Periapical Radiographs in Determining Peri-Implant Bone Defect Size and Type: A Prospective Clinical Study

Peri-İmplant Kemik Defekti Boyutu ve Türünün Belirlenmesinde Periapikal Radyografilerin Rolü: Prospektif Klinik Çalışma

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ABSTRACT

INTRODUCTION: This study evaluated accuracy of periapical radiographs (PAs) in measuring peri-implant bone defects and identifying defect types in peri-implantitis patients. Additionally, it assessed the consistency of probing depth measurements using plastic and metal periodontal probes.

MATERIAL and METHODS: A prospective clinical study included 28 patients (51 implants, 96 defects) diagnosed with peri-implantitis. Radiographic defect dimensions were measured on PAs using standardized techniques and compared with intraoperative findings. Defect types were classified based on radiographic and surgical observations. Probing depth measurements were performed using metal Williams and plastic UNC-12 probes. Statistical analyses included dependent t-tests, Bland-Altman plots, and Kappa coefficients.

RESULTS: PA radiographs underestimated defect dimensions compared to intraoperative measurements, with mean differences of 0.34 mm (depth) and 0.32 mm (width) ($p < 0.001$). Repeatability of radiographic measurements was excellent (ICC = 0.997). Moderate agreement ($\kappa = 0.47$) was observed between radiographic and intraoperative classifications, with highest concordance for type 1c and 1d defects. Substantial agreement ($\kappa = 0.71$) was found between metal and plastic probe measurements.

CONCLUSION: Standardized PAs provide acceptable accuracy for assessing peri-implant defects, despite slight underestimation. Moderate agreement in defect classification supports their clinical utility. Both probes demonstrated substantial consistency, reinforcing their validity in peri-implantitis diagnostics.

Keywords: *Peri-implantitis, dental implants, bone resorption, radiography, periodontal probing*

ÖZ

GİRİŞ: Bu çalışma, peri-implantitis hastalarında periapikal (PA) radyografilerin vertikal peri-implant kemik defekti boyutlarını ve defekt türlerini belirlemedeki etkinliğini değerlendirmiştir. Ayrıca, plastik ve metal periodontal problarla yapılan sondalama derinliği ölçümlerinin tutarlılığı incelenmiştir.

GEREÇ ve YÖNTEM: Peri-implantitis teşhisi konmuş 28 hasta (51 implant, 96 defekt) dahil edilmiştir. Standardize PA radyografilerde defekt derinlikleri ve genişlikleri ölçülerek intraoperatif ölçümlerle karşılaştırılmıştır. Defekt tipleri radyografik ve cerrahi gözlemlerle sınıflandırılarak uyum analiz edilmiştir. Sondalama derinliği, metal Williams ve plastik UNC-12 problarla ölçülmüştür. İstatistiksel analizler bağımlı t-testleri, Bland-Altman grafikleri ve Kappa analizi ile yapılmıştır.

BULGULAR: PA radyografiler defekt boyutlarını intraoperatif ölçümlere göre daha düşük göstermiştir (derinlik farkı: 0.34 mm, genişlik farkı: 0.32 mm; $p < 0.001$). Radyografik ölçümlerin tekrarlanabilirliği mükemmel bulunmuştur (ICC = 0.997). Defekt sınıflandırmalarında orta düzeyde uyum ($\kappa = 0.47$) belirlenmiş, tip 1c ve 1d en yüksek uyumu göstermiştir. Metal ve plastik problar arasında güçlü uyum ($\kappa = 0.71$) saptanmıştır.

SONUÇ: PA radyografiler, peri-implant kemik defektlerinin değerlendirilmesinde güvenilirdir ancak boyutları bir miktar düşük tahmin eder. Defekt sınıflandırmalarındaki orta uyum, cerrahi öncesi klinik kullanımını desteklemektedir. Metal ve plastik problar, peri-implantitis teşhisinde tutarlı ölçümler sunmaktadır.

Anahtar Kelimeler: *Peri-implantitis, dental implantlar, kemik rezorpsiyonu, radyografi, periodontal sondalama*

