducibility and accuracy in measuring distances and angles on 2D digital conventional and 3D CBCT radiographic examination. One (1) dry skull was scanned twice with Vatech digital radiographic machine and I-CAT CBCT, using guttap-percha as fiducial markers and without guttap percha. The radiographic images without guttap-percha were displayed by OsiriX software. 34 orthodontists performed cephalometric analysis on both types of radiographic images. Results: The reproducibility of anatomical landmarks between the 2D and 3D radiographic images was different on X coordinate of the A, B and Go, X and Y coordinates of the ANS, and Y coordinate of the PNS and Me. No significant differences between the linear measurement and the gold standard on the 2D and 3D radiographic images were found for Go-Me and UAFH. There were statistically significant differences between the angle measurement and the gold standard on 2D and 3D radiographic images, but not clinically significant for SNB and ANB. There were no significant differences in the accuracy of linear and angles measurement on the 2D and 3D CBCT radiographic images, except for SNA.

The orthodontists' reproducibility in determining some anatomical landmarks on 2D and 3D radiographic examination is different. Orthodontists' accuracy in measuring distances and angles on 2D and 3D radiographic examination is no different.

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Introduction

Conventional cephalometry is one of the standard diagnostic tools for analyzing orthodontic cases. It is used to evaluate the craniofacial complex, diagnosis of anomalies, determination of morphology and growth, investigation of relationship between craniofacial complex with dental structure, planning treatment and evaluating the growth and treatment.¹⁻³

In 1998, the use of cone beam computed tomography (CBCT) in dentistry was introduced. Since that, the popularity of CBCT had increased

rapidly. Scan results taken from CBCT could give a representation of the patient's head and simulation of surgical procedures. CBCT found to be helpful in some cases such as orofacial cleft, dentofacial deformity, and impaction teeth cases. However, the higher radiation dose of a CBCT scan makes it could not replace the conventional radiograph as a regular diagnostic tool.⁴⁻⁷

There are several studies investigated the ability of CBCT radiographic images in cephalometry analysis. Vlijmen et al and Kumar et al compared between conventional radiographs and CBCT radiographic image in measuring some variables in cephalometry analysis. Kumar et al reported that there was no significant difference between both types of radiographic images except for the mandibular length. Meanwhile Vlijmen et al stated that there was clinically significant difference between the distance and angle measurements on

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conventional radiograph and 3D CBCT radiographic image.^{8,9}

Although the use of CBCT became more popular, many orthodontists haven't truly understood how to utilize the diagnostic data taken from CBCT. The ability of CBCT radiographic images as diagnostic tool remains to be investigated. The purpose of this study was to compare the orthodontists' reproducibility and accuracy in measuring distances and angles on 2D digital conventional and 3D CBCT radiographic examination.

Materials and methods

Radiography

One dry skull was borrowed from Department of Anatomy, Universitas Indonesia. The skull was selected with the following criteria: presence of permanent upper and lower incisors; presence of first permanent upper and lower molars; presence of a reproducible and stable occlusion. Nine landmarks were identified on each skull and labeled with heated guttap percha by BS and K. The mandible was related to the skull based on the position of the condyle in the fossa and maximum occlusal interdigitation. The mandible was fixed with broad tape from the ipsilateral temporal bone around the horizontal ramus of the mandible to the contralateral temporal bone.

The skull was scanned with I-CAT CBCT (Imaging Sciences International, Inc. Hatfield, USA) machine and Vatech (Vatech America, Inc. New Jersey, USA) digital imaging machine. The skull was placed in an acrylic box, and the box was placed on the headrest of the I-CAT machine to mimic the position of the patient's head. The position of the skull in the acrylic box was arranged so that the midsagittal plane coincided with the midline light beam. Once the skull was in proper position, the skull was then fixed with wax. The I-CAT CBCT scan was taken in 22 cm field of view, 120 kVp; 18.54 mAs, with a 0.4 voxel resolution. The size of voxel resolution was chosen based on the previous study by Berco et al and Damstra et al.^{10,11}

The same skulls were positioned in the cephalostat on the Vatech digital imaging machine by fixing it between the ear rods. The ear rods were placed in the pori accoustici externi and the Frankfurt Horizontal was parallel to the floor. Cephalometrics radiographs were

taken according to the following radiographic settings: 84 kVp; 10 mA. The skull was scanned twice with each modality. First, we scanned the skull with guttap percha as landmark. Then, the guttap percha were detached and the skull was scanned again in the same position. The radiographic images with guttap percha from both modalities were used as the gold standard.

