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Posted Date: 11 March 2026

doi: 10.20944/preprints202603.0827.v1

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Effect of Horizontal Angulation on Radiographic Measurement of the Contact Point–Alveolar Bone Crest Distance: An In Vitro Study

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Featured: Application

- Accurate measurement of contact point–bone crest distance is essential for assessing periodontal health and predicting aesthetic outcomes.
- Periapical radiographic angulation significantly affects bone measurements, with deviations beyond 10° causing clinically unreliable results.
- Digital radiographs provide a more reliable, less invasive method for monitoring periodontal bone changes compared to probing alone.

Abstract

Linear measurements are used on radiographs for various purposes, such as measuring lengths in endodontics, analysing bone loss in periodontal disease and making age determinations in forensic dentistry. The purpose of this study was to analyse the accuracy of periapical radiographs for the measurement of the contact point to the crest of the bone compared to the actual measurements of a dried skull. A dried skull had lead squares measuring 1 x 1mm attached to the contact point and the bone crest. Each site was radiographed using a parallel technique with a Rinn holder. The radiographs were taken perpendicularly to the tooth and repeated at 10° and 20° horizontal angulations. The results showed that variation in the angle of the radiograph had a significant effect on the resulting measurements, $F(1.7, 26.9) = 218.265$, $p < 0.001$. The results from this study indicate that when measuring the contact point to the crest of the bone, a shift of 20° from the perpendicular of the tooth has a significant effect on the radiograph measurement and the actual measurement of the contact point to the crest of the bone on the actual skull.

Keywords: contact points; crest of bone; periapical radiographs; linear measurements

1. Introduction

The majority of bone-level studies have concentrated on assessing changes in bone levels around teeth and dental implants. It is important to assess the progression or absence of periodontitis [1] and peri-implantitis [2] as continued loss will lead to tooth or implant loss. The term 'bone loss' is defined as the difference between the septal bone height and the expected normal height for the patient.

A cemento-enamel junction (CEJ) within 2-3mm of the crestal bone height is the normal radiographic appearance of the healthy periodontium. In anterior teeth, it is also expected to see a thin and pointed margin in the inter-crestal bone, a crestal bone that is continuous with the lamina dura of the adjacent tooth, and a thin and even width in the mesial and distal periodontal space.

 doi:10.20944/preprints202603.0827.v1

Direct observation was undertaken when Tarnow studied the distance of the contact point to the crest of the bone after a surgical mucoperiosteal flap was raised [3]. This has been adopted as the gold standard for predicting the presence or absence of a black triangle and is frequently referenced. This procedure is highly invasive, and is not a practical way to measure the distance in everyday specialist or general practice.

Radiographs allow the clinician to visualise the surrounding bone support of the teeth. They work by absorption and transmission of the X-ray (roentgen rays) beam. Bone and teeth have a higher density, and therefore, they attenuate the beam more than low-density structures such as soft tissue. The use of radiographs involves exposing the patient to radiation, but in most periodontal and prosthodontic patients, radiographs are regularly taken for assessment. Another drawback of radiographs is that they produce 2D images of a 3D object.

When periodontal probes are used to assess bone loss and attachment loss, the probes have 1mm increments, and the 95% confidence interval for any depth changes is 2-3mm. This means that these measurements are not that meaningful clinically. The pressure and design of the probes will also influence the measurements. If the probing pressure is too great or the point is very narrow, then the probe may enter the connective tissue and overestimate the probing depth (Figure 1). As a result, a series of papers were published, changing the direction of clinically related periodontal research [4–7].

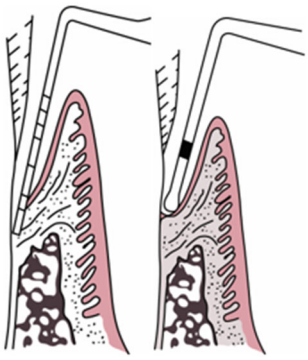


Table papers developed the concept of the 'burst theory'. This theory states that periodontal disease is not a linear loss of bone, but rather progresses in bursts of activity. However, this theory may have been developed based on an inaccurate or artificial division of lesions into active and inactive sites by the probing data [8]. The active lesions were only recorded when there was a distance of 2-3mm with a 95% interval confidence level, and any sites with smaller losses were recorded as inactive. Therefore, it is not surprising that the disease appeared to progress in bursts since it was recorded only when the 2-3mm level was reached and smaller changes were missed.