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INTRODUCTION

Precise diagnosis of peri-implantitis and peri-implant bone defects comprises a thorough clinical and radiographic examination. Early detection of these defects leadsaround

to a more favorable prognosis, while an inaccurate diagnosis can lead to several undesirable complications including mucosal recession, and loss of implant osseointegration.[1] In order for a bone defect to be detected on radiographs, the reduction in the amount of calcified tissue has to reach approximately 30-50%, which delays the timely and complete detection.[2,3] Histometric,[4] cadaver[5] and clinical studies[6] have demonstrated that radiographic assessment may underestimate peri-implant crestal/marginal bone levels compared to actual measurements. Notably, factors such as arch, implant location, placement timing, and alveolar edge level do not appear to influence this trend.[6] Additionally, measurements of peri-implant bone defects on periapical radiographs (PAs) were found to be between 0.6-2.3 mm less than measurements during surgery.[7-10] The determination of bone level on PAs may be inaccurate due to distortion in bone width and height which depends on the angulation of the x-ray beam.[11] Accordingly, the differences between radiographic measurements and actual defect sizes gain importance in order to prevent delays in treatment through early diagnosis. In addition to radiographic measurements, clinical probing depth evaluations play a crucial role in the diagnosis of peri-implant bone defects. Studies have shown that the type of periodontal probe can influence the accuracy of measurements.[12] Plastic probes, which are often used to avoid damaging implant surfaces, may yield less precise results compared to metal probes due to differences in flexibility and tactile feedback.[13]

In studies comparing the efficiency of various radiographic imaging techniques for assessing crestal bone loss around implants, PAs consistently outperformed panoramic radiography (PR). This is largely attributed to PR's lower spatial resolution and non-linear distortions, which lead to a dimensional deviation of 82% in most cases.[14] Cone beam computed tomography (CBCT) which prevents overlapping of anatomical structures and allows visualization of buccal and lingual cortical bone plates in addition to mesial and distal bone, has been shown to be inferior,[15-18] superior[19,20] or similar[21] to PAs in detecting peri-implant crestal bone losses. In vitro design of these studies limits the interpretation of results since movement artifacts and soft tissue attenuation are not reproducible in experimental conditions.[22] In addition to the measurement of peri-implant bone defect dimensions, determination of the defect type has been suggested as an important indicator of therapeutic outcome of nonsurgical and surgical periodontal treatments.[23] Studies demonstrated that narrower defect angles were more prone to achieve greater radiographic bone fill,[23] and circumferential defects were more conducive to reveal higher changes in probing pocket depth and clinical attachment level at 6 and 12 months compared to other defect morphologies.[24] CBCT has been reported to better detect dehiscence and fenestration defects, whereas PAs were more accurate in the visualization of interproximal defects, emphasizing their continued role in the initial assessment of peri-implant tissues.[25] CBCT images suffer from scattering and beam hardening artifacts, particularly from zirconia dental implants, a drawback that cannot be improved with the use of metal artifact-reduction software.[26]

There is still no consensus in the literature regarding whether the morphological characteristics of the defect have an impact on the prognosis, and therefore initial acquisition of PAs has been recommended[7,27] due to the high radiation dose, cost and the presence of artefacts during CBCT imaging.[27] However, few studies have evaluated the compatibility of PAs with intraoperative measurements for classification and assessing the size of vertical bone defects around implants,[7-9,20] and only three of these studies have been conducted in clinical settings on human subjects.[7-9] Therefore, the aim of this study is to assess the accuracy of PAs in measuring the size of vertical defects around implants in patients diagnosed with peri-implantitis, and to determine the concordance between the defect types identified during surgery and radiologically. Additionally, we aimed to assess the agreement between probing depth measurements obtained using plastic and metal probes at peri-implantitis sites.

MATERIALS and METHODS

Study Design

Patients referred to the Department of Periodontology, following clinical and panoramic radiographic examinations at the Oral Diagnosis & Radiology outpatient clinic, were included in this prospective study in a 6-month period. Those with complaints of bleeding, swelling, and inflammation around dental implants were enrolled. Detailed medical and dental histories were obtained, followed by clinical examinations for all participants.

The general oral clinical examination included the assessment of oral hygiene, periodontal and mucosal diseases, occlusal relationships, prosthetic restorations, and the position and condition of the implants. The clinical evaluation of the implant sites focused on several factors, such as the amount of keratinized mucosa around the implant, probing depth, and the presence of bleeding. Additionally, the presence of purulent exudation and the mobility of the implants were examined. Peri-implantitis was defined according to Renvert et al.[28] as follows: *1*) visual evidence of inflammation in the peri-implant soft tissues along with bleeding on probing and/or suppuration, *2*) increasing probing pocket depths compared to those recorded at the time of supra-structure placement, *3*) progressive bone loss relative to the radiographic bone level assessed one year after the implant-supported prosthetic reconstruction, and *4*) in the absence of initial radiographs and probing depths, radiographic bone loss of ≥3 mm and/or probing depths of ≥6 mm, combined with profuse bleeding.