Cephalometry

The 3D radiographic image from I-CAT CBCT machine was saved as DICOM file. The 2D radiographic image from Vatech digital radiographic machine was saved as TIFF and converted to DICOM file. Both images were displayed with OSIRIX software (Pixmeo Sarl, Inc. Bernex, Switzerland). Same software was used to identify and measure distances and angles. The 3D radiographic image was displayed from lateral view and the slice thickness was arranged so all landmarks could be identified (Thickness = 88). The 2D radiographic image was calibrated before analyzed (1 pixel = 0.273891).

Both radiographic images (Figure 1) were analyzed by 34 orthodontists with the following criteria; member of IKORTI (Indonesian Association of Orthodontists); had experience minimum 3 years after graduated; maximum age 55 years old; and still active as an orthodontist. All orthodontists identified 9 landmarks and measured 7 widely used cephalometric analysis (Table 1) twice for both radiographic images, each time with an interval of 1 week.¹²⁻¹⁵

Landmark	Definition
Sella (S)	Center of pituitary fossa of the sphenoid bone.
Nasion (N)	Intersection of the internasal suture with the nasofrontal suture in the midsagittal plane.
PointA (A)	Deepest point of the curve of the maxilla, between anterior nasal spine and the dental alveolus.
Point B (B)	Deepest point in the concavity along the anterior border of the symphysis.
Anterior nasal spine (ANS)	The tip of the anterior nasal spine
Posterior nasal spine (PNS)	The most posterior point of the posterior nasal spine.
Gonion (Go)	Most convex point where the posterior inferior curve of the ramus meet the body of mandible.
Menton (Me)	Most inferior point of the symphysis.
Pogonion (Pog)	Most anterior point on the mid-sagittal symphysis.
ANS-PNS	Distance between point ANS and PNS (mm)
Go-Me	Distance between point Go and Me (mm)
Upper Anterior Facial Height (UAFH)	Distance between N and ANS (mm)
Lower Anterior Facial Height (LAFH)	Distance between ANS and Me (mm)
SNA	Angle between point S, N, and A
SNB	Angle between point S, N, and B
ANB	Angle between point A, N, and B

Table 1. Lateral cephalometric landmark, distances and angles in this study.



Figure 1. 2D digital and 3D CBCT radiographic examination in this study.

Statistical Analysis

Intra-observer reliability was calculated using paired t-test and Bland-Altman. The landmarks position was recorded in the format of x and y coordinates. The mean position of the 9 landmarks identified by 34 orthodontists was defined as the “gold standard”. The reproducibility was calculated by measuring the mean distance in millimeters between the “gold standard” and the locations identified by the 34 orthodontists. The reproducibility of landmark identification in each of two radiographic images could be compared as the difference in magnitude of the distance from the mean,

between radiographic images. Reproducibility could also be compared visually with the 95% confidence ellipse scatterplot. Scatterplot with smaller ellipse means that it has better reproducibility (Figure 2-10).

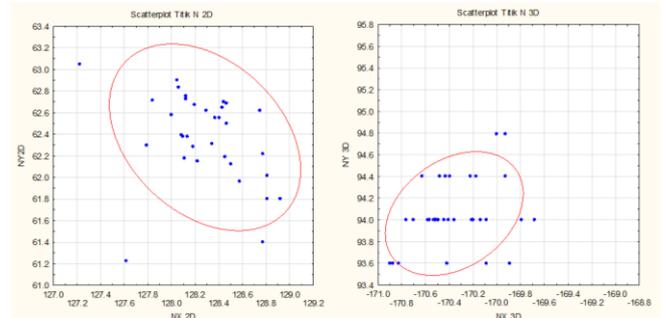


Figure 2. Scatterplot diagram of landmark S.

