http://dx.doi.org/10.17159/2519-0105/2021/v76no7a1

The accuracy of various radiographic modalities for implant therapy

SADJ August 2021, Vol. 76 No. 7 p396 - p403

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ABSTRACT

Aims and objectives

To investigate the dimensional accuracy of radiographic techniques utilized during implant therapy.

Design and Methods

Six dried human skulls were used to compare three dimensions in ten anatomical segments. Linear distances in-between metallic markers were measured and compared physically, and virtually on cone-beam computed tomography (CBCT) volumes, panoramic (PAN) and periapical (PA) radiographs. The angular distances along the curved arches of both jaws (connecting the upper metallic markers) were measured using cords. One-way ANOVA (p-value < 0.05) tests were executed to statistically analyze the mean differences between physical and virtual distances measured. The intra-class correlation coefficient (ICC) was used to analyze the level of consistency of observers.

Results

Statistically significant overall mean difference of all distances comparing physical and radiographic (CBCT, PAN, and PA), with the CBCT showed the least overall submillimeter discrepancy in the maxilla (M.D= -0.638 mm, SD= 0.203) and mandible (M.D=0.326 mm, SD=0.23). Overestimations exceeding a millimeter were found in maxilla (M.D=2.229 mm, SD=0.856) and mandible (M.D =3.832 mm, SD=1.272) of measurements performed on panoramic radiographs. Periapical radiographs exhibited an overall mean maxillary underestimation of -3.707 mm, (SD=1.31) and mandibular mean overestimation of 1.849 mm (SD=0.875).

Conclusion

CBCT demonstrated a superior submillimeter overall accuracy in comparison to periapical and panoramic radiographs. While PAN and PA presented with individual dimension precision (submillimeter difference), the overall mean of difference for these modalities was inferior when compared with CBCT. CBCT showed superior dimensional stability and thus it is recommended during implant planning phases.

Keywords

CBCT, accuracy, panorama, implant, periapical.

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INTRODUCTION

Radiographic assessment during various phases of dental implant therapy has become indispensable. Panoramic radiography is the most popular and the backbone radiographical procedure prescribed during daily practice and different phases of implant therapy.[1-3] On the other hand, the new era introduced by the cone-beam computed tomography (CBCT) aided to reform the treatment planning approaches and the diagnostic abilities of the practitioners.[4] CBCT allows for dimensionally accurate 3D imaging[5-7] that facilitates the aid of various applications e.g., computer-guided surgical procedures.[8]

Each radiographic modality can offer both advantages and drawbacks, but providing precise and reproducible dimensions of the anatomical site of interest is a vital requirement.[9,10] A submillimetre radiographic measurement error is still tolerable during implant treatment according to multiple reports.[11,12] Inconsistent evidence was found on the ideal radiographic modality (particularly from a dimensional accuracy perspective) that is most suitable to be used during the planning phase.[10]

The assessment of the vertical bone dimensions for implant purposes on the panoramic radiographs, especially in non-complex cases was reported.[3,10,13-18] On the contrary, other reports[19-23] provided opposite evidence as these radiographs may predispose risks due to possible dimensional inaccuracies encountered (particularly if no magnification factors are considered).

As the maxilla and mandible are curved and in multi-dimensions, the presentation of these structures on a certain radiograph should be evaluated when a dimensional analysis is to be carried out for implant planning purposes; this indicates the consideration of angular measurements in certain anatomical regions (where applicable).

The authors presume that reproducing 2D radiographic dimensions on 3D physical structures (i.e., jaws) may predispose inaccuracies. The current investigation tries to add to the pool of evidence on the accuracy of linear and physical angular measurements (for implant planning purposes) in various radiographic modalities.

MATERIAL AND METHODS

Six dried human skulls (gender and ethnicity have been neglected) were collected from the Division of Clinical Anatomy, Faculty of Medicine, Stellenbosch University (Cape Town, South Africa) after obtaining ethical approval for degree purposes (Number: BM19/1/20, University of the Western Cape, South Africa). The adult-size skulls were provided with fully edentulous maxilla and mandible, and with the calvarium cut off. Metallic bearing balls of known diameter (4.5mm) were fixed directly on the mandibular and maxillary bone surfaces using a rigid sticky wax.