Initial radiological evaluations were conducted on panoramic radiographs. Following the assessments, patients with vertical bone defects around the implants were informed about surgical treatment, and those who chose to undergo surgery were included in the study based on the inclusion and exclusion criteria outlined below:

Inclusion Criteria

- Presence of at least one radiographic vertical peri-implant bone defect on a proximal surface, at least one year after prosthetic loading, according to the definition of peri-implantitis as described above,[28]
- Root-shaped, tissue or bone-level design dental implants,
- Implants positioned at an angle of no more than 25° in the vertical plane.
- Class 1 bone defects according to the Schwarz et al.[2] peri-implant defect classification (Type 1b, 1c, 1d and 1e) (Figure 1).
- Consent to participate

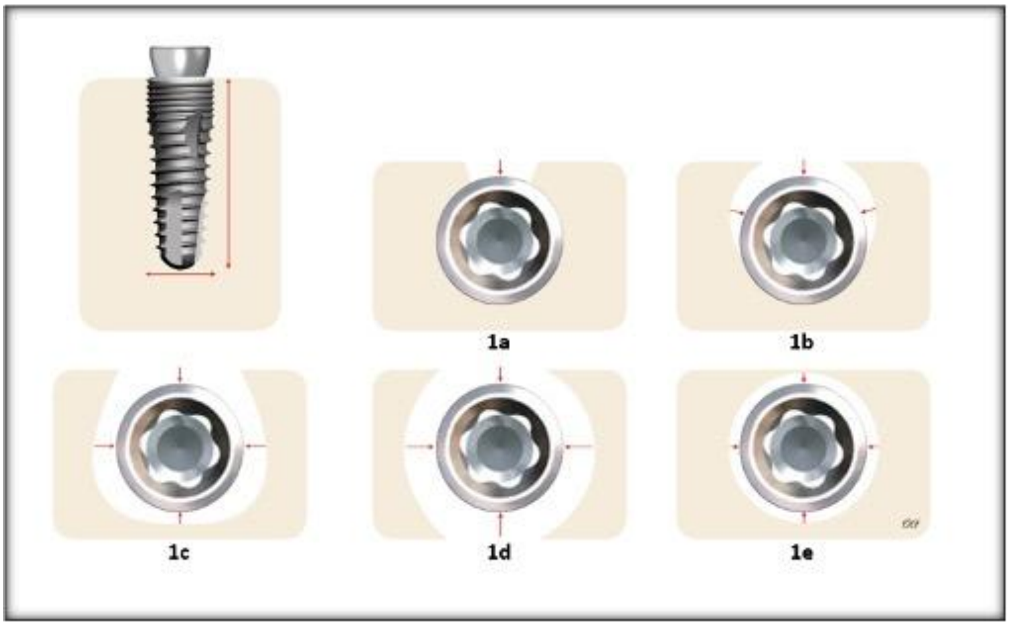

Figure 1: Peri-implant defect classification according to Schwarz et al.[2]

Exclusion Criteria

- Presence of systemic diseases that contraindicate surgery, pregnancy, or lactation,
- Failure to comply with necessary oral hygiene recommendations,
- Cases where the distance between two implants is insufficient to assess vertical/horizontal bone loss,
- Class 2 bone defects.[2]

The study design was approved by the Ethics Committee of Ege University, Faculty of Medicine (2018, Decision No: 18-9/22). Individuals who agreed to participate were required to sign an informed consent form prepared in accordance with the revised Helsinki Declaration from the 64th General Assembly.

Preoperative Clinical Measurements

Preoperative clinical assessments at the initial visit included measurements of the width of keratinized mucosa, modified gingival index and modified plaque index, and probing depth. The keratinized mucosa was measured on the mid-buccal surface of the implants using the Roll technique. Probing depth was measured after removing the suprastructures to minimize errors related to probing angulation. To ensure the examiner's calibration and assess the repeatability of probing depth measurements, 28 implants (112 surfaces in total) were measured twice, 24 hours apart, on the mesial, distal, buccal, and oral surfaces. Repeatability was evaluated using Weighted Kappa analysis, showing high agreement with a κw of 0.91.[29]

Measurements were performed twice using metal Williams and plastic UNC 12 probes. The values from four surfaces (mesial, distal, buccal, oral) around the implants were rounded to the nearest millimeter and recorded. A gentle force of approximately 0.25 N was applied during probing (Figure 2).

Figure 2: Probing depth measurements using (a) Williams probe and (b) plastic UNC-12 probe on distal aspect of an implant with a peri-implant vertical defect.