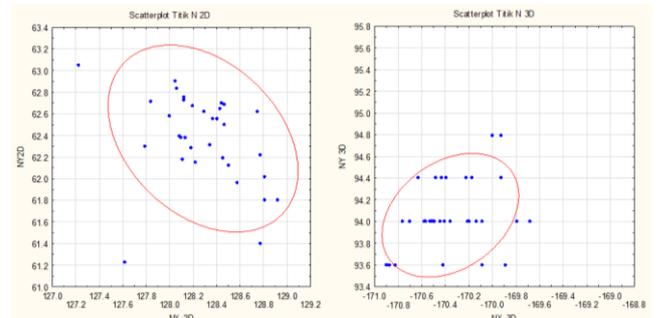


Figure 3. Scatterplot diagram of landmark N.

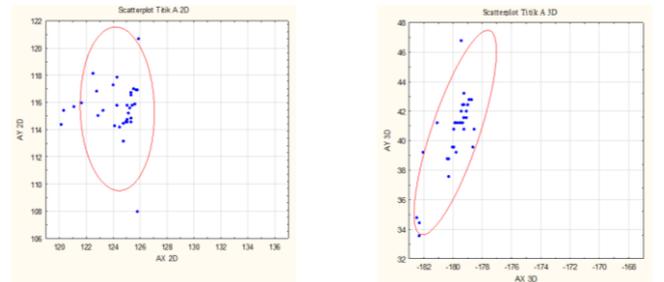


Figure 4. Scatterplot diagram of landmark A.

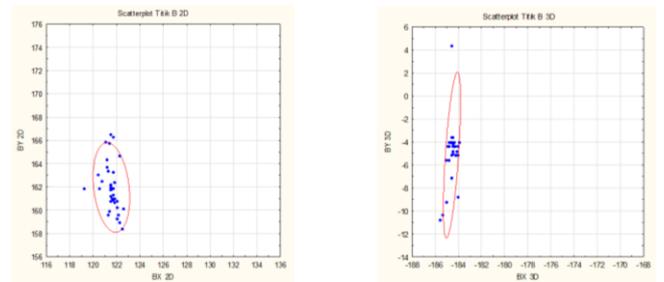


Figure 5. Scatterplot diagram of landmark B.

The radiographic images taken from the skull with guttap percha were analyzed with the same software to measure the distances and

angles. The results were used as the gold standard. Orthodontist's accuracy on each radiographic image was calculated by comparing the gold standard with the value measured by orthodontist. Statistical analysis we used was simple t test. The orthodontist's accuracy in doing cephalometric analysis on 3D and 2D radiographic image was compared with paired t-test.

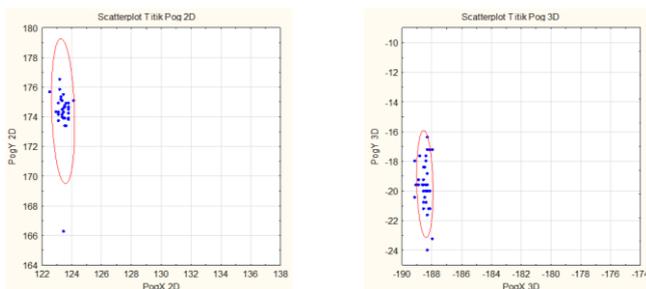


Figure 6. Scatterplot diagram of landmark Pog.

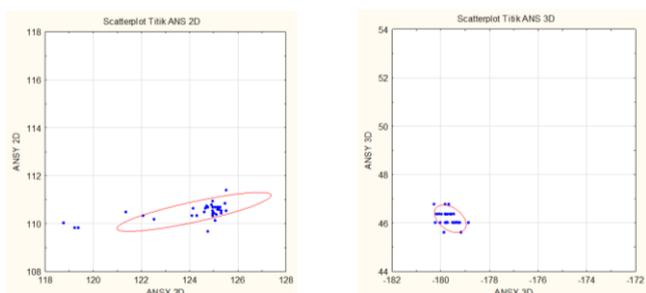


Figure 7. Scatterplot diagram of landmark ANS.

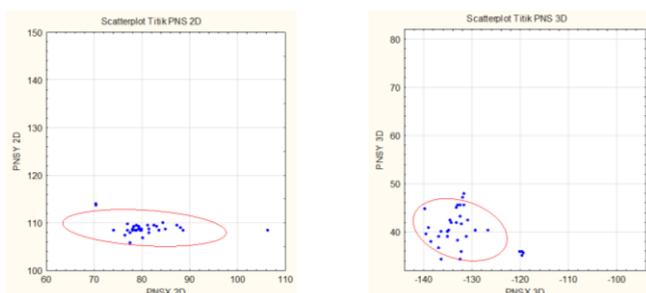


Figure 8. Scatterplot diagram of landmark PNS.