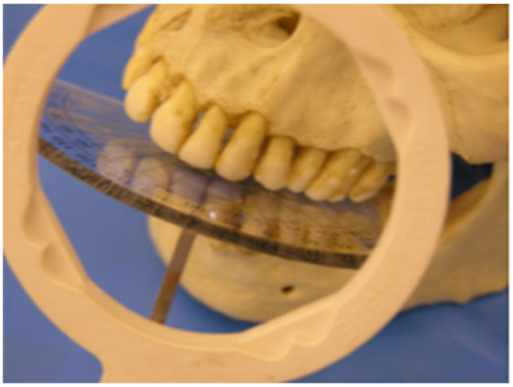
For this reason, more sophisticated methods were needed to record the progression of the disease. Thus, the use of digital radiographs to assess the bone loss was developed. The use of radiographs in periodontal disease allows the clinician to record the condition of the bone throughout the course of the disease [9]. They also allow the identification of the amount of bone destruction and local contributing factors. These methods are direct measurements to determine the amount of marginal bone loss [10,11].

The purpose of this study was to analyse the accuracy of periapical radiographs for the measurement of the contact point to the crest of the bone in relation to the actual measurement on a dried skull.

2. Materials and Methods

 doi:10.20944/preprints202603.0827.v1

Where applicable, this study is reported following the STARD guidelines[12]. Ethical approval was granted by National Health services Manchester Foundation trust (NHS MFT) (reference number: 08/H1011/49). A dried human skull with intact dentition was used. Each of the contact points and the crests of the bone were marked with a small lead marker to standardise the measurement points and allow them to show on the radiographic image. Digital Vernier callipers were used to measure the actual distance of the crest of the bone to the contact point. An aiming device was constructed which consisted of a Rinn radiographic holder attached to a protractor to take the radiographs with the tube shifted to the desired angle (Figure 2). Radiographs for each of the contact points to the crests of the bone were taken at 0°, i.e. perpendicular to the tooth, then at 10° and 20° angulations.



3. Results

The measurements were analysed using a one-way repeated-measurement ANOVA on IBM SPSS version 20. Table 1 shows the descriptive statistics with the mean and the standard deviation for each of the different angulations.

Table 1. Descriptive statistics.

	Mean	Std. Deviation	N
0°	1.5629	0.32640	17
10°	1.4671	0.28146	17
20°	0.5212	0.06499	17
Tooth measure	1.5635	0.19497	17

To determine whether the data violated the assumption of sphericity, Mauchly's test of Sphericity showed the criteria were not met (Table 2).

Table 2. Mauchly's test of Sphericity.

Effect	Value	F	Hypothesis	Error df	Sig.	Partial Eta Squared
Pillai's Trace	0.988	370.467	3.000	14.000	.000	.988
Wilk's Lambda	0.012	370.467	3.000	14.000	.000	.988
Hotelling's Trace	79.386	370.467	3.000	14.000	.000	.988
Roy's Largest Root	79.386	370.467	3.000	14.000	.000	.988

Within Subject Effect	Mauchly's W	Approx Chi-Square	Df	Sig.			
					Greenhouse-Geisser	Huynh-Feldt	Lower bound

 doi:10.20944/preprints202603.0827.v1

Factor 1	0.281	18.697	5	0.002	0.560	0.618	0.333

Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(5) = 18.697$, $p < 0.05$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates with sphericity $\varepsilon = 0.56$ used for the variation in measurements. Table 3 shows the Within-Subjects Effects test used to counteract the violation of sphericity.

Table 3. Tests of Within-Subjects Effects.

Source	**Type III sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Sphericity Assumed	13.111	3	4.370	218.265	.000	.932
Greenhouse-Geisser	13.111	1.679	7.807	218.265	.000	.932
Huynh-Feldt	13.111	1.854	7.072	218.265	.000	.932
Lower Bound	13.111	1.000	13.111	218.265	.000	.932
Error (Factor 1) Sphericity Assumed	0.961	48	0.020			
Greenhouse-Geisser	0.961	26.870	0.036			
Huynh-Feldt	0.961	26.662	0.032			
Lower Bound	0.961	16.000	0.060			

Factor 1	Mean	Std. Error	95% Confidence Intervals	
			Lower Bound	**Upper Bound**
1	1.563	0.079	1.395	1.731
2	1.467	0.068	1.322	1.612
3	0.521	0.016	0.488	0.555
4	1.564	0.047	1.463	1.664

Table 4 presents the final *post hoc* test, which looks at the difference in the group means.

Table 4. Pairwise comparisons.