Five regions (segments) in each jaw were selected as follows: A-segment (anteriorly), M/C-segment (**M**: mental foramen region in the mandible and **C**: Canine segment in the maxilla), and P-segment (posteriorly). Each segment in the mandible contains three balls aligned in a triangular pattern (Y-ball placed on the top of the alveolar ridge, and two parallel balls with one on the buccal (X-ball) and lingual/palatal surfaces (Z-ball)). In the maxilla, only marker balls (X and Y) were placed (**Figure 1**).

Hight (DV: distance vertical), length (DH: distance horizontal), and width (DLA, DLP, DUA, DUP: distance lower/upper anterior/posterior) between these balls were measured physically by a digital caliber (Mastercraft®, South Africa) with 0,03mm accuracy, and 0,01mm repeatability.

The caliber readings were confirmed manually using a ruler before the analysis of every skull. Finally, thin nylon cords were fixed directly on the upper cortex of the ridge between the Y balls (conforming to the anatomy of the bone) and then measured by the caliber's ruler.

The skulls were mounted on a tripod during examinations with the mandibles that were supported with uniformly-sized sponges placed under the mandibular angles (bilaterally) simulating an ideal radiographic position. A uniform level between the left and right sides of the mandible was ensured using a combination square with a spirit level which also acted as a physical upper limit (tangent) for DV measurements.

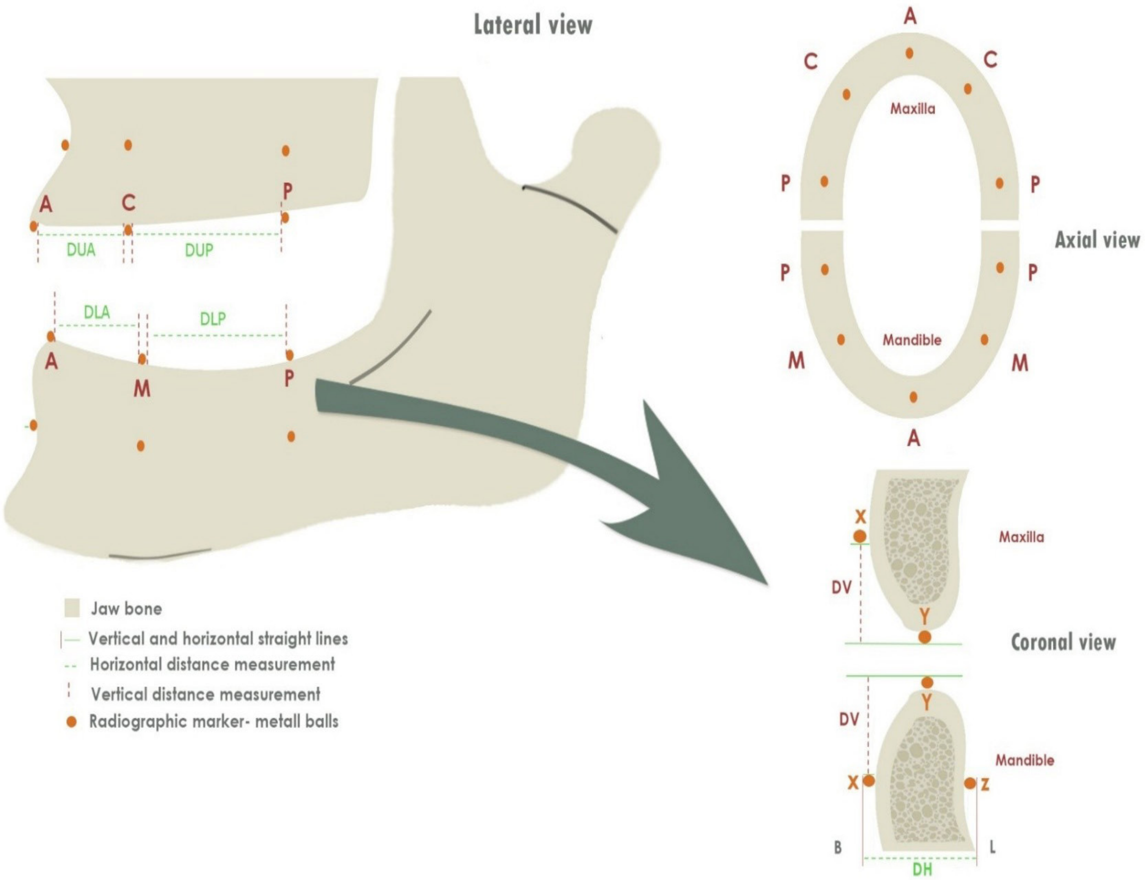

Figure 1. Measurements' diagram (Reprinted from Beshtawi, 2021).[40]

The ideal radiographic position during CBCT and panoramic examinations were ensured with the aid of the units' positioning laser markers (Figure 2).