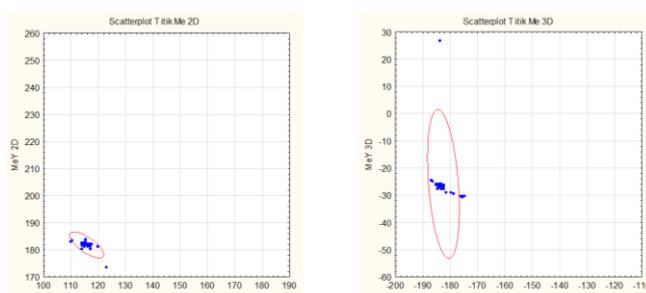


Figure 9. Scatterplot diagram of landmark Me.

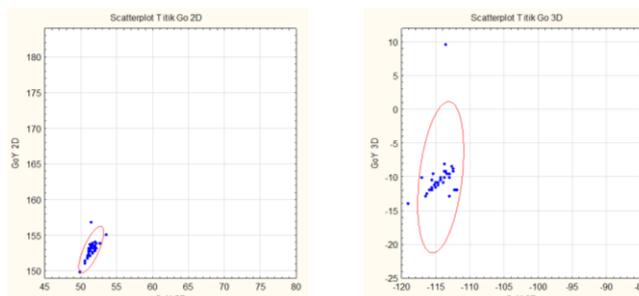


Figure 10. Scatterplot diagram of landmark Go.

Results

Landmark	Coordinate	I		II		P
		Mean	SD	Mean	SD	
Sella (S)	X	61.85	1.78	61.84	1.75	0.946
	Y	68.14	1.32	68.18	1.38	0.678
Nasion (N)	X	128.14	0.40	128.28	0.36	0.075
	Y	62.44	0.51	62.37	0.40	0.573
A	X	124.29	1.66	124.31	1.58	0.911
	Y	115.41	3.13	115.53	1.95	0.677
B	X	121.53	0.46	121.56	0.63	0.772
	Y	162.02	2.17	161.95	2.13	0.879
Pogonion (Pog)	X	123.43	0.37	123.42	0.31	0.900
	Y	174.47	1.65	174.38	1.60	0.478
Anterior Nasal Spine (ANS)	X	124.45	1.75	124.18	1.60	0.042*
	Y	110.45	0.53	110.49	0.33	0.564
Posterior Nasal Spine (PNS)	X	80.61	6.82	80.50	6.15	0.833
	Y	108.98	1.53	108.94	1.49	0.813
Menton (Me)	X	114.93	2.51	115.77	2.27	0.036*
	Y	182.11	0.62	181.82	1.58	0.305
Gonion (Go)	X	51.53	0.88	51.46	0.66	0.597
	Y	152.88	1.65	153.00	1.20	0.576

Table 2. Intraobserver reliability in identifying landmark on 2D radiographic image.

The reliability of 34 orthodontists for both radiographs is shown in Table 2 and Table 3. Based on paired t test, 34 orthodontists showed good reliability in identifying landmark on both radiographic image, unless for ANS and Me in horizontal direction (x coordinate). In measuring distances and angles, all orthodontists also had good reliability, except for Go-Me in 3D radiographic image (Table 4 and Table 5) However, the error between the first and second examination on those landmark and measurement which statistically had poor reliability was less than 1 mm, so it was clinically insignificant.

The orthodontists showed better reproducibility in identifying S, N, A, B, Pog, and ANS on 3D radiographic image (Table 6). Meanwhile, in identifying PNS, Me, and Go, the orthodontists showed better reproducibility on 2D radiographic image. From nine landmarks, ANS is the most reproducible point and PNS is the most difficult point to identify and the least reproducible.