Preoperative Radiological Examination

PA radiographs were obtained with the Digora Optime storage phosphor plates (SPP) system (Soredex Corp., Tuusula, Finland) using intraoral film holders (Dentsply/Rinn Corporation, Elgin, IL) to keep the plates parallel to the long axis of the teeth. A size #2 SPP was used for all exposures. Radiographic images were captured before removing the suprastructures to ensure the film holder remained in a fixed and stable position. However, if over-height prosthetic restorations obstructed parallel placement of the film to the implant, images were taken after the restorations were removed. Prior to imaging, two fully round metal wires, each 10 mm in length and 0.6 mm in thickness, were attached parallel to the short and long edges of the phosphor plate, with one wire positioned horizontally and the other vertically. SPPs were exposed with a Gendex Oralix DC dental x-ray unit (Gendex Dental Systems, Milan, Italy) operating at 60 kVp, 7 mA, 0.25 sec., and the plates were scanned immediately after exposure. The images were transferred to a personal computer with 8-bit contrast depth in TIFF format (Toshiba Satellite U50t-A-10P Core i5-4200U) and saved using coded identifiers for each implant surface to mask patient data. The images were examined in a quiet room with appropriate lighting, and the radiographic peri-implant defect type[2] was determined by one of the investigators who was blinded to the patient selection process and initial panoramic radiographical examination (AG).

Linear radiographic measurements were conducted using a Java-based software (Image-J 3.0, NIH, Bethesda, USA), employing the 10 mm wires as reference objects in the relevant planes (Figure 3). The vertical defect depths on mesial and distal surfaces of the implants were measured as the distance from the most coronal point of the alveolar crest (projected onto the implant body) to the deepest point of the defect. Defect width measurements were taken as a horizontal line extending from the mesial and distal surfaces at the most coronal point of the alveolar crest to the implant body (Figure 3). The measurements were conducted by the same blinded examiner who carried out the radiological defect classification (AG). All measurements were repeated 3 times, and the mean of the three measurements was considered as the average defect depth and defect width. The same examiner re-measured defect depths and widths, and re-evaluated defect types on a randomly selected half of the PA images one month later.

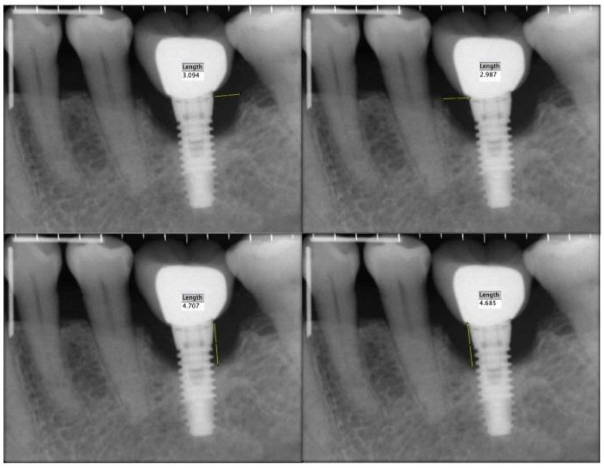

Figure 3: Class 1, type d peri-implant bone defect and two 10 mm metal wires attached to the phosphor plate, aligned in horizontal and vertical planes. Defect width (a, b) and defect depth (c, d) measurements on distal and mesial aspects of an implant with a peri-implant vertical defect.

Surgery and intraoperative measurements

All surgical procedures and intraoperative measurements were conducted by the same investigator responsible for patient selection and the preoperative clinical assessments (AT). Local anesthesia was applied to the surgical site using a solution of 2% lidocaine with 1/100,000 epinephrine (Jetokain®, Adeka İlaç San Tic Aş, Turkiye). A full-thickness flap was raised from both the vestibular and oral surfaces, and granulation tissue within the flap and around the implant was carefully excised. The defect depths on mesial and distal surfaces of the implants were measured as the distance from the most coronal point of the alveolar crest (projected onto the implant body) to the deepest point of the defect using a blunt-tipped spreader with a plastic stopper (Figure 4). Defect widths were measured as a horizontal line extending from the mesial and distal surfaces at the most coronal point of the alveolar crest to the implant-abutment junction. The distance from the tip of the spreader to the edge of the plastic stopper was then measured using a digital caliper (BTS-12043, Newland Industrial Co, Zhejiang, China) with a precision of 0.01 mm. Each measurement was performed three times, and the arithmetic mean was calculated and recorded. Additionally, the intraoperative peri-implant defect type was determined during this process.[2]

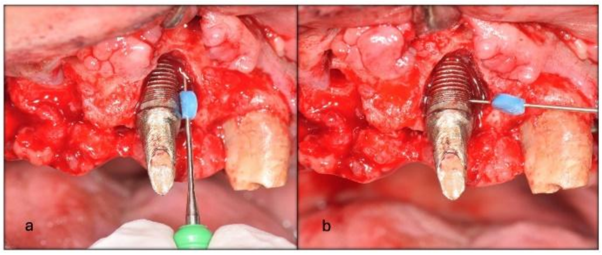

Figure 4: Intraoperative (a) defect depth and (b) defect width measurements on the distal aspect of an implant with a peri-implant vertical defect.