Parallel radiographic technique (with the aid of film holders) was employed during intraoral periapical examinations. The corresponding radiographic measurements were carried out virtually (Figure 3).

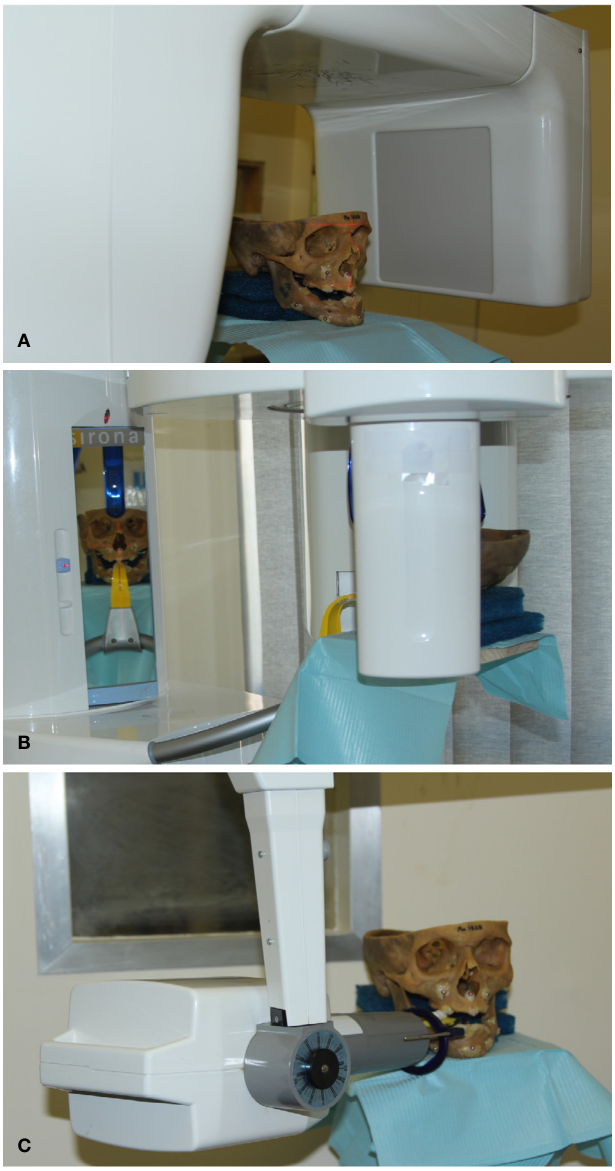

Figure 2. X-ray machines that were used (A) CBCT, (B) panoramic, and (C) periapical x-ray machines.

Table I shows the models ofx-ray machines utilized, the exposure parameter selected, and the distances measured for each modality.