Landmark	Coordinate	I		II		P
		Mean	SD	Mean	SD	
Sella (S)	X	106.31	0.42	106.53	0.52	0.092
	Y	75.06	0.87	75.09	0.61	0.848
Nasion (N)	X	170.33	0.35	170.36	0.31	0.676
	Y	94.17	0.84	94.06	0.31	0.448
A	X	179.81	1.11	179.84	1.06	0.870
	Y	40.35	2.72	40.55	2.62	0.587
B	X	184.65	0.52	184.56	0.39	0.343
	Y	5.60	2.20	5.13	2.65	0.138
Pogonion (Pog)	X	188.39	0.34	188.46	0.30	0.333
	Y	19.62	1.86	19.53	1.69	0.744
Anterior Nasal Spine (ANS)	X	179.46	0.50	179.61	0.33	0.053
	Y	46.13	0.35	46.18	0.30	0.513
Posterior Nasal Spine (PNS)	X	132.35	5.77	132.46	5.59	0.871
	Y	40.41	3.96	40.45	0.64	0.962
Menton (Me)	X	181.51	3.47	182.47	3.01	0.049*
	Y	28.04	1.63	27.42	1.53	0.140
Gonion (Go)	X	115.68	5.41	114.29	1.58	0.162
	Y	10.94	1.60	10.06	3.75	0.210

*statistically significant (P<0.05)

Table 3. Intraobserver reliability in identifying landmark on 3D radiographic image.

Landmarks	Coordinate	2D		3D		Diff (2D-3D)	P
		Mean	SD	Mean	SD		
Sella (S)	X	0.6	1.65	0.31	0.25	0.29	0.304
	Y	0.64	1.14	0.54	0.38	0.1	0.615
Nasion (N)	X	0.24	0.18	0.22	0.16	0.02	0.429
	Y	0.23	0.23	0.28	0.38	-0.05	0.474
A	X	1.14	1.07	0.7	0.61	0.44	0.014*
	Y	1.26	1.48	1.88	1.51	-0.62	0.054
B	X	0.31	0.30	0.54	0.37	-0.23	0.012*
	Y	1.36	1.03	1.61	1.57	-0.25	0.399
Pogonion (Pog)	X	0.23	0.22	0.18	0.15	0.05	0.163
	Y	0.72	1.41	1.17	1.03	-0.45	0.046*
Anterior Nasal Spine (ANS)	X	1.18	1.3	0.26	0.24	0.92	0.000*
	Y	0.3	0.26	0.19	0.17	0.11	0.031*
Posterior Nasal Spine (PNS)	X	3.49	5.23	4.17	4.11	-0.68	0.619
	Y	0.78	1.22	2.47	2.00	-1.69	0.000*
Menton (Me)	X	1.6	1.36	2.2	1.92	-0.6	0.063
	Y	0.53	0.71	1.17	1.12	-0.64	0.010*
Gonion (Go)	X	0.45	0.51	1.51	2.35	-1.06	0.014*
	Y	0.81	0.1	1.33	1.55	-0.52	0.087

*statistically significant (P<0.05)

Table 6. Reproducibility of cephalometry landmarks on 2D and 3D CBCT radiographic examination.

Measurement	I		II		P
	Mean	SD	Mean	SD	
ANS-PNS	45.20	4.90	44.90	4.60	0.641
Go-Me	69.90	3.60	70.60	2.20	0.126
UAFH	48.00	0.75	48.00	0.64	0.986
LAFH	71.60	1.11	71.80	1.11	0.595
SNA	80.98	2.24	80.79	2.22	0.449
SNB	81.21	1.49	81.09	1.62	0.485
ANB	-0.23	1.64	-0.29	1.76	0.738

*statistically significant (P<0.05)
 Table 5. Intraobserver reliability in distance and angles measurement on 2D radiographic examination

Measurement	I		II		P
	Mean	SD	Mean	SD	
ANS-PNS	47.90	6.90	48.50	6.60	0.556
Go-Me	69.30	3.70	70.20	3.50	0.026
UAFH	48.00	1.00	47.90	0.50	0.785
LAFH	74.20	1.60	73.80	1.60	0.122
SNA	83.48	1.28	83.44	1.05	0.847
SNB	81.61	1.12	81.61	0.61	0.978
ANB	1.87	0.76	1.83	0.68	0.735

*statistically significant (P<0.05)

Table 4. Intraobserver reliability in distance and angles measurement on 2D radiographic examination.