Treatment decisions were based on the prognosis classification by Froum and Rosen.[30] Following measurement completion, interventions such as resective or regenerative peri-implantitis treatment, or implant removal, were chosen according to defect size, implant survival prognosis, and available bone support. Patients were provided with postoperative care instructions and monitored closely for any complications.

Statistical Analysis

The minimum sample size required to evaluate the agreement between radiographic and intraoperative measurements at 80% power and p=0.05 significance level was calculated using G* Power 3.0 software (Heinrich- Heine- Universität, Düsseldorf, Germany), which revealed a sample size of 89 proximal defects.

Descriptive data included the modified gingival index, modified plaque index scores, and keratinized mucosa measurements. Weighted Kappa was applied to evaluate the compatibility of preoperative probing depth measurements using metal Williams and plastic UNC-12 probes. The Kappa coefficient was used to assess interobserver agreement for radiographic defect type classification. The repeatability of radiographic defect depth and width measurements was assessed with intraclass correlation coefficient (ICC).

The agreement between radiographically and intraoperatively identified defect types was evaluated using Kappa coefficient. The differences between radiographic and intraoperative measurements of defect depth and width were assessed using a dependent sample t-test, with Bland-Altman plots presented alongside the analysis. All statistical analyses were performed using SPSS Version 21.0 (IBM, Armonk, NY), with results evaluated at a 95% confidence interval and a significance level of p=0.05.

RESULTS

A total of 88 patients with bleeding, swelling, and inflammation around dental implants were initially assessed. Of these, 37 met the inclusion criteria. Among them, 5 did not attend their scheduled appointments, 3 chose to continue treatment in private clinics, and 1 was excluded due to insufficient communication and cooperation. Therefore, 28 patients were ultimately included in the final analysis.

The study included 28 patients (10 males and 18 females), aged between 35 and 74 years. A total of 51 implants and 96 vertical defects were evaluated across these patients. Among the 51 implants, 34 were located in the mandible (comprising 7 canines, 9 premolars, and 18 molars), while 17 implants were situated in the maxilla (including 3 canines, 8 premolars, and 6 molars). The mean width of keratinized mucosa was determined to be 1.65 ± 1.30 mm, while the modified gingival index was 2.06 ± 0.61 mm, and the modified plaque index was 2.04 ± 0.78 mm.

Probing depth measurements were obtained from 204 surfaces (mesial, distal, buccal, oral) surrounding 51 implants using Williams and UNC-12 probes. The mean probing depth was 6.75 ± 1.41 mm with the Williams probe, and 6.62 ± 1.23 mm with the UNC 12 probe. The compatibility between measurements was assessed using the Weighted Kappa, yielding a κw value of 0.71, indicating a substantial agreement between the two probes (standard error: 0.02, 95% CI: 0.66-0.75).[29]

Defect type

The type and distribution of vertical peri-implant defects as determined on PA radiographs and during surgery are presented in Table 1. The interobserver agreement for radiographic defect type classification was calculated as κ=0.88, signifying a strong level of concordance.[29]

Based on intraoperative evaluations, the most common peri-implant defects were type 1c (39.2%), followed by type 1d (29.4%), type 1e (27.5%), and type

1b (3.9%). The highest agreement between PA radiographs and intraoperative assessments was observed for type 1c (25.4%) and type 1d (23.5%) defects, while the lowest agreement was found for type 1b. The Kappa coefficient for the compatibility between PA radiographs and intraoperative assessments was calculated as 0.47, indicating moderate agreement.[29]

Table 1: The frequency of peri-implant defect types as determined on PA radiographs and intraoperatively.

Defect type	PA radiographs n (%)	Intraoperative n (%)	Agreement between PAs and intraoperational assessments n (%)	Kappa coefficient	SD	%95 CI
1b	0 (0)	2 (3.9)	0 (0)	0.47	0.1	0.28-0.66
1c	21 (41.2)	20 (39.2)	13 (25.4)			
1d	14 (27.5)	15 (29.4)	12 (23.5)			
1e	16 (31.4)	14 (27.5)	8 (15.7)			