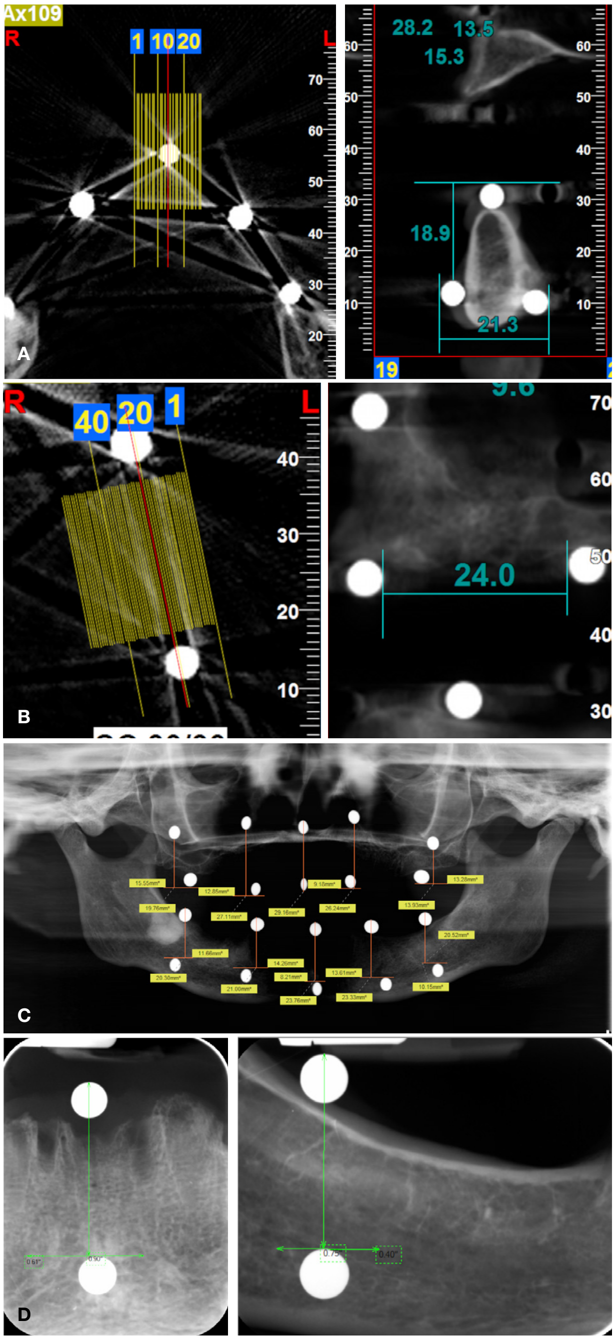

Figure 3. Virtual measurements captured on CBCT volumes (A&B), panoramic (C), periapical (D) radiographs..

Table 1. Radiographic x-ray models and exposure parameters used.

Modality	Model	Exposure parameters	Distances measured (maxilla and mandible)
PA	• Phosphor plates. • Plate scanner: SOREDEX® DIGORA™ Optime (Kavo/ Soredex®, Helsinki, Finland). • Desktop user-grade monitor.	70 kVp, 2 mAs	DV
PAN	• Sirona® Orthophos XG3 (Dentsply Sirona, Bernsheim, Germany). • Desktop user-grade monitor.	64 kVp, 112 mAs	DV, DLA, DLP, DUP, and DUA
CBCT	• Newtom® VGi (CEFLA s.c., Imola, Italy) • Barco® (Kortrijk, Belgium) Eonis 22" medical monitor 2MP (1920×1080 pixels).	"Full scan" mode 110 kVp, 1-10 mA	DV, DH, DLA, DLP, DUP, and DUA.

Key - PA: periapical, **PAN:** panoramic radiograph, **CBCT:** cone beam computed tomography, **DV:** distance vertical, **DH:** distance horizontal, **DLA:** distance lower anterior, **DLP:** distance lower posterior, **DUP:** distance upper posterior, and **DUA:** distance upper anterior.

Table 2. Overview of the statistical analysis at each anatomical point and at entire jaw measurement difference in millimeters (i.e., radiographic vs. physical measurements), (Reprinted from Beshtawi, 2021).[40]

Mandible

Side	Point	Distance	Modality	Mean value (SD)		CBCT vs. Physical	Pan vs. Physical	PA vs. Physical
RHS	Point p	DV	Physical	15.02 (3.4)	M.D	1.18	4.87	2.252
			CBCT	16.2 (3.1)	SD	-2.02	-2.02	2.02
			PAN	19.89 (3.9)	P.V	1	0.154	1
			PA	17.27 (3.6)				
		DH	Physical	18.59 (1.9)	M.D	0.362		
			CBCT	18.95 (2.1)	SD	-1.17		
					P.V	0.764		
		DLP	Physical	23.19 (3.9)	M.D	-0.738	1.63	
			CBCT	22.45 (3.8)	SD	-2.21	-2.21	
			PAN	24.82 (3.7)	P.V	1	1	
	Point M/C	DV	Physical	17.22 (4.2)	M.D	1.582	6.692	2
			CBCT	18.8 (4.4)	SD	-2.64	-2.64	-2.64
			PAN	23.91 (5.3)	P.V	1	0.118	1
			PA	19.22 (4.2)				
		DH	Physical	19.02 (0.9)	M.D	0.127		
			CBCT	19.15 (0.9)	SD	-0.538		
					P.V	0.819		
		DLA	Physical	18.63 (3.8)	M.D	-0.927	0.907	
			CBCT	17.7 (3.8)	SD	-2.3	-2.3	
			PAN	19.53 (4.4)	P.V	1	1	
Center	Point A	DV	Physical	16.05(4.41)	M.D	2.047	7.56	2.15
			CBCT	18.1(5.50)	SD	-3,036	-3,036	-3,036
			PAN	23.61(6.5)	P.V	1	0.13	1
			PA	18.2(4.27)				
		DH	Physical	21.44 (1.6)	M.D	0.31		
			CBCT	21.75 (1.5)	SD	-0.91		
					P.V	0.74		
LHS	Point M/C	DV	Physical	15.5 (3.4)	M.D	0.7	5.238	1.56
			CBCT	16.2 (3.6)	SD	-2.29	-2.29	-2.29
			PAN	20.74 (4.8)	P.V	1	0.199	1
			PA	17.06 (3.9)				
		DH	Physical	19.46 (0.7)	M.D	0.242		
			CBCT	19.7 (0.9)	SD	-0.46		
					P.V	0.611		
		DLA	Physical	17.05 (4.2)	M.D	-0.698	1.31	
			CBCT	16.35 (4.0)	SD	-2.31	-2.31	
			PAN	18.36 (3.8)	P.V	1	1	
	Point P	DV	Physical	13.41 (2.92)	M.D	0.49	3.94	1.28
			CBCT	13.9 (2.68)	SD	-1.83	-1.83	-1.83
			PAN	17.35 (3.52)	P.V	1	0.259	1
			PA	14.68 (3.435)				
		DH	Physical	19.56 (2.2)	M.D	0.34		
			CBCT	19.9 (2.2)	SD	-1.27		
					P.V	0.795		
		DLP	Physical	21.5 (5.1)	M.D	-0.452	2.33	
			CBCT	21.1 (5.2)	SD	-3.25	-3.25	
			PAN	23.83 (6.5)	P.V	1	1	
Overall						0.326* (0.23)	3.832* (1.272)	1.849* (0.875)

Maxilla

Side	Point	Distance	Modality	Mean value		CBCT vs. Physical	Pan vs. Physical	PA vs. Physical
RHS	Point p	DV	Physical	17.67 (1.6)	M.D	-0.671	1.155	-3.786
			CBCT	17 (2.0)	SD	1.07	1.07	1.07
			PAN	18.83 (2.4)	P.V	1	1	0,012*
			PA	13.89 (1.2)				
		DUP	Physical	22.29 (3.3)	M.D	-.698	1.55	
			CBCT	21.6 (3.2)	SD	1.99	1.99	
			PAN	23.85 (3.8)	P.V	1	1	
	Point M/C	DV	Physical	24.25 (4.1)	M.D	-0.15	3.97	-4.57
			CBCT	24.1 (3.9)	SD	2.41	2.41	2.41
			PAN	28.22 (4.8)	P.V	1	0.689	0.436
			PA	19.69 (3.8)				
		DUA	Physical	16.68 (3.9)	M.D	-0.73	1.32	
			CBCT	15.95 (3.9)	SD	2.39	2.39	
			PAN	18 (4.6)	P.V	1	1	
Center	Point A	DV	Physical	24.92 (2.5)	M.D	0.227	6.055	-0.8357
			CBCT	25.15 (2.6)	SD	2.07	2.07	2.07
			PAN	30.97 (4.1)	P.V	1	0.05	1
			PA	24.09 (4.7)				
LHS	Point M/C	DV	Physical	21.34 (2.4)	M.D	-0.293	3.801	-3.775
			CBCT	21.05 (2.5)	SD	1.56	1.56	1.56
			PAN	25.15 (3.1)	P.V	1	0.147	0.153
			PA	17.57 (2.8)				
		DUA	Physical	16.59 (3.9)	M.D	-0.988	1.465	
			CBCT	15.6 (3.7)	SD	2.313	2.313	
			PAN	18.05 (4.3)	P.V	1	1	
	Point P	DV	Physical	15.36 (3.2)	M.D	-1.807	-0.777	-5.578
			CBCT	13.55 (3.1)	SD	2.08	2.08	2.08
			PAN	14.58 (3.7)	P.V	1	1	0.086
			PA	9.78 (4.3)				
		DUP	Physical	21.73 (2.9)	M.D	-0.633	1.522	
			CBCT	21.1 (2.7)	SD	1.895	1.895	
			PAN	23.26 (4.0)	P.V	1	1	
Overall						-0.638* (0.203)	2.229* (0.856)	-3.707* (1.31)