Ukuran	2D				3D			
	Standar Baku	Rerata	SD	P	Standar Baku	Rerata	SD	P
ANS-PNS	49.93	46.49	4.62	0.000*	50.95	48.45	6.61	0.035*
GO-ME	70.98	70.60	2.18	0.305	71.04	70.33	3.48	0.239
UAFH	47.97	48.02	0.75	0.726	47.99	47.91	0.49	0.335
LAFH	72.52	71.77	1.11	0.000*	72.87	73.99	0.14	0.000*
SNA	83.04	80.89	2.11	0.000*	83.37	83.46	1.03	0.591
SNB	82.67	81.15	1.48	0.000*	82.65	81.61	0.78	0.000*
ANB	0.37	-0.26	1.6	0.028*	0.72	1.85	0.62	0.000*

*statistically significant (P<0.05)

Table 7. Distance and angle measurements accuracy on 2D conventional and 3D CBCT radiographic examination.

Measurement	I		II		P
	Mean	SD	Mean	SD	
ANS-PNS	47.90	6.90	48.50	6.60	0.556
Go-Me	69.30	3.70	70.20	3.50	0.026
UAFH	48.00	1.00	47.90	0.50	0.785
LAFH	74.20	1.60	73.80	1.60	0.122
SNA	83.48	1.28	83.44	1.05	0.847
SNB	81.61	1.12	81.61	0.61	0.978
ANB	1.87	0.76	1.83	0.68	0.735

*statistically significant (P<0.05)

Table 5. Intraobserver reliability in distance and angles measurement on 2D radiographic examination.

Measurement	2D		3D		Diff (2D-3D)	P
	Mean	SD	Mean	SD		
ANS-PNS	4.24	2.34	3.10	4.73	1.03	0.452
Go-Me	0.76	2.63	1.27	3.33	0.51	0.289
UAFH	0.46	0.44	0.41	0.45	0.05	0.558
LAFH	0.92	0.63	1.24	1.09	0.32	0.181
SNA	2.23	2.02	0.80	0.64	1.43	0.000*
SNB	1.53	1.48	1.04	0.78	0.49	0.055
ANB	1.12	1.30	0.80	1.02	0.32	0.303

*statistically significant (P<0.05)

Table 8. Differences in measurement accuracy between 2D conventional and 3D CBCT radiographic examination.

In measuring distances, there was significance difference between the value of ANS-PNS and LAFH that orthodontists measured and the gold standard on both radiographic images. Meanwhile, in measuring angles, only the SNA on 3D radiographic image showed no differences between the mean value that orthodontist measured and the gold standard (Table 7 and Table 8)

Discussion

Reproducibility and accuracy of thirty four orthodontists in analyzing 2D and 3D digital radiographic image were compared. In this study 2D and 3D radiographic image were obtained from the same skull so it could be compared. Dry skull was used because it is unethical to expose patients with radiation twice (conventional radiograph and CBCT). Dry skull was also used to eliminate the distortion caused by the soft tissues so the identification of bony landmark could be more accurate.

It had been reported by Richardson et al that landmark identification with an error below 1 mm is still considered precise.¹⁶ Based on this criterion, only point S and N in this study could be considered accurate along both x and y-coordinate by both 3D and 2D radiographic images. Pog and Go accurate along both coordinates only on 2D radiographic image. Meanwhile ANS accurate along both coordinates only on 3D radiographic image.

Another study by Liu et al reported that the accepted normal range in cephalometric measurement was ± 2 mm.¹⁷ Using this definition of precision, most of landmarks would be considered precise in this study with the exception of PNS in x-coordinate for both images, y-coordinate for 3D radiograph image, and Me in x-coordinate for 3D radiograph image.

Based on the scatterplot diagrams, S and N on 3D radiographic image showed better reproducibility compared to 2D radiographic image (Figure 2 & 3). There was one outlier seen in landmark S scatterplot diagram 2D radiographic image (Figure 2). This outlier caused the mean value on the 2D radiographic image greater than it should be, although it was still considered to be precise. This outlier might happened because the orthodontist was fatigued which lead to inaccuracy in landmark identification.

McClure et al reported similar results when comparing landmark identification on conventional radiograph and digital radiograph.¹⁸ They found that point B, Gn, L1T, S, N, and U1T précised on both radiographs. Based on this report, we could see that S and N are the most reproducible landmarks. S point or sella tursica is an imaginary point located in the center of the pituitary fossa of the sphenoid bone. The specific form of the S point which is look like a saddle

made it easy to be identified. N point could also be identified easily because it located in the surface of the skull, and we could see the intersection between internasal and nasofrontal suture clearly.

