Original Article

Evaluation of Precision of Dimensional Measurements of the Mandible on Panoramic Radiographs: A Digital Radiographic Study

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ABSTRACT

Introduction: Panoramic radiography is a good screening tool for visualizing the entire maxillofacial complex. It provides a comprehensive view in diagnosing the underlying pathology and planning treatment. Magnification and distortion is an inherent property of panoramic machine. Taking this into account, the present study was conducted to evaluate the precision of dimensional measurements of the dry human mandibles on digital panoramic radiographs and to evaluate their dimensional stability.

Materials and Methods: Twenty-five dry human mandibles were selected. 1 mm^2 metal markers were placed on the predetermined anatomical points on mandibles. Digital panoramic radiographs were obtained. The linear and angle measurements were made on mandibles and their images. Statistical analysis for intraexaminer and interexaminer reliability was performed using ANOVA test. Manufacturers magnification index and calculated magnification index was estimated for each variable in order to evaluate the dimensional stability of our machine.

Results: There was no statistical difference between the linear measurements made on a single side of panoramic images. The horizontal measurements crossing the midline were found to be highly statistically significant ($P < 0.001$).

Conclusion: Digital panoramic radiographs were dimensionally stable for measuring the gonial angle and linear measurements on the same side. However, the linear measurements of the structures that traverse the midline are not reliable.

Keywords: Digital radiography, Dimensional stability, Mandibles, Measurements, Orthopantomography

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INTRODUCTION

Panoramic radiography is a very popular and most widely accepted that conveniently provides the clinician with a comprehensive view of maxillofacial complex with relatively reduced radiation dose.[1,2] However, the limitation being is its inability to confirm the dimensions of the structures shown on the radiographs correspond to real dimensions of the exposed structures.[2-4] The inherent property of panoramic radiographs is magnification and distortion. Distance of the object between the X-ray source and film is responsible for the magnification of the filmed structures. In the sharply depicted layer, the image is free of distortion.[3-5]

The advent of digital imaging has revolutionized Radiology.[2,4,5] This is the result of both technologic innovation in image acquisition process and the development of networked computing systems for image retrieval and transmission.[5,6] There is a shift in paradigm from conventional to the digital system because of the ease of storage, processing, and many more advantages.[2,5,6]

The aim of our study was to evaluate the precision of dimensional measurements of the dry mandible on digital panoramic radiographs and to evaluate their dimensional stability. The various measurements in our study benefit clinicians in evaluating and planning treatments. This includes planning for pre and post dental implant evaluation orthognathic surgery, periapical surgery, split osteotomy, assessing risk and prevent traumatic injuries to adjacent vital structures, determining mandibular asymmetry (hemifacial microsomia), orthodontic screening, treatment planning, and sex determination.

MATERIALS AND METHODS

This comparative study was undertaken to evaluate the dimensional accuracy of digital panoramic radiographs at Dayananda Sagar College of Dental Sciences, Bengaluru using dry human mandibles. Twenty-five mandibles were selected randomly, which varied from dentate to completely edentulous. 1 mm^2 metal markers were used as landmarks to denote the points at which distances were measured. These markers were located on the predetermined anatomical points.

Following anatomical landmarks were used as reference points for performing the measurements:

Vertical Measurements (Figure 1)

1. UBM-LBM (S): Distance between upper and lower border of mandible in the midline of sagittal line.
2. R UBM-LBM (FM): Distance between upper and lower border of mandible in line perpendicularly drawn at medial opening of right mental foramen.
3. L UBM-LBM (FM): Distance between upper and lower border of mandible in line perpendicularly drawn at medial opening of left mental foramen.
4. R UBM-LBM: Distance between upper and lower border of mandible in line perpendicularly drawn at the distal border of the crown of right third molar or at the mesial border of trigonum retromolar in the edentulous mandible.
5. L UBM-LBM: Distance between upper and lower border of mandible in line perpendicularly drawn at the distal border of the crown of left third molar or at the mesial border of trigonum retromolar in the edentulous mandible.

Horizontal Measurements (Figure 2)

1. Co-Co: Distance between highest points of the left and right condylar processes.
2. PM-PM: Distance between highest points of the left and right coronoid processes.
3. Go-Go: Distance between left and right gonion points.