Defect depth and defect width

Table 2 presents the mean intraoperative and radiographic measurements of defect depth and width for both mesial and distal peri-implant defects. The repeatability of the measurements on PA radiographs was determined to be excellent, with a high reliability demonstrated by an ICC of 0.997.[31] The intraoperative measurements of defect depths, while comparable, were statistically higher than those obtained from periapical radiographs for both mesial and distal peri-implant defects ($p<0.001$). The average difference between defect depth measurements (both mesial and distal) was calculated as 0.34 ± 0.37 mm, with a 95% CI of [0.74, 1.00] ($p < 0.001$). In none of the cases did PA radiographs overestimated the defect depths compared to measurements during surgery. Figure 5a illustrates the scatter plot comparing mean intraoperative and radiographic defect depth measurements, with the line y=x indicating where the measurements are equal. A greater proportion of data points fall below the y=x line, indicating that radiographic measurements tend to underestimate defect depth compared to intraoperative measurements ($p<0.001$). Additionally, Figure 5b presents a Bland-Altman plot, where the x-axis represents the mean intraoperative and radiographic measurements, while the y-axis displays the difference between these measurements.

Table 2: The mean and SD of intraoperative and radiographic measurements for peri-implant defects (mm).

	Intraoperative defect depth	Radiographic defect depth	Defect depth difference	Intraoperative defect width	Radiographic defect width	Defect width difference
Mesial peri-implant defects	4.27 ± 0.69	3.93 ± 1.05	0.34 ± 0.36 (p<0.001) 95 % CI [0.96, 1.38]	2.57 ± 0.42	2.03 ± 0.19	0.54 ± 0.23 (p<0.001) 95 % CI [0.75, 1.07]
Distal peri-implant defects	4.43 ± 0.72	4.11 ± 1.13	0.32 ± 0.41 (p<0.001) 95 % CI [0.66, 0.97]	2.45 ± 0.65	2.28 ± 0.81	0.17 ± 0.15 (p<0.001) 95 % CI [0.63, 0.92]
Mean	4.34 ± 0.59	3.99 ± 0.96	0.34 ± 0.37 95 % CI [0.74, 1.00]	2.13 ± 0.19	1.80 ± 0.13	0.32 ± 0.06 95 % CI [0.74, 0.95]

Similarly, intraoperative defect width measurements were statistically greater than those obtained from PA radiographs, with a mean difference of 0.32 ± 0.06 for both mesial and distal defects and a 95% confidence interval [0.74, 0.95] ($p<0.001$). The measurements from PA radiographs were lower than those obtained during surgery for all cases. The comparison between mean intraoperative and radiographic defect width measurements is presented in Figure 5c, where the y=x line represents equal measurements. Data points below this line indicate that radiographic measurements tend to underestimate defect width compared to intraoperative measurements ($p<0.001$). Figure 5d shows a Bland-Altman plot, with the x-axis representing the mean of intraoperative and radiographic measurements, and the y-axis showing the difference between these values.