MsClure et al also stated that the imprecision in point S identification in vertical direction (y-coordinate) have more implication in inaccuracy of measuring SNA and SNB compare to error in horizontal direction (x-coordinate).¹⁸ Meanwhile error in point N identification on both directions has the same impact on SNA and SNB value. Point A and B are the most inferior point that forms SNA and SNB angles. Therefore, error in horizontal direction on both points would have more implication in inaccuracy of angle measurement.

In this study, S point showed greater error in vertical direction 2D radiographic image. Meanwhile A point identification showed imprecision in both directions. These errors, especially error in the A point lead to inaccuracy of SNA measurement in 2D radiographic image. Landmark identification error could be caused by the experience of the observer, or the difficulty to identify the exact location of A point because it was located in the curving surface. The bone structure on the premaxilla was also thinner so it made the image looked more radiolucent and unclear. Meanwhile, on 3D radiographic image, the slice thickness was arranged so the surface of the maxilla has more radioopacity and could be traced easier. Rakosi was also stated that A point is one of the most difficult point to be located. Therefore, orthodontists should be more careful when identified the A point.²⁰

On Table 7 and 8 we could see that there were significant differences between the gold standard with the value that orthodontists measured in SNB and ANB. Previous report by Cancado stated that difference below 1.5° is not clinically significant.²¹ According to this report, we concluded that though SNB and ANB were statistically different with the gold standard, the differences were not clinically significant.

In this study, ANS on 3D radiographic image was the most precise and has the best reproducibility. ANS is the tip of anterior nasal spine and located in the surface of the skull. The sharp edge anatomical shape of ANS made it easier to be identified compared to other landmarks located in the curvy surface such as Go, A and B. However, reproducibility of ANS in

2D radiographic image was not as good as 3D radiographic image. This happened because, in 3D radiographic image, we arranged the thickness of the slice and used the maximum intensity projection mode, so the image would be more radiopaque and easier to be identified compared to 2D radiographic image.

Meanwhile, PNS was the least reproducible point in this study. Based on t test and scatterplot diagram (Figure 8), PNS was imprecise on both types of radiographic images. PNS which is located inside the skull and superimposed with many anatomical structures made it difficult to be identified. Similar with the study by Liu et al and McClure et al, the PNS imprecision in horizontal direction was greater than vertical. As the result of this, the ANS-PNS distance measurement by orthodontist was not accurate on both radiographs.^{17,18}

On Table 6 we could see that there were significant differences in identifying landmark Me and Go between 2D and 3D radiographic image. Both landmarks showed better reproducibility in 2D and imprecision in 3D radiographic image. The identification of the exact location of Me and Go is more difficult because it located in curvy surface. However, a better view of mandibular symphysis in 2D radiograph image compared to 3D made the identification of Me in 2D radiographic image easier. Even though the reproducibility of Me and Go especially was poor, the measurement of Go-Me was accurate. This might happen because both landmarks were imprecision on horizontal direction in the same distance. On the other hand, the poor reproducibility of Me resulted in inaccuracy of LAFH measurement (ANS-Me).

Definition of landmarks was given to the orthodontists before they started the cephalometric analysis. However, some landmarks were more difficult to identify than others. Definition that used the word "the deepest point" or "the intersection" would be more difficult to identify than the word "the tip" and thus caused imprecision.

In this study, the orthodontists did the cephalometry analysis with Osirix software, digitally. Even though the orthodontists were taught how to use the software before they started to analyze, some of them were not used to do the analysis digitally. Orthodontists also used to analyze the conventional radiographic image, they are not accustomed to analyze the

3D radiographic image taken from CBCT. This could be the reason of imprecision in identifying landmark which was lead to inaccuracy in measurement. In the future, orthodontists need to improve their knowledge about CBCT and examining the CBCT images. According to European Commission and AAOMR, orthodontists have the obligation to improve their professional skill in examining CBCT scan results.^{21,22}

Conclusions

- The orthodontists' reproducibility in examining 2D radiographic image is different compare to 3D radiographic image in several landmarks: A, B, and Go in x-coordinate, PNS and Me in y-coordinate, and ANS in both coordinates.
- The accuracy of distance measurement between 2D digital and 3D CBCT radiographic examination was no different.

The accuracy of angular measurement between 2D digital and 3D CBCT radiographic examination was no different, except for SNA.

Declaration of Interest

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