(I)factor1	**(J)factor1**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval for Difference**	
					Lower Bound	Upper Bound
1	2	0.096	0.036	0.098	-0.012	0.203
	3	1.042*	0.067	0.000	0.841	1.243
	4	-0.96	0.048	1.000	-0.146	0.145
2	1	-0.096	0.036	0.098	-0.203	0.012
	3	0.946*	0.057	0.000	0.775	1.117
	4	-0.96	0.043	0.230	-0.225	0.032
3	1	-1.042*	0.067	0.000	-1.243	-0.841
	2	-.0946	0.057	0.000	-1.117	-0.775
	4	-1.042	0.032	0.000	-1.137	-0.948
4	1	0.001	0.048	1.000	-0.145	0.146
	2	0.096	0.043	0.230	-0.032	0.225
	3	1.042*	0.032	0.000	0.948	1.137

Effect	Value	F	Hypothesis	Error df	Sig.	Partial Eta Squared
Pillal's Trace	0.988	370.467	3.000	14.000	.000	.988

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Wilk's Lambda	0.012	370.467	3.000	14.000	.000	.988
Hotelling's Trace	79.386	370.467	3.000	14.000	.000	.988
Roy's Largest Root	79.386	370.467	3.000	14.000	.000	.988

*Mean difference is significant.

The results showed that the variation in the angle of the radiograph had a significant effect on the resulting measurements, F (1.7, 26.9) = 218.265, $p < 0.001$, $\omega^2 = 0.401$.

4. Discussion

Several factors that affect the image include the geometry and position of the radiographic film. The angulation of the beam in relation to the object and the film can alter the measurement of the final image. While this study examined horizontal shifts in the beam angulation, other studies examined changes in vertical angulation and showed that a change of up to 20° only made a minor contribution to the total measurable error. This corresponds to the trigonometrical calculation that a 10° shift in the beam from parallel to the tooth and bone results in a 1.5% error in the projection of anatomical distances between two points [13].

A shift in the angulation of the tube may also affect the perceived position of the crest of the bone, especially in patients with periodontal disease, if there are interproximal bone defects. In the anterior and premolar region the effect of a change in angulation is less than in the molar region because any distortion due to angulation shift is dependent on the thickness and the shape of the structure [14].

Assessment of the position of the alveolar crest depends on the direction of the X-ray beam relative to the bone and the film position. The true anatomical dimensions will be projected on the film if the bone is at a right angle to the beam and the film is parallel to the long axis of the tooth.

Various methods were proposed to describe and aid in the identification of the crest of the bone [15]. The criteria described are related to the crest of the interproximal bone and the CEJ:

- 'Ideal' CEJ – the most apical extent of the enamel that interfaces with the root surface. This can be seen where the change in the radiographic density of the enamel and the root surface is identical to where there is a change in the contour between the crown and root.
- 'Ideal' crest – the most apical location of the interproximal bone, which is clearly defined as a radiographic change in the density. In a 'non-ideal' crest there are vertical defects where the bone slopes away from the root surface. The crest is then marked as where it slopes away from the tooth.

Radiographs are not perfect images and are affected by distorting factors, including magnification. Magnification depends on the relationship between the object, the X-ray source and the image receptor. Therefore, both a reduction in the object-to-film distance or an increase in the X-ray-to-film distance will decrease magnification. An uneven magnification of different parts of the image results in image sharpness because the radiation from the machine comes from an area (a focal spot) rather than a point. This causes a shadow called an 'umbra', which is the image, surrounded by a blurred area called the 'penumbra'. Therefore, the larger the focal area, the larger the blurred area will be. In modern machines, this focal area is around 1mm, but with use over time, it will increase. Sharpness also decreases with an increase in the X-ray-to-object distance.

The object being radiographed is a 3D object; it has height, width and depth. The radiograph, however, only portrays a 2D image, i.e. height and width. This means there is a degree of perspective needed. Prior knowledge of the anatomical relationships and normal dimensions of the structures being radiographed is required. Different techniques produce different geometrical projections that cause different image distortions. The two radiographic techniques are the bisecting-angle and paralleling techniques.

 doi:10.20944/preprints202603.0827.v1

These techniques have been compared in the field of endodontics in relation to working length estimation [16], root filling length [17] and periapical lesion [18]. Forsberg [16] showed that a paralleling radiographic technique was superior to the bisecting-angle technique in reproducing the anatomy of the root apex. In approximately 95% of cases, the distance between the instrument and the apex of the tooth was correctly reproduced.

Further, the study stated that in the in vitro study, the paralleling technique was so accurate that a master cone radiograph was not needed [19].

When the actual linear measurement is taken to assess bone loss, there have been several validation studies on dry skulls that have shown that the bone loss and radiographic measurement are highly correlated [20,21].

On a radiograph, there appears a dense white line that lines the socket of the tooth and the crest of the bone. The name of this structure is the lamina dura, and its presence is determined by the position of the root in the bone and the beam angulation and not necessarily the bone integrity. Looking at the lamina dura on bitewing and periapical radiographs of the same area, there is no correlation between the lamina dura in these two images [22]. There is no difference in the mineral content of the lamina dura and the adjacent bone, but it is probably just more densely packed with fewer marrow spaces [23]. When the presence or absence of the lamina dura was studied, it appears that it does not relate to inflammation, loss of attachment, bleeding or pocketing [22].

The pattern is different when considering the loss of lamina dura in periodontally involved teeth or due to systemic disease. In periodontal disease, the crestal lamina dura is lost around specific teeth, whereas in systemic disease, it is lost from around all sockets and crests [24]. The systemic diseases that are associated with loss of lamina dura are hyperparathyroidism, Gaucher's disease, scleroderma and Paget's disease.

Osteoporosis and osteopenia are both bone conditions where the bone remodelling is favoured by resorption over deposition. Both these diseases cause a reduction in bone density. They are of the same entity but differ in severity, with osteoporosis consisting of a bone density lower than 2.5 standard deviations from the normal and osteopenia between 1 - 2.5 standard deviations lower than the normal (Reddy 2001). Both diseases share the same risk factors as periodontal disease, such as smoking, certain medications, and certain systemic diseases. There are also genetic and age factors in common with periodontal disease and osteoporosis/osteopenia. Studies have found a positive link between periodontal disease and osteoporosis. It has also been found that low bone density is related to interproximal bone loss that persists even after allowing for confounding factors [25–27]. A study found that women with osteoporosis had a greater clinical attachment loss and gingival recession than women with normal bone density [28].

While a radiographic image is a 'snapshot' in time, dental diseases tend to be dynamic and change over time. A diagnosis of disease progression cannot be made from a single radiograph. An assessment needs to be made over time to see if things are progressing or static. The results from this study, which measured the contact point to the crest of bone, showed that a 20° shift from the tooth's perpendicular had a significant effect on radiographic measurements and on actual measurements on the dried skull. This finding was likely due to the contact point becoming obscured by the overlapping of the teeth as the beam deviated from perpendicular to the tooth. This would make determining the actual contact point more difficult and may require some guesswork to estimate the contact point.

The limitation of radiographs is that they are two-dimensional images of three-dimensional objects. This means that complex bony defects may be hidden by higher surrounding bony walls. They also only show the gross changes and underestimate the actual extent of the bone loss. The early bone changes do not cause sufficient changes in density to be detected by the radiograph (Mann, Pettigrew et al. 1985). The loss of attachment must be present for 6-8 months before changes are seen to the bone, and loss is evident on the radiograph [29]. There needs to be 30%-50% mineral loss in the bone before a clinician's eyes can detect a change. With conventional radiographs, measurements of the amount of bone loss can be done with a Schei ruler [30] which has been found to be as accurate

 doi:10.20944/preprints202603.0827.v1

as surgical exploration. Nowadays, with the introduction of computer aids and image processing, it is possible to measure it digitally and to detect 5% bone loss with 90% sensitivity, specificity and overall accuracy [31,32].

Also, with the use of high-quality digital radiographs and modern methods, it is possible to detect changes of 0.1mm [33]. When looking at the crest of the bone, it may get burnt out due to processing errors or incorrect exposure. Yet with digitised images, it is possible to correct these and better visualise the crest of the bone [34,35].

5. Conclusions

To predict the presence of a black triangle, it is important to measure the contact point to the crest of the bone, and if radiographs are used, ensure the measurements on the radiographs are accurate representations.

Within the limitations of this in vitro study, it was found that Radiographs taken at 0° and 10° have a significant correlation with the actual measurement from the crest of the bone to the contact point. At 20° from the perpendicular, this measurement is not significant. Therefore, clinically, we can rely on a measurement with up to 10° deviation from the perpendicular, but when increased to 20°, it becomes more difficult to see the contact point, and therefore, we see a difference in the radiographic measurement and the actual measurement.

Author Contributions: Conceptualization (JC & SM), initial writing (JC & SM), Results (MG), Supervision (MG), Final Writing and editing (JC & SM).

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical approval was granted by National Health services Manchester Foundation trust (NHS MFT) (reference number: 08/H1011/49).

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available upon request.

Acknowledgments: In this section, you can acknowledge any support given which is not covered by the author contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments). Where GenAI has been used for purposes such as generating text, data, or graphics, or for study design, data collection, analysis, or interpretation of data, please add "During the preparation of this manuscript/study, the author(s) used [tool name, version information] for the purposes of [description of use]. The authors have reviewed and edited the output and take full responsibility for the content of this publication.".

Conflicts of Interest: All authors declare that there was no conflict of interest in this study. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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