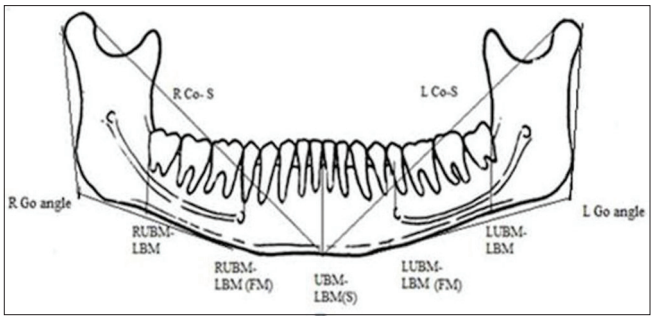

Figure 1: Schematic representation of vertical, oblique, angle measurements on dry mandible

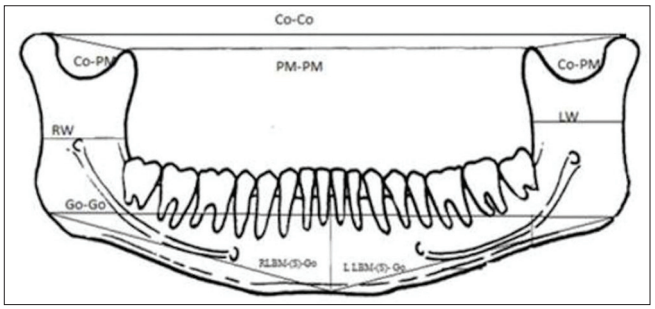

Figure 2: Schematic representation of horizontal measurements on dry mandible

4. R LBM(S)-Go: Distance between lower border of mandible in sagittal line and gonion point of the right side of the mandible.
5. L LBM(S)-Go: Distance between lower border of mandible in sagittal line and gonion point of the left side of the mandible.
6. RW: Width of the right ramus.
7. LW: Width of left ramus.
8. R Co-PM: Distance between the highest point of right condylar process and the highest point of right coronoid process.
9. L Co-PM: Distance between the highest point of left condylar process and the highest point of left coronoid process.

Oblique Distances (Figure 1)

1. R Co-S: Distance between the highest point of right condylar process and lower border of mandible in sagittal line.
2. L Co-S: Distance between the highest point of left condylar process and lower border of the mandible in the sagittal line.

Angle (Figure 1)

1. R Go-angle: Angle between tangents of right corpus and right ramus of the mandible.
2. L Go-angle: Angle between tangents of left corpus and left ramus of the mandible.

The measurements were first performed on the dry mandibles by means of vernier caliper using the

predetermined points and the angle was measured using Universal bevel protractor (Figure 3). The mandibles were stabilized using the modeling wax of even dimension (Figure 4).

A custom made acrylic stand and calibrated holder was designed such that they did not absorb any X-rays nor superimposed itself on the radiographs. Subsequently, the stabilized mandibles along with the calibrated holder and acrylic stand were placed in the PLANMECA PROSCAN pantomographic machine (No: 688036 - version 13), with exposure parameters of 60 kvp and 0.5 mA. During exposure, each mandible was centered in the midline of the pantomogram, horizontally perpendicular to the midline; the light cross of the pantomograph was used as a guide. These calibrations and guidelines helped to place the mandibles in the exact location each time it was positioned and could be reproduced in the same fashion. Thus the method was consistently standardized.

Figure 3: Measurement of gonial angle using universal bevel protractor

Figure 4: Positioning of mandible on custom-made stand (frontal view)

The measurements were made on digital panoramic radiographs using Dimaxis-pro software.[7] To assess reliability, 3 different examiners measured vertical, horizontal, oblique, and angular parameters on 7 mandibles and their images twice during a month period. Statistical analysis for intraexaminer and interexaminer reliability was performed using ANOVA test. The most consistent examiner measured the rest of the mandibles and their respective images twice during a month period. The manufacturer listed the magnification factor of the machine as 1:1.2. Thus, magnification index was calculated for each variable by using an equation:

Magnification index = Distance on radiograph: Distance on dry mandible.[7]

Followed by calculation of descriptive statistics that included the arithmetic mean (X), standard deviation (SD), and standard error (SE). The t-test was used to compare the difference between the manufacturer magnification index and calculated magnification index for all measured variables.

RESULTS

Descriptive statistics (Mean, SD, SE, and mean difference) for all vertical, horizontal, oblique, and angular measurements were calculated as well as their calculated magnification indices. There was no significant difference in measurements between the three observers for the parameters on the first seven mandibles and their respective images; therefore intra and interexaminer reliability was consistent. Thus, all the three observers were found to be consistent in their measurements.

Tables 1-4 show that the mean differences among the linear measurements on the single side of the images were consistent and statistically insignificant. However, Table 2 shows the differences among Co-Co, PM-PM, and Go-Go measurements between dry mandible and digital measurement methods were found to be statistically significant. The difference in mean measurements between calculated and manufacturer's magnification index was found to be statistically significant ($P < 0.001$) for all variables (Tables 5-8). The calculated magnification index for all the linear variables was less than manufacturer's magnification index (Tables 5,7,8). Whereas for variables comprising Co-Co, PM-PM, Go-Go was greatly enlarged than the manufacturer's magnification index besides the other horizontal variables that did not cross the midline (Table 6). This indicates that these horizontal measurements, which cross the midline should not be considered.

Table 1: For vertical measurements

Measurement	Method	Mean (X)	SD	SE	Mean difference	*t*	*P* value
UBM-LBM	Dry mandible measurement	23.0904	4.1005	0.8201	−0.238	−0.207	0.837
	Digital measurement	23.3280	4.0217	0.8043			
R UBM-LBM (FM)	Dry mandible measurement	14.0792	3.4659	0.6932	−0.051	−0.051	0.959
	Digital measurement	14.1304	3.6148	0.7230			
L UBM-LBM (FM)	Dry mandible measurement	13.4584	3.5608	0.7122	−0.478	−0.465	0.644
	Digital measurement	13.9360	3.7013	0.7403			
R UBM-LBM	Dry mandible measurement	22.2748	3.2684	0.6537	−0.470	−0.502	0.618
	Digital measurement	22.7448	3.3492	0.6698			
L UBM-LBM	Dry mandible measurement	21.9632	2.3927	0.4785	−0.231	−0.329	0.744
	Digital measurement	22.1940	2.5712	0.5142			

SD: Standard deviation, SE: Standard error

Table 2: For horizontal measurements

Measurement	Method	Mean (X)	SD	SE	Mean difference	*t*	*P* value
Co-Co	Dry mandible measurement	99.1904	9.0719	1.8144	−72.640	−19.183	<0.001*
	Digital measurement	171.8304	16.6190	3.3238			
PM-PM	Dry mandible measurement	94.4208	9.9276	1.9855	−22.504	−6.411	<0.001*
	Digital measurement	116.9252	14.4748	2.8950			
Go-Go	Dry mandible measurement	94.7212	8.1966	1.6393	−32.547	−9.971	<0.001*
	Digital measurement	127.2684	14.1133	2.8227			
R LBM (S)-Go	Dry mandible measurement	84.3520	3.5956	0.7191	−0.064	−0.062	0.950
	Digital measurement	84.4160	3.6560	0.7312			
L LBM (S)-Go	Dry mandible measurement	83.7924	3.3178	0.6636	−0.827	−0.895	0.375
	Digital measurement	84.6196	3.2188	0.6438			
RW	Dry mandible measurement	29.2936	3.1329	0.6266	−0.433	−0.483	0.632
	Digital measurement	29.7268	3.2131	0.6426			
LW	Dry mandible measurement	29.9540	2.5531	0.5106	−0.526	−0.686	0.496
	Digital measurement	30.4800	2.8626	0.5725			
R-Co-PM	Dry mandible measurement	33.8736	3.2728	0.6546	−0.427	−0.449	0.655
	Digital measurement	34.3004	3.4440	0.6888			
L-Co-PM	Dry mandible measurement	34.6572	3.1931	0.6386	−0.179	−0.191	0.849
	Digital measurement	34.8364	3.4420	0.6884			

*Significant difference. SD: Standard deviation, SE: Standard error

Table 3: For oblique measurements

Measurement	Method	Mean (X)	SD	SE	Mean difference	*t*	*P* value
R Co-S	Dry mandible measurement	116.9408	5.6201	1.1240	−0.394	−0.256	0.799
	Digital measurement	117.3348	5.2532	1.0506			
L Co-S	Dry mandible measurement	116.5244	3.4384	0.6877	−0.106	−0.106	0.916
	Digital measurement	116.6300	3.6029	0.7206			

SD: Standard deviation, SE: Standard error

Table 4: For angle measurements

Measurement	Method	Mean (X)	SD	SE	Mean difference	*t*	*P* value
R Go-angle	Dry mandible measurement	121.3280	9.7158	1.9432	−0.976	−0.349	0.728
	Digital measurement	122.3040	10.0296	2.0059			
L Go-angle	Dry mandible measurement	119.8540	7.0014	1.4003	−1.046	−0.531	0.598
	Digital measurement	120.9000	6.9241	1.3848			

SD: Standard deviation, SE: Standard error

DISCUSSION

The goal of our study was to evaluate the precision of dimensional measurements of the dry human mandible on digital panoramic radiographs and to evaluate their dimensional stability. Numerous studies have been performed to evaluate the dimensional precision on panoramic radiographs using various methodologies. Catic *et al*.[7] in their study found that there was no statistically significant difference observed between

Table 5: Vertical distances on calculated magnification indexes and manufacturer's magnification index

Measurement	Index	Mean (X)	SD	SE	Mean difference	*t*	*P* value
UBM-LBM	Calculated magnification index	1.0123	0.0235	0.0047	−0.174	−24.114	<0.001*
	Manufacturer's magnification index	1.1860	0.0273	0.0055			
R UBM-LBM (FM)	Calculated magnification index	0.9864	0.1138	0.0228	−0.260	−4.402	<0.001*
	Manufacturer's magnification index	1.2463	0.2723	0.0545			
L UBM-LBM (FM)	Calculated magnification index	1.0267	0.0752	0.0150	−0.149	−5.856	<0.001*
	Manufacturer's magnification index	1.1759	0.1027	0.0205			
R UBM-LBM	Calculated magnification index	1.0213	0.0252	0.0050	−0.154	−19.928	<0.001*
	Manufacturer's magnification index	1.1756	0.0294	0.0059			
L UBM-LBM	Calculated magnification index	1.0101	0.0324	0.0065	−0.179	−17.793	<0.001*
	Manufacturer's magnification index	1.1892	0.0385	0.0077			

*Significant difference. SD: Standard deviation, SE: Standard error

Table 6: Horizontal distances on calculated magnification indexes and manufacturer's magnification index

Measurement	Index	Mean (X)	SD	SE	Mean difference	*t*	*P* value
Co-Co	Calculated magnification index	1.7409	0.1806	0.0361	1.044	26.432	<0.001*
	Manufacturer's magnification index	0.6972	0.0797	0.0159			
PM-PM	Calculated magnification index	1.2438	0.1449	0.0290	0.266	7.090	<0.001*
	Manufacturer's magnification index	0.9780	0.1190	0.0238			
Go-Go	Calculated magnification index	1.3518	0.1767	0.0353	0.449	10.427	<0.001*
	Manufacturer's magnification index	0.9029	0.1229	0.0246			
R LBM (S)-Go	Calculated magnification index	1.0008	0.0069	0.0014	−0.198	−91.714	<0.001*
	Manufacturer's magnification index	1.1992	0.0083	0.0017			
L LBM (S)-Go	Calculated magnification index	1.0101	0.0170	0.0034	−0.178	−34.325	<0.001*
	Manufacturer's magnification index	1.1884	0.0196	0.0039			
RW	Calculated magnification index	1.0149	0.0196	0.0039	−0.168	−27.770	<0.001*
	Manufacturer's magnification index	1.1828	0.0230	0.0046			
LW	Calculated magnification index	1.0170	0.0216	0.0043	−0.163	−24.570	<0.001*
	Manufacturer's magnification index	1.1805	0.0253	0.0051			
R-Co-PM	Calculated magnification index	1.0124	0.0224	0.0045	−0.173	−24.929	<0.001*
	Manufacturer's magnification index	1.1858	0.0266	0.0053			
L-Co-PM	Calculated magnification index	1.0047	0.0178	0.0036	−0.190	−34.443	<0.001*
	Manufacturer's magnification index	1.1948	0.0211	0.0042			

*Significant difference. SD: Standard deviation, SE: Standard error

Table 7: Oblique distances on calculated magnification indexes and manufacturer's magnification index

Measurement	Index	Mean (X)	SD	SE	Mean difference	*t*	*P* value
R Co-S	Calculated magnification index	1.0036	0.0125	0.0025	−0.192	−50.088	<0.001*
	Manufacturer's magnification index	1.1959	0.0146	0.0029			
L Co-S	Calculated magnification index	1.0009	0.0070	0.0014	−0.198	−90.856	<0.001*
	Manufacturer's magnification index	1.1990	0.0084	0.0017			

*Significant difference. SD: Standard deviation, SE: Standard error

Table 8: Angle measurements on calculated magnification indexes and manufacturer's magnification index

Measurement	Index	Mean (X)	SD	SE	Mean difference	*t*	*P* value
R Go-angle	Calculated magnification index	1.0079	0.0049	0.0010	−0.183	−120.266	<0.001*
	Manufacturer's magnification index	1.1906	0.0058	0.0012			
L Go-angle	Calculated magnification index	1.0088	0.0049	0.0010	−0.181	−120.434	<0.001*
	Manufacturer's magnification index	1.1896	0.0057	0.0011			

*Significant difference. SD: Standard deviation, SE: Standard error

dry human mandibles and radiographic measurement methods with respect to all the linear measurements ($P > 0.05$), excluding for structures crossing the midline, which was in agreement with our results (Tables 1-4).

Schulze *et al*.[6] assessed the precision and accuracy of panoramic measurements using digital panoramic software (Sidexis version 2.1). They concluded that vertical measurements were less reproducible than horizontal, in contrast to our study, the reasons for this

discrepancy could be due to a systematic measurement error i.e. variation due to the examiner, due to image magnification and systematic error due to the method. The variation attributed to such an error could be due to different software used in their study[6] with the different machine (Digital Orthophos DS – Sirona Dental Systems) and different manufacturer's magnification index (1:1.22).

The measurement error in our study was avoided as three examiners, who measured twice during a month period did the measurements and each one was consistent in measuring. Thus, the remaining measurements were performed by one of the examiners. Gröndahl *et al*.[8] suggest that reliability of measurements can be improved by multiple readings that was followed in our study. It's agreed that performance of a single observer with any method is relatively reproducible.

Our machine reproduced most precise vertical measurements as the mandibles were placed in the sharply depicted image layer. Hence, proper positioning of mandibles in focal trough followed by a standard operative technique, magnification error can be reduced on digital panoramic radiographs. Various studies by Catic *et al*.[7] Vasquez *et al*.[9] and Tronje *et al*.[10] showed more reproducible vertical measurements that was similar in our study.

The inherent property of panoramic radiographs is magnification and distortion that pose problems for dental practitioners in making measurements. The magnification factor listed by manufacturer varies from machine to machine. Therefore, we calculated the magnification index for all the variables measured, in order to evaluate the dimensional stability. It was found that the calculated magnification index was inferior than the manufacturers listed magnification index except for the structures crossing the midline. The results were not in agreement with Catic *et al*.[7] wherein, they found that the calculated magnification index of all the vertical variables compared to manufacturer's magnification index were insignificant. The difference for the results could be due to use of different orthopantomographic machine (conventional orthophos D3200 - Siemens), with different manufacturers magnification index of 1.22.

Every machine magnifies an object to a certain extent according to magnification index of that machine. According to Kjellberg *et al*.[11] manufacturer's magnification index might not be correct for all areas of the panoramic radiograph. The calculated magnification index was significantly less than manufacturer's magnification index, which was similar to Laster *et al*.[12]

Values of all the variables that spread on one side of the mandible had low calculated indices, values ranging from 1.008 to 1.1948; these were significantly lower than manufacturer's magnification index (Table 6). For all the horizontal distances that traversed the midline of the mandible, the calculated magnification index were higher than that of the manufacturer's magnification indexes (Table 6) that was statistically significant (<0.001). The results were in agreement with studies lead by Catic *et al*.[7] Tronje *et al*.[10] Razi *et al*.[13] Larheim and Scanaes.[14]

The horizontal distances crossing the midline were particularly unreliable as a result of a change in the angle of the central beam that was made to compensate for the curvature of the mandible. Kambylafkas *et al*.[15] have revealed the horizontal measurements were unreliable because of the nonlinear variation in magnification at different object depths. Another explanation could be that the radiographic image was "laid out" as the film in the cassette moves across the narrow slit opening. The resultant radiograph was flattened image of a curved structure.

The oblique and angle measurements done on the dry mandible and its respective digital panoramic radiographs showed no significant difference (Tables 3 and 4). The calculated magnification index and the manufacturer's magnification index were statistically significant (Tables 7 and 8), which was in agreement with Catic *et al*.[7]

CONCLUSION AND RECOMMENDATIONS

The measurements on digital radiography are quite acceptable and reliable for clinical use as long as the structures do not traverse the midline. Repeated measurements lead to a reduction in the systematic error and magnification to a loss of accuracy. Nevertheless, care must be taken to keep the errors inherent in panoramic radiography in mind whenever an exact assessment of distance is required. The variation in mandibular shape, considering different dental arches, could change its position in the image layer, and consequently the resulting image. Therefore, future studies should address the mandibles with different shapes comparing with different machines to assess the reliability.

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