*Statistically significant difference, $p<0.05$, Negative values indicate underestimation while positive ones indicate overestimation.
M.D: measurement discrepancy, **SD:** standard deviation, **P.V:** p-value, **RHS:** right hand side, **LHS:** left hand side, **PA:** periapical, **PAN:** panoramic radiograph, **CBCT:** cone beam computed tomography, **DV:** distance vertical, **DH:** distance horizontal, **DLA:** distance lower anterior, **DLP:** distance lower posterior, **DUP:** distance upper posterior, and **DUA:** distance upper anterior.

A one-way ANOVA test was used to determine if there was a statistically significant difference between the physical and radiographic (CBCT, PAN, and PA) distances. Pairwise comparisons with Bonferroni correction were used to determine how large those differences were and to determine where those differences were.

If there were no statistically significant differences between the different modalities, then the two differences were deemed similar, as the p-value was greater than 0.05 and the confidence interval included zero. If the confidence interval included zero, this implied that at some stage the difference was zero and thus there was no difference in the estimation of the distance of the points between the physical point or any of the three modalities (CBCT, PAN, or PA). The mean measurement difference (M.D) was calculated in millimeters and using the following equation:

M.D = mean radiographic measurements – mean physical measurements

The intra-class correlation coefficient (ICC) was used to analyze the level of consistency of the results between the two observers. All the physical measurements were repeated a week after the primary analysis (except for the angular measurements) by both observers. The primary observer repeated all radiographic measurements in all the radiographic modalities a week after the primary analysis.

The second observer was requested to repeat the measurements for three skulls in each radiographic modality tested.

RESULTS

Statistical significance was elicited for all the overall mean differences between physical and radiographic distances (on PAN, CBCT, and PA) in both jaws. The panoramic overall mean distance differences in both jaws were overestimated (by 2.229 mm and 3.832 mm for maxilla and mandible, respectively). On the other hand, periapical radiographs' overall mean differences recorded underestimation of -3.707mm in the maxilla and overestimation by 1.849mm in the mandible. While both conventional two-dimensional modalities (i.e., PA and PAN) recorded mean differences exceeding a millimeter, CBCT, by contrast, provided the least submillimeter discrepancy in both, maxilla (M.D = -0.638 mm) and mandible (M.D = 0.326 mm).

In comparison to the overall mean difference, the statistical analysis of measurement differences acquired in each individual segment (point) did not elicit any statistical significance (between CBCT or PAN or PA vs. physical distances), except in the distance vertical (DV) of point P (R. maxilla) of the PA. Among all the investigated twenty-three individual points (segments), the mean differences between CBCT and physical distances were the least over the three modalities (Max. 2.047mm and Min. 0.127mm). The statistical analysis is further demonstrated in Tables 2 and 3.

Table 4 documents the differences between the linear and angular measurements (alveolar arc lengths), i.e., DUP/DLP, DUA/DLA. Of the 36 readings obtained, 21 of them exceeded the 1 mm (over or underestimating).

Table 3. Number of readings (i.e., showing discrepancies) per each imaging technique (Reprinted from Beshtawi, 2021).[40]

Comparison	PA (10 readings)	Pan (18 readings)	CBCT (23 readings)
Discrepancy over 1 mm limit (Over or underestimation)	9/10	16/18	4/23
Detailed description of data			
Overestimation (>0mm)	**5/10**	**17/18**	**11/23**
Maxilla	0	8|R* [1.15-6.05 mm]	1|M* (0.22 mm)
Mandible	5|R* [1.27-2.52 mm]	9|R* [0.9-7.56 mm]	10|R* [0.31-2.04 mm]
Underestimation (<0mm)	**5/10**	**1/18**	**12/23**
Maxilla	5|R* [-0.83-5.57 mm]	1|M* (-0.77)	8|R* [-0.15-(-1.8) mm]
Mandible	0	0	4|R* [-0.4-(-0.92) mm]
|R*: Range, M*: Maximum			

Table 4. The differences between physical linear and angular distances in millimeters (Reprinted from Beshtawi, 2021).[40]

Skull #		Right side		Left side	
		DUP/DLP	DUA/DLA	DUP/DLP	DUA/DLA
1	Maxilla	**0,36**	**-5,04**	**0.95**	**-2,42**
	Mandible	0,78	-3,48	-1,58	-3,88
2	Mandible	0,25	0.84	0,04	-1,81
3	Mandible	**-0,78**	**-3,3**	**-3,08**	**-1,65**
4	Maxilla	-1,58	-0,44	-3,09	0.9
	Mandible	-4,03	0.54	-0,33	-1,08
5	Mandible	**-2,61**	**-2,55**	**-0,05**	**-4,64**
6	Maxilla	0,34	-4,9	-0,8	-6,41
	Mandible	-4,01	-2,8	-2,08	-0,24
Linear measurements - curved M.	*Positive values indicate that the linear measurements were bigger than angular ones and vice versa. Values in red: >1 or -1 mm difference (21 readings/36) Values in Black: -1>0<1 difference (15 readings/36				

Nonetheless, those 21 readings were all negative indicating that the angular measurements were more than the values of the linear ones (i.e., the linear physical distances underestimate their angular counterparts).

All measured distances showed excellent inter and intra-examiners reliability (using the intraclass correlation coefficient) except in three points (segments) which were poor, moderate, and good.

DISCUSSION

Despite the statistical significance elicited for the overall measurement discrepancies between physical vs. all radiographic modalities compared, clinically significant distortions were only attained from periapical and panoramic measurements. The discrepancy of measurements was inconsistent with the numerous anatomical segments investigated. In this investigation, it was noted that the reliability of the radiographic dimensions was highly influenced by the radiographic position during periapical and panoramic radiographic examinations. While the current investigation was performed under simulated clinical settings, such an approach may not be constantly achieved in an ordinary, everyday clinical environment. A submillimeter radiographic measurement discrepancy on CBCT volumes mentioned to be clinically insignificant.[24,25,26] Although we accept this small margin of error, it is challenging to consider the clinical significance of this minute discrepancy when related to the spatial location of vital structures, it can mean the difference between success and failure.

CBCT technique was reported to provide highly precise dimensions of the studied anatomical structures.[5-7,26-28] Within a high overall accuracy, slight measurement overestimation[25,29,30] and underestimation[7,31-33] were mentioned.[26] Consequently, during the planning of surgical procedures, a safety zone of 2mm still applies.[26] The current investigation concurs with the previous reports regarding the accuracy of CBCT while revealing an overall submillimeter accuracy (-0.638, 0.326mm for maxilla and mandible, respectively). Nevertheless, CBCT volumes showed an over-millimetre discrepancy in the vertical distance (DV) at 3 individual mandibular sites [1.18mm - 2.04mm] and one in the maxilla (-1.8mm).

Multiple factors may impact the accuracy of CBCT measurements e.g. the imposed artefacts (like beam hardening and motion artefacts), exposure settings, and the software used.[26] The head position does not affect the CBCT volume accuracy.[34,35] However, generating cross-sectional images based on an inaccurate and unsynchronized (radiographically and physically) virtual orientation of the head (particularly the sagittal tilting) might lead to inaccurate measurements if transferred to the patient's mouth, as it affects the height of subsequent cross-sections.[36] Some dimensional discrepancies discovered at the surgical setting are a result of the erroneous transfer of virtually performed measurements on the cross-sectional slices.[37] We, therefore, highlight the importance of accurate identification and synchronization of reference landmarks (radiographically and clinically).

The reproducibility of 2D radiographic linear measurements of 3D physical structures is the most likely source of discrepancies (Figure 4). The shortest linear distance measured (physically) between two segments (points) was -in general- less than the angular counterpart which was measured with the cord placed directly on the alveolar ridge. Such a finding should be considered clinically while performing "free-hand" implantology, and a reference measurement mark point to the drilling site need to be reproduced in the patient's jaw.

While possible magnification and inherent distortions are the main disadvantages, panoramic radiographs are a common radiographic procedure that offers a wide range of advantages.[1,38] Multiple reports indicated dimensional reliability and beneficial use of these radiographs especially in the posterior segments of the jaws;[3,10,13-18,39] yet, opposing evidence also exist.[19-23] Compared to our findings, the overall measurement discrepancies exceeded the 1mm range in maxilla and mandible (2.229, 3.832mm, respectively), indicating overall inferior accuracy. Out of 18 panoramic individual points measurements, the mean difference was over 1mm in 16 locations in maxilla and mandible, overestimated (>0mm) in 17 readings [1.15 – 7.56mm], and underestimated (>0mm) in one reading (-0.77mm).

Comparable findings were noted in periapical radiographs measurements where overall measurement discrepancies of -3.707 for maxilla and 1.849mm for mandible were found. Mandibular measurements showed less discrepancy – although >1mm- compared to maxillary ones. Although performed in a simulated ideal setting, anatomical variations (e.g., ridge inclination, shallow palate) in the maxilla may readily cause distortions, as ideal parallelism between the axis of the alveolar ridge and the x-ray receiver was challenging. In mandible and excluding the

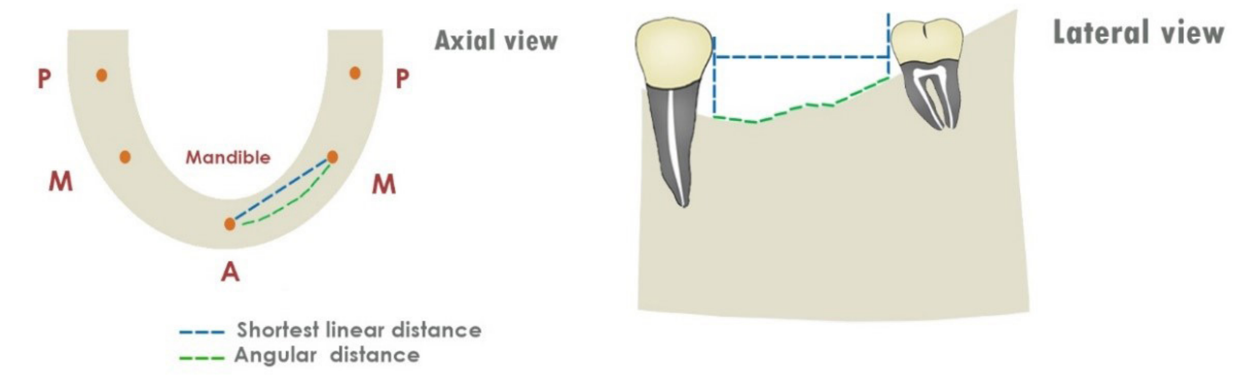

Figure 4. Illustration of the assumed angular distances between various jaw segments (Reprinted from Beshtawi, 2021).[40]

muscle repulsion (which may occur in real patients) in the floor of the mouth, achieving ideal parallelism was unchallenging and was translated in reduced measurement discrepancies in the mandible compared to the maxilla. Though PA showed accurate individual dimensions at multiple anatomical sites, the accuracy was inconsistent throughout the analysis. As a result, accurate reproduction of the anatomical structures may not be guaranteed in every clinical setting.

CONCLUSIONS

Compared to panoramic and periapical radiographs, CBCT achieved superior sub-millimeter accuracy in the maxilla and mandible. Measurements done at the maxillary sites showed more accuracy compared to the mandibular sites on panoramic radiographs, however, the highest discrepancy values were noted in the anterior regions. In contrast, the opposite was noted on periapical radiographs examinations i.e., measurements obtained from the mandible revealed better accuracy than the maxillary sites. While panoramic and periapical radiographs exhibited individual accurate measurements, the overall differences indicate inferior dimensional accuracy compared with CBCT. In this paper, the accuracy of the CBCT modality is verified and thus is recommended for implant planning.

Limitations

Angular measurements were not repeated for inter- and intra- observers' agreements.

Acknowledgements

The authors would like to thank the following for their assistance/collaboration during the study:
- Research Senate, University of the Western Cape (South Africa) for funding the project.
- Staff of the Division of Clinical Anatomy, Faculty of Medicine and Health Sciences, Stellenbosch University, South Africa.
- Dr Faheema Kimmie-Dhansay, for the statistical analysis.

Disclosure

The authors declare no conflict of interest. This article is submitted out of a successful PhD study, that was funded by Senate Research, University of the Western Cape, South Africa.

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