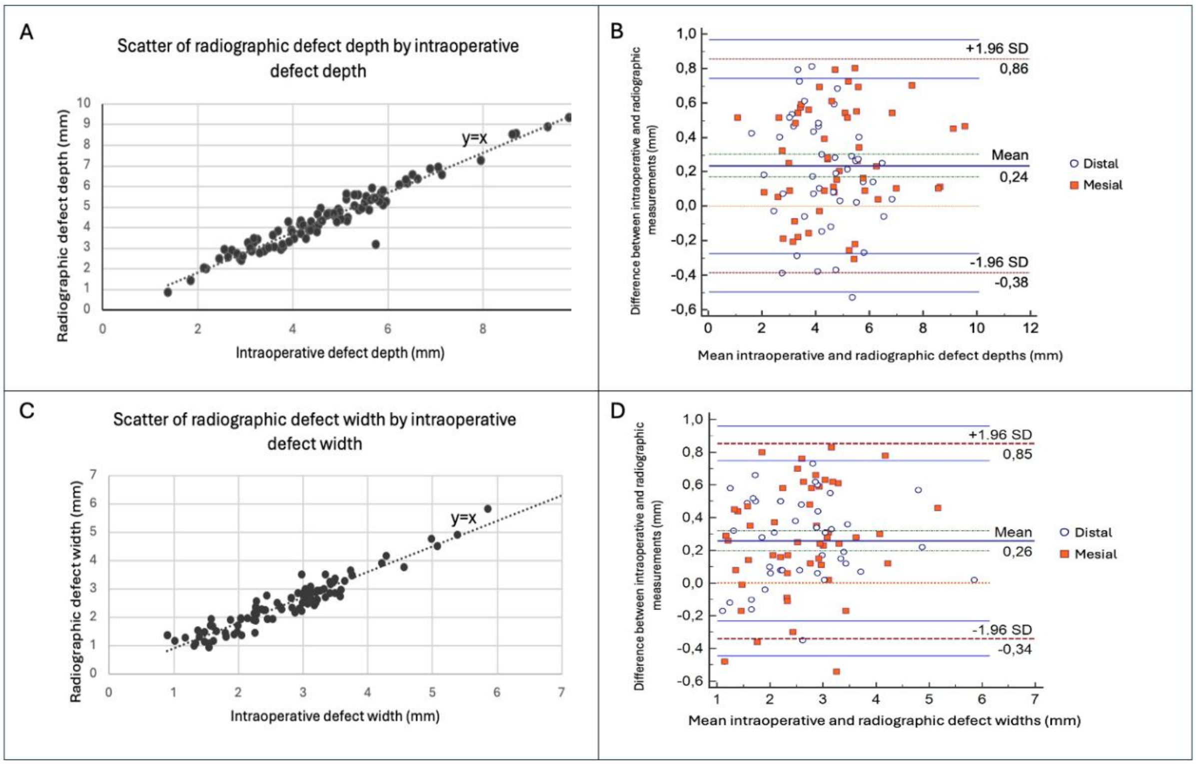

Figure 5: *A*) Scatter plot displaying the defect depth measurements obtained from PA radiographs and during surgery. *B*) Bland-Altman plot-The mean intraoperative and radiographic defect depth measurements, and the difference between these measurements (mm). *C*) Scatter plot displaying the defect width measurements obtained from PA radiographs and during surgery. *D*) Bland-Altman plot-The mean intraoperative and radiographic defect width measurements, and the difference between these measurements (mm).

DISCUSSION

Detection of peri-implant bone loss requires radiographic and clinical assessment with longitudinal monitoring. Accurate detection is essential to prevent complications, preserve implant stability, and ensure favorable outcomes.[1,32] Current evidence supports PA radiography as the first-choice imaging method when peri-implant disease is suspected,[20,32] owing to its accessibility, low cost, patient comfort, and high spatial resolution. Nevertheless, only a few studies[7-9] have directly compared PA findings with intraoperative measurements of vertical bone defects. Serino et al.[7] assessed 46 implants and found PA radiographs underestimated bone loss by 0.6–0.7 mm, with only 21% of radiographic assessments matching intraoperative findings. García-García et al.[8] also reported significant underestimation (0.8 mm mesial, 1.5 mm distal) and poor concordance in defect morphology, with type 1e defects frequently classified as 1d. Christiaens et al.[9] examined 50 implants and noted even greater discrepancies, with PAs underestimating bone levels by an average of 2.3 mm.

Our findings are consistent with these reports,[7-9] confirming the tendency of PA radiographs to underestimate defect size. However, the degree of underestimation in our study (0.34 mm depth, 0.32 mm width) was smaller. This improved accuracy may be attributed to the use of film holders, the paralleling technique, and calibration with vertical and horizontal reference markers, which minimized distortion and improved scaling across planes. Unlike García-García et al.,[8] who reported poor agreement, we observed moderate concordance between PA and surgical classifications. Agreement was highest for types 1c and 1d, the most common defects in our sample. These morphologies, characterized by dehiscence combined with intrabony components, may be easier to recognize radiographically. In contrast, type 1b defects were rare (3.9%), reflecting their lower clinical prevalence and the difficulty of detecting buccal-only defects radiographically. The findings of the present study align with those of the prior reports,[7-9] indicating that PA radiographs tend to underestimate defect dimensions when compared to intraoperative measurements. However, although statistically lower than surgical measurements, the defect measurements on PA radiographs in the present study were less underestimated than previously reported, with a mean difference of 0.34 mm for defect depth and 0.32 mm for defect width. The accuracy and reliability of intraoral radiographs for assessing peri-implant diseases depend heavily on the standardization of technical factors and X-ray geometry, particularly the spatial alignment between the image receptor plane, the teeth, and the central X-ray beam.[32] Optimal imaging results occur when the X-ray beam is positioned perpendicular to both the long axis of the teeth and the plane of the image receptor, minimizing distortion of the teeth and surrounding periodontal structures. In addition to the use of film holders and the paralleling technique in the present study, the minimized discrepancies between PA radiographs and intraoperative measurements may be attributed to the incorporation of two distinct reference materials-one positioned vertically and the other horizontally-to improve calibration accuracy across multiple planes. This dual-reference approach likely minimized dimensional distortions by providing more precise scaling for measurements, resulting in a closer approximation to intraoperative dimensions. Additionally, unlike the findings of García-García et al.,[8] who reported poor agreement, our results showed a moderate level of agreement between surgical assessments and PA radiographs in determining defect type. The highest agreement between PA radiographs and intraoperative assessments occurred with type 1c and type 1d defects, which were also the most commonly identified defect types during surgery. Type 1c defects, characterized by buccal bone dehiscence in combination with a circumferential defect, and type 1d defects, defined by buccal and oral bone dehiscences along with mesial and distal intrabony defects, may present specific features that enhance their detectability on PA radiographs.[2] The higher prevalence of these defect types in our study population could also enhance radiographic familiarity, potentially increasing diagnostic accuracy for these configurations. By contrast, the frequency of type 1b defects was very low in our sample (3.9%). This may reflect the relative rarity of this defect configuration in clinical settings, as well as the inherent difficulty of detecting buccal-only defects radiographically compared to circumferential or combined morphologies.

Accurate detection of bone defects is influenced by their size, regardless of the imaging modality used, since radiographic evidence becomes visible only after 30-50% of bone has resorbed.[32] PA radiographs may underestimate the extent of bone loss in less extensive defects, particularly in the early stages of periodontal disease,[33] especially when the paralleling technique with film holders is not used during image capture.[34] Furthermore, the two-dimensional nature of PA radiographs limits their assessment in providing a comprehensive view of the bucco-lingual aspects of the interproximal bone.[34] CBCT imaging is the method of choice for early detection of peri-implant bone loss and assessment of defect morphology in these cases. In previous studies, the diagnostic accuracy of CBCT for peri-implant bone loss varied based on study design and defect morphology.[35,36] In cadaver models, CBCT generally showed good sensitivity and specificity for circumferential and infrabony defects but lower accuracy for dehiscences.[37-39] In animal studies, it either overestimated or underestimated defect size, depending on factors such as defect configuration, location, and the presence of imaging artifacts like scattering and beam hardening.[37-39] A recent integrated review[25] on the use of CBCT for detecting peri-implant bone defects noted that CBCT could overestimate or underestimate the severity of bone loss, generally with an error margin within 1 mm. Its accuracy decreased for defects smaller than 3 mm, limiting its sensitivity for detecting early peri-implant bone loss.[40] While CBCT was more effective than PA radiography for identifying dehiscence and fenestration defects, PA radiographs were more precise in assessing interproximal defects, underscoring their importance in the initial evaluation of peri-implant inflammation. Additionally, studies have shown that PA radiographs demonstrate higher inter-observer consistency compared to CBCT in detecting peri-implant bone defects,[41] while both imaging options exhibit clinically acceptable performance for assessing these defects. The primary concern with CBCT examinations lies in the limited evidence supporting its use for diagnosing intrabony and furcation defects,[32,42,43] and its application may not significantly influence treatment decisions to warrant the associated high radiation dose. Therefore, it may be suggested that the use of film holders, the paralleling technique, and reference materials of known length positioned both vertically and horizontally can improve alignment between PA radiographic and surgical measurements, highlighting the continuing potential of calibrated PA radiographs as a reliable and minimally invasive tool for assessing defect depth and type.[32,42,43]

The secondary aim of this study was to evaluate the consistency between probing depth measurements obtained with plastic and metal probes in peri-implantitis-affected areas. While the Williams probe recorded a slightly higher mean probing depth compared to the UNC-12 probe, the results showed substantial agreement between the two, as indicated by a κw value of 0.71. This highlights the reliability and suitability of both probes for assessing peri-implant probing depths and conducting consistent, accurate clinical evaluations of peri-implantitis.

Several limitations should also be considered when interpreting these results. The relatively small sample size may restrict the generalizability of the findings, although this reflects the realities of clinical practice where patients may miss appointments, change treatment preferences, or be unable to complete follow-up. In addition, only Class 1 defects (types 1b–1e) were included, meaning the results cannot be directly extrapolated to other defect morphologies. Another limitation is the absence of CBCT as a complementary reference standard; although intraoperative findings were used as the gold standard, future investigations incorporating CBCT could provide a more comprehensive three-dimensional assessment of peri-implant bone defects. Finally, the two-dimensional nature of PA radiographs restricts the evaluation of buccal and lingual bone plates, which may lead to underestimation of defect dimensions compared with intraoperative measurements.

CONCLUSION

The PA radiographs, when standardized with film holders, the paralleling technique, and calibrated reference materials, demonstrate reliable accuracy in assessing peri-implant bone defects. Despite a tendency to slightly underestimate defect dimensions compared to intraoperative measurements, the discrepancies were minimal, confirming their clinical applicability. The moderate agreement between radiographic and intraoperative defect classifications, particularly for interproximal defects, further supports the continued use of PA radiographs in initial peri-implant defect evaluations. Additionally, the substantial agreement between probing depth measurements obtained with plastic and metal probes highlights the reliability of both probes for clinical assessment of peri-implantitis.

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