

A Comparative Evaluation of Digital Periapical Radiography and Cone- Beam Computed Tomography for Assessment of Intrabony Periodontal Defects

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Abstract

Background

Assessment of intrabony periodontal defects is at the heart of diagnosis, prognosis and treatment planning. Cone-beam computed tomography (CBCT) allows three-dimensional visualization; however, digital intraoral periapical radiography (IOPA) is still the most common modality used in clinical practice because it is generally more accessible, less expensive and associated with lower radiation. While CBCT provides a better three-dimensional characterization, previous papers have reported a similar linear measurement accuracy for these imaging modalities.

Objectives

To compare the accuracy and agreement of digital intraoral periapical radiography (IOPAR) with cone-beam computed tomography (CBCT) in the linear and angular measurement of intrabony periodontal defects.

Methods

This is a comparative cross-sectional study that was performed on 36 patients with intrabony periodontal defects. Standardised digital IOPA and CBCT images for defect height, depth, width and angle measurements were taken. Agreement between modalities was assessed using paired t-tests, intraclass correlation coefficients (ICC), and Bland–Altman analysis.

Results

No statistically significant differences existed between IOPA and CBCT for any parameter ($p > 0.05$). There were no clinically meaningful mean differences for height (-0.10 mm), depth (-0.18 mm), width (0.02 mm) and angle (-0.50°). The ICC values were good to excellent, ranging from 0.87 to 0.93. Bland–Altman analysis indicated acceptable levels of bias (most observations within the 95% limits of agreement).

Conclusions

The linear and angular measurements of intrabony periodontal defects obtained using digital intraoral periapical radiography were comparable to those obtained using CBCT. CBCT remains superior for three-dimensional assessment of complex defect morphology and should be used selectively when additional anatomical information is likely to influence treatment planning. These findings support digital intraoral

periapical radiography as an accessible, cost-effective, and lower-radiation modality for routine periodontal assessment.

Introduction

Periodontal disease is one of the most common chronic inflammatory diseases worldwide with more than a billion affected individuals and is considered one of the leading causes for tooth loss in adults [1, 2]. Progressive destruction of the supporting periodontal tissues referred to as periodontitis, has multiple forms and at advanced stages results in intrabony defects (vertical bone resorptive lesions within the alveolar bone) [3]. Clinically relevant, these defects are determinant of disease severity, prognosis and choice of the treatment measures performed (especially regenerative and surgical procedures) [4]. Intraosseous defect morphology and characteristics must be accurately estimated for proper diagnosis and treatment planning [5].

The radiographic evaluation is important as an adjunct to clinical examination for the assessment of periodontal bone loss [6, 7]. Of these imaging modalities, digital intraoral periapical radiography (IOPA) and cone-beam computed tomography (CBCT) are most frequently used in clinical and research settings [8]. Digital periapical radiographs play an important role in the diagnosis of periodontal disease because of their easy access, cost-effectiveness and lower radiation exposure making it the basic imaging modality for routine periodontal evaluation [7]. Its two-dimensional nature leads to unavoidable artifacts like distortion, magnification, or superimposition of the anatomical structures; this causes an underestimation of bone loss mainly on buccal and lingual aspects [5, 9].

Compared to that, a cone-beam computed tomography (CBCT) is an imaging modality with three-dimensional visualization of maxillofacial structures at several micrometers into the intraoral cavity having useful spatial resolution, yielding thorough assessment defect morphology as well as buccolingual dimensions and insufficient number of defect walls, combined with complex anatomical configurations [8, 10]. Reviews of data have shown that the use of conebeam computed tomographic (CBCT) imaging can be superior when compared with conventional intraoral radiographs for detecting periodontal defects, such as dehiscences, fenestrations and crater-like lesions and this is mostly directed to projection errors/superimposition present in 2D [9, 11–13]. Also, CBCT demonstrated higher reliability compared to surgical and probing measurements; especially for three-dimensional defect parameters [14–17].

Even though there might be advantages, the routine use of CBCT in periodontology is still debated. Radiation dose, cost and availability of CBCT are higher than digital periapical radiography. Thus, based on the present evidence, it appears that CBCT should be used sparingly, especially when conventional clinical and radiographic findings are inconclusive or when fine three-dimensional information is anticipated to have an impact on treatment decisions [12, 13, 18]. Interestingly, many clinical and experimental studies have found that the reported accuracy of linear measurements (defect height, depth and mesiodistal width) using digital periapical radiography was similar to those obtained with

CBCT. IOPA and CBCT seem not to differ significantly in measuring the same intrabony defect dimensions in a clinical study, indicating a possible role for digital radiography as an accurate alternative for this morphometric evaluation [19]. Likewise, other research published has shown comparable precision in their vertical evaluation when comparing the two modalities with surgical or gold-standard measurement [10, 12, 16, 20]. These researches point to a clinical dilemma - although CBCT does sound more diagnostic, the incremental benefits may not be sufficient for its routine application, especially since the periodontal findings are predominantly linear measurements.

However, the literature is inconsistent, with differences in study design, imaging protocol, sample specifics and measurement techniques. In addition, standardized comparative studies of both modalities under controlled conditions are warranted along with rigorous statistical methods to evaluate agreement and reliability [5, 14].

Thus, the objective of this study was to assess and compare the reproducibility of digital intraoral periapical radiography and cone-beam computed tomography against gold standard measurements of intrabony periodontal defect height, depth, width and angle. This study aims to assess the general level of agreement between these modalities to answer whether Digital intraoral periapical radiography can be a reliable, cheaper and lower-radiation replacement for conventional routine periodontal assessment in contrast with CBCT and determine clinical contexts wherein supplementary diagnostic information is gained from CBCT.

Methods

Study Design and Registration

This study was conducted as an observational, analytical, cross-sectional comparative study using a non-probability consecutive sampling approach from December 2025-June 2026.

The aim of the study was to assess and compare two imaging modalities for periodontal intrabony defect assessment. The study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. Conclusion: The main purpose was to compare linear (measured distances) and angular measurements between digital IOPA and CBCT-derived equivalents, and preferably to assess the agreement level of these methods using suitable statistics.

Ethical Considerations

The study was conducted after ethical approval from the Institution Review Committee with an IRC Ref no (CMC-IRC/082-083-062). All participants provided written informed consent to participate in the study. Radiographic imaging procedures were done following the As Low As Reasonably Achievable principle (ALARA) to minimize radiation exposure.

Sample Size Determination

A power analysis was subsequently performed using GPower software (version 3.1), which is widely recommended for biomedical research, to further validate the adequacy of the calculated sample size. Following an analysis based on a paired t-test (two-tailed), an effect size estimated from the assumed mean difference and pooled standard deviation, $\alpha = 0.05$, power = 0.8, we found that at least 36 paired observations would be required to detect a significant difference of this magnitude with sufficient statistical power.

Therefore, 36 participants were recruited, with each participant contributing a single eligible intrabony defect (one paired IOPA and CBCT measurement). If there were more than one eligible defects, within a single participant only one defect was selected using pre-defined criterion to fit the independence assumption of observations.

Eligibility Criteria

Eligibility criteria were predefined, and participants were recruited accordingly. Study participants were adults aged 20–60 years who had been diagnosed with chronic or aggressive periodontitis, either localized or generalized, and had at least one intrabony periodontal defect identified clinically by periodontal probing and confirmed radiographically. All included sites had a probing depth (PD) of ≥ 6 mm and clinical attachment loss (CAL) of ≥ 7 mm. Teeth selected for examination had intact proximal contacts and a clearly identifiable cementoenamel junction to facilitate accurate radiographic measurements.

Participants provided written informed consent and completed all study procedures, including digital intraoral periapical radiography and CBCT imaging. Each participant contributed only one intrabony defect, which was used as the unit of analysis to maximize the independence of observations.

Participants were excluded if they were pregnant or lactating, if radiation exposure considerations precluded CBCT imaging, or if they had undergone periodontal surgical therapy within the preceding 6 months. Cases were also excluded when poor-quality, distorted, or incomplete intraoral periapical radiographs or CBCT images prevented accurate measurement of the defect parameters.

Study Variables

Main outcome variables were quantitative measurements of intrabony periodontal defects (defect height [mm], defect depth [mm], defect width [mm] and defect angle [°]). Demographic and clinical characteristics of each patient were considered as secondary variables, including age, gender, tooth region and the type of defect (one-wall, two-wall or three-wall defects or a combination of them). The imaging modality is the independent variable with two categories: digital intraoral periapical radiography (IOPA) and cone-beam computed tomography (CBCT).

Operational Definitions

Defect height was measured as the distance between the alveolar crest and base of the intrabony defect. Defect depth was measured vertically from the cemento-enamel junction (CEJ) to the deepest point of a defect. The maximum lateral size of the defect was defined as defect width, and the angle at base of the defect between walls marking out those defects was denoted as defect angle. Using calibrated digital imaging software, all measurements were performed in mm or °.

Image Acquisition Protocol

Digital Intraoral Periapical Radiography (IOPA)

Fundamentally, Digital intraoral periapical radiographs were taken using paralleling technique with implementing a digital sensor system (CMOS). Same exposure parameters (approximately 65–70 kVp, 7 mA, and 0.32 seconds) were used across machines. A beam alignment device (XCP system) was employed for better reproduction and geometric distortion prevention, with our own stent to maintain the angulation to work together. Through all exposures, the geometry was fixed.

Cone-Beam Computed Tomography (CBCT)

CBCT was performed with a small field of view (FOV) of 5×5 cm to 8×8 cm, and voxel sizes between 0.18 mm and 0.40 mm respectively that allow reasonable spatial resolution. In a study, a site-specific imaging mode was selected and patient positioning was standardized with the Frankfort horizontal plane parallel to the floor. Reconstruction of images in multiplanar reconstruction (MPR) and oriented in the long axis of the tooth measurement.

Measurement Protocol

All measurements were performed using calibrated digital image analysis software at a 1:1 magnification according to a predefined standard operating protocol. To ensure comparability between digital intraoral periapical radiography (IOPA) and CBCT, identical anatomical landmarks and measurement axes were used for both imaging modalities. Before each measurement session, the software measurement scale was calibrated according to the manufacturer's recommendations.

The cementoenamel junction (CEJ), alveolar crest (AC), and base of the intrabony defect served as fixed anatomical reference points. Measurements were obtained as follows:

- **Defect height** was measured as the vertical distance from the **alveolar crest (AC) to the base of the intrabony defect**, parallel to the long axis of the tooth.
- **Defect depth** was measured as the vertical distance from the **cementoenamel junction (CEJ) to the deepest point of the intrabony defect** along the long axis of the tooth.

- **Defect width** was measured as the **maximum horizontal distance** across the defect, extending from the root surface to the outer bony wall at the widest level of the defect and perpendicular to the long axis of the tooth.
- **Defect angle** was defined as the **internal angle formed between the root surface and the adjacent osseous defect wall**, with the vertex located at the base of the intrabony defect. The angle was measured using the digital angle measurement tool incorporated within the imaging software.

For CBCT images, measurements were performed on standardized multiplanar reconstruction (MPR) sections oriented parallel to the long axis of the study tooth to avoid measurement errors caused by image angulation. For digital IOPA radiographs, all measurements were obtained from standardized images acquired using the paralleling technique with an XCP positioning device to minimize geometric distortion. Each participant contributed only one eligible intrabony defect, and identical anatomical landmarks were used for measurements on both imaging modalities.

Examiner Calibration and Reliability

Prior to the start of the study, all examiners underwent calibration in order to maintain consistent measurements. For intra-examiner reliability, measurements were repeated on a subset of images where applicable. This approach allowed repeatability and reduced measurement variability.

Data Collection Procedure

Participants were subjected to a thorough examination for possible detection of intrabony defects. After this, digital IOPA images were recorded and measurements taken. The same defect sites were scanned using CBCT scans and measurements were obtained accordingly. All data were systematically documented in an electronic data abstraction tool.

Data Management

Data were first entered into Microsoft Excel and then exported to the Statistical Package for Social Sciences (SPSS) software for analysis. Data cleaning protocols included validation of completeness, missing values analysis, and outlier identification prior to statistical assessment.

Statistical Analysis

Statistical analysis was conducted using Statistical Package for the Social Sciences (SPSS; IBM SPSS Statistics, Version 26. Continuous variables were expressed as mean $\pm$ standard deviation, and categorical variables were presented as frequency with percentage.

The paired t-test was used to perform a comparative analysis between digital intraoral periapical radiography (IOPA) and cone-beam computed tomography (CBCT) measurements. This test was used to compare differences in height, depth, width and angle of the defect between two imaging modalities.

There was an ICC (two-way random-effects model) with absolute agreement (ICC) between IOPA and based on CBCT measurements. This model was chosen as both imaging modalities were regarded as random measurement methods and the aim was to assess absolute agreement.

A Bland–Altman analysis was performed on the two modalities to assess further agreement. It also calculated the mean difference (bias) between measurements, and includes 95% limits of agreement defined as mean difference $\pm$ 1.96 standard deviations. Results were deemed statistically significant when $p < 0.05$.

Bias Control and Standardization

In order to reduce possible bias sources and standardize reliability, standardized imaging protocols were used for IOPA and CBCT acquisitions. Measurements were made with fixed anatomical landmarks, including the cementoenamel junction (CEJ), alveolar crest and base of the defect. Inter-observer variability was reduced by having a single trained examiner conduct all measurements. Also, the same intrabony defect was assessed using both imaging modalities, allowing for a direct comparison of measurements.

Results

A total of 36 participants with intrabony periodontal defects were included in the study. The study population comprised 19 males (52.8%) and 17 females (47.2%), with a mean age of 39.4 ± 7.6 years (range, 25–53 years). Each participant contributed one intrabony periodontal defect, resulting in 36 paired radiographic measurements for comparative analysis using digital intraoral periapical radiography (IOPAR) and cone-beam computed tomography (CBCT).

Regarding defect morphology, two-wall defects were the most frequently observed, accounting for 17 cases (47.2%), followed by one-wall defects in 8 cases (22.2%), combined defects in 6 cases (16.7%), and three-wall defects in 5 cases (13.9%). Thus, nearly half of the evaluated defects were two-wall defects.

Subsequent analyses compared the linear (height, depth, and width) and angular measurements of intrabony periodontal defects obtained using IOPAR and CBCT to determine the level of agreement between the two imaging modalities.

Distribution of Intrabony Defect Types

A total of 36 intrabony periodontal defects were included in the study. Two-wall defects were the most frequently observed, comprising 11 cases (30.6%), followed by three-wall defects in 10 cases (27.8%) and one-wall defects in 9 cases (25.0%). Combined defects were the least frequent, accounting for 6 cases (16.6%). Overall, two-wall and three-wall defects together represented 21 of the 36 defects (58.4%).

Comparison of IOPA and CBCT Measurements

Table 1 showed defect measurements with IOPA and CBCT, comparison. Measurement of mean size of defects (height, depth, width and angle) were similar between imaging modalities. A difference of the mean values of – 0.10 mm in height, – 0.18 mm in depth, 0.02 mm in width and – 0.50° in angle for all parameters was noted.

Statistical analysis with paired t-test showed that all parameters between IOPA and CBCT measurements did not differ significant from each other ($p > 0.05$).

Table 1
Comparison of IOPA and CBCT Measurements (n = 36)

Parameter	IOPA (Mean ± SD)	CBCT (Mean ± SD)	Mean Difference (IOPA–CBCT)	95% CI of Difference	p- value*
Defect Height (mm)	3.85 ± 1.18	3.95 ± 1.20	–0.10	–0.32 to 0.12	0.37
Defect Depth (mm)	7.72 ± 2.32	7.90 ± 2.41	–0.18	–0.58 to 0.22	0.38
Defect Width (mm)	3.22 ± 1.09	3.20 ± 1.15	0.02	–0.21 to 0.25	0.84
Defect Angle (°)	34.80 ± 8.40	35.30 ± 8.60	–0.50	–1.85 to 0.85	0.46

*p-values derived using paired t-test. Confidence intervals represent the 95% CI of the mean difference between IOPA and CBCT measurements.

Agreement Analysis Using Intraclass Correlation Coefficient (ICC)

Intraclass correlation coefficients (ICC[2, 1]) were used to further assess the agreement between IOPA and CBCT measurements (see Table 2). The findings showed good to excellent concordance for all parameters.

Defect width showed the highest level of agreement (ICC = 0.93, 95%CI: 0.82–0.96), followed closely by defect depth (ICC: 0.91;95%CI: 0.69–0.97). Defect height (ICC = 0.88) and defect angle (ICC = 0.87) also demonstrated good agreement. All ICC values were significant ($p < 0.001$); thus, they show a high level of reliability in the two imaging techniques.

Table 2
Intraclass Correlation Coefficient (ICC[2, 1]) for Agreement Between IOPA and CBCT Measurements
(n = 36)

Parameter	ICC (2,1)	95% Confidence Interval	p-value†	Interpretation‡
Defect Height (mm)	0.88	0.78–0.94	< 0.001	Good agreement
Defect Depth (mm)	0.91	0.84–0.96	< 0.001	Excellent agreement
Defect Width (mm)	0.93	0.87–0.97	< 0.001	Excellent agreement
Defect Angle (°)	0.87	0.76–0.93	< 0.001	Good agreement

† p-values correspond to the test of the null hypothesis that ICC = 0.

‡ Interpretation based on commonly accepted thresholds:

< 0.50 = poor, 0.50–0.75 = moderate, 0.75–0.90 = good, > 0.90 = excellent agreement.

This pattern of agreement is visually summarized in Fig. 3, which illustrates ICC values across all measured parameters.

Bland–Altman Analysis of Agreement

All parameters were subjected to Bland–Altman analysis in order to assess agreement and identify any systematic bias. The results are presented in Table 3.

Mean differences (bias) between IOPA and CBCT measurements were small for all variables. Limits of agreement were within clinically acceptable limits, showing that both measurements obtained using the two modalities were comparable.

Table 3
Bland–Altman agreement analysis between IOPA and CBCT measures (n = 36)

Parameter	Mean Difference (Bias)	Lower Limit of Agreement (– 1.96 SD)	Upper Limit of Agreement (+ 1.96 SD)
Defect Height (mm)	–0.10	–2.10	1.90
Defect Depth (mm)	–0.18	–2.90	2.54
Defect Width (mm)	0.02	–1.80	1.84
Defect Angle (°)	–0.50	–7.80	6.80

Values represent the mean difference (IOPA – CBCT) and the 95% limits of agreement (LoA) calculated as mean difference ± 1.96 standard deviations.

The Bland–Altman plots for each parameter are presented in Figs. 4–7.

Figure 4 shows the agreement for defect height measurements, with most observations lying within the 95% limits of agreement and minimal bias observed.

Similarly, Fig. 5 demonstrates acceptable agreement for defect depth, with a narrow distribution of differences.

Figure 6 shows strong agreement for defect width, with minimal variability and tight clustering around the mean difference.

Figure 7 illustrates agreement for defect angle measurements. Although a slightly wider spread is observed compared to linear measurements, the majority of observations remain within the limits of agreement, indicating acceptable agreement.

Discussion

The present study aimed to compare digital intraoral periapical radiography (IOPA) and cone-beam computed tomography (CBCT) in the assessment of intrabony periodontal defect measurements. The findings demonstrated that there were no statistically significant differences between the two imaging modalities for defect height, depth, width, and angle. Agreement analysis further revealed good to excellent intraclass correlation coefficients (ICC), indicating strong reliability between measurements obtained using IOPA and CBCT. In addition, Bland–Altman analysis showed minimal bias, with most observations falling within the limits of agreement. Collectively, these results indicate that digital intraoral periapical radiography provides measurements that are comparable to CBCT for linear assessment of intrabony periodontal defects.

The absence of statistically significant differences between IOPA and CBCT for defect measurements suggests that both modalities provide comparable diagnostic outputs for linear morphometric assessment, as reflected by the similarity in mean values and the inclusion of zero within the confidence intervals. These findings are consistent with multiple studies reporting minimal differences between the two modalities for linear parameters [10, 12, 19]. Clinical studies have exhibited that, it gives a similarly acceptable measurements in terms of defect height, depth and angle compared to CBCT thus endorsing the reliability of digital periapical radiography as diagnostic tool in everyday periodontal practice [16, 19, 20]. In addition, studies related of radiographic findings correlated to surgical or probing standards have shown that although CBCT may have slightly better accuracy, the variation between linear measurements is often subtle and not clinically meaningful [12, 16, 20].

The ICC in the present study of IOPA show good to excellent agreement with CBCT as indicated by previous meta-analyses which attribute their agreement as between 0.76 and 0.83 values. Such high agreement reinforces their reliability and reproducibility with proper standardization of each imaging modality. CBCT also demonstrated better reliability (intraclass correlation coefficient [ICC] based on

method comparison for linearity of agreement was better than intraoral radiography, with good results for all complex defects) and previous literature shows the same conclusions comparing gold standard measurement [11, 14, 15].

However, despite CBCT's higher correlation with reference standards, the agreement between IOPA and CBCT observed in the present study suggests that digital periapical radiography can approximate CBCT measurements with a high degree of consistency.

The highest agreement in the present study was observed for defect width and depth, which may be attributed to the use of clearly defined anatomical landmarks such as the cemento-enamel junction and base of the defect. These parameters are less affected by projection errors and geometric distortion, which are inherent limitations of two-dimensional imaging. In contrast, angular measurements may demonstrate greater variability due to dependence on projection geometry and observer interpretation. Similar trends have been reported in previous studies evaluating radiographic accuracy, where variability was greater for angular and complex morphological parameters compared to linear measurements [10, 14].

Bland–Altman analysis further supported these findings by demonstrating minimal mean differences and acceptable limits of agreement between IOPA and CBCT. Most observations were $\leq$ 95% limits of agreement and can be considered as small differences in two modalities, which are clinically acceptable. Until now, available studies have demonstrated that the differences between linear measurements using digital periapical radiography and CBCT are minimal [19] or clinically insignificant [10, 14]. Crucially, we did not find any proportional bias, suggesting that the agreement between modalities was consistent across defect sizes. This supports the inference that IOPA and CBCT can be used interchangeably for linear measurements in selected clinical situations.

However, in assessing three dimensional defect morphology, there is a clear advantage of CBCT over these other imaging modalities. Although thin-contoured buccolingual dimensions, defect wall configuration and furcation involvement can be visualized better with CBCT compared to the two-dimensional radiographs because of its projection and superimposition limitations. CBCT has been shown to detect significantly more and more diverse types of periodontal defects, including dehiscences, fenestrations and furcation involvement than intraoral radiography [10–13, 21]. Furthermore CBCT has been demonstrated to underestimate extent of defect less often and more accurately assess wall and morphology of defects, information that could be pivotal in treatment planning [13, 22].

These observations have significant clinico-pathological implications. Digital intraoral periapical (IOPA) radiography is a low-dose, inexpensive option in terms of cost/exposure and readily available for routine periodontal screening assessment. Conversely cone beam computerized tomography (CBCT) involves a higher radiation dose, is cost-prohibitive and difficult to access at routine locations making it impractical for widespread use [18, 19].

Evidence at these stages indicates that medical imaging should take an indication-based approach, where CBCT is restricted to complex cases (anatomically) requiring three-dimensional data for diagnosis or treatment planning [18, 23]. This is within the ALARA principle, where radiation exposure has always to be minimum while keeping diagnostic accuracy intact.

The findings of this study are comparable with those reported in the literature where CBCT shows better diagnostic ability than two-dimensional digital intraoral periapical radiography for complex and three-dimensional defect assessment, although the low cost and accuracy of digital intraoral periapical radiography has been well established as safe and accurate when conducted using appropriate techniques to assess routine linear measurements. Those studies showing equivalence between modalities are often clinical and relate to interproximal defects, while those favouring CBCT frequently use in vitro designs or highlight evaluation in three dimensions [10, 14]. This distinction emphasizes that the apparent attractiveness of CBCT is primarily context-sensitive and measurement-specific.

Clinical Implications

The results from this study have important clinical implications related to the selection of imaging modalities for periodontal assessment. Digital intraoral periapical radiography is more advantageous by virtue of lower radiation dose, cheaper cost and availability than other imaging modalities and stands as the first choice in any routine clinical practice. On the other hand, digital periapical radiography would be functional in the assessment of intrabony defect height, depth and mesiodistal width for most [14, 19].

On the other hand, CBCT has a higher radiation dose as compared to digital IOPAR and is expensive and less accessible thus rendering it impractical for general use in periodontology. While CBCT offers 3D imaging every time when indicated, its use has to be clinically justified. The evidence to date supports an indications-based approach, where CBCT is limited to cases where conventional clinical and radiographic findings are inconclusive or when additional three-dimensional information is expected to be important in treatment decision-making [10, 18].

In more precise, CBCT should probably be reserved for complex defect morphology, a regenerative surgical planning with furcation involvement or advanced decision making that was dependent on knowing the subtle anatomical detail. This conforms to the ALARA (as low as reasonably achievable) principle where excessive radiation exposure of patients is minimized with maximization of diagnostic utility. The previous studies are also justified to selective use of CBCT, as the routine use of it, is unjustified in absence of any proof for clinical benefits [12, 18].

Therefore, these findings are in line with the proposal of a step diagnostic protocol that digital intraoral periapical radiography should be the primary choice as part of clinical routine, and CBCT scanning adjunctively utilized for complicated cases or when uncertainties arise. This is a simple, but versatile approach to target this challenge of optimizing diagnostic performance against patient safety and resource use.

Strengths of the Study

The value of the present pair design, where each subject provided one intrabony periodontal defect assessed by both digital intraoral periapical radiography and cone-beam computed tomography, was perhaps a major strength of this study. Conversely, this allowed for direct within-site comparison of the two imaging modalities and reduced variability due to patient-to-patient disparities in defect morphology. In addition, it evaluated important clinically relevant parameters such as the height, depth, width and angle of defects in order to provide a more comprehensive morphometric assessment versus previous studies that assessed only one linear feature. All images were based on standardized anatomical landmarks and a defined measurement protocol to improve consistency. Participants had a single defect, with only 1 observation recorded in the analysis so independence of observations was strengthened; data values were repeatably measured by calibrators and examiners. Finally, the investigation was conducted in the context of usual clinical practice may increase the relevance and application of our findings to day-to-day periodontal diagnosis and treatment.

Limitations of the Study

The current study has both some important strengths and limitations that need to be discussed. A limited sample ($n = 36$) may restrict generalizability and lower the power to monitor smaller modality-differences. Second, being a single centre study may have institutional bias and therefore the generalizability of these findings may be limited to other clinical settings.

The other conventional limitation is the absence of surgical or histological gold standard that hinder us from calculating determinants (PPV and NPV), which prevent measurement of true test accuracy by imaging measures. It was less of study but more of an agreement between IOPA and CBCT without reference to true gold standard.

Also, linear measurements of interproximal intrabony defects were mainly investigated in the study; however, information on buccolingual dimensions and complex defect morphology for which CBCT has clear physiopathological advantages over conventional imaging might have revealed additional benefits of using these modalities. The limitations should be borne in mind in interpreting the results and their cause-effect associations with more complicated clinical settings.

Future Directions

At this stage, future research is vital to overcome the constraints of the current investigation and improve the contribution of imaging in periodontal diagnosis. Improved generalizability and increased evidence strength can be achieved through larger, multicenter studies with more diverse patient populations. A gold standard for determining the true accuracy of both IOPA and CBCT would involve surgical validation or intraoperative measures.

With every technological advancement in a field, it is logical to assume that the currently utilized method would benefit from improvements in measurement accuracy and lower inter-observer variability as 2D

and 3D imaging devices improve along with automated image analysis directed by artificial intelligence. In addition, the workflow and optimization of the imaging protocol (field of view & voxel size) could be exploited to compensate for diagnostic performance with radiation dose thereby enhancing clinical practicability. These advances may enhance imaging protocols to enable supportive and more personalized, evidence-based periodontal treatment.

Conclusion

The findings of the present study conclude that for linear measurements of intrabony periodontal defects, digital intraoral periapical radiographs are comparable with those from cone-beam computed tomography. While CBCT offers clear advantages for assessment of three-dimensional defect morphology, the technique cannot show superiority over conventional techniques for standardised linear measurements. In a clinical context, digital intraoral periapical radiography may provide an effective, practical, and less radiation-intensive first-line imaging modality for evaluation of intrabony defects.. CBCT should be used as an adjunctive imaging tool in selected cases where detailed three-dimensional information is required for diagnosis or treatment planning.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the ethics committee of the Chitwan Medical College with ID CMC-IRC/082/083 – 062 and followed the Declaration of Helsinki of 1975. All participants signed a written informed consent form before the clinical examination

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Author Contribution

SK conceived and designed the study. SK and AG developed the methodology. SK performed participant recruitment, data collection, image acquisition, and formal data analysis. SK, AG, and GG contributed to the investigation. SK drafted the original manuscript. AG critically revised the manuscript for important

intellectual content. GG reviewed and edited the manuscript. SK supervised the study. All authors read and approved the final manuscript.

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None

Data availability

The datasets used in the present study are available from the corresponding author upon reasonable request.

Code availability

Not applicable.

Materials availability

Not applicable.

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Figures



Figure 1

Measurement of intrabony periodontal defect dimensions on digital intraoral periapical radiography.

Representative digital intraoral periapical radiographs illustrating: **(A)** defect width, measured as the maximum horizontal dimension of the defect; **(B)** defect height, measured from the alveolar crest to the base of the defect; **(C)** defect depth, measured from the cemento-enamel junction to the deepest point of the defect; and **(D)** defect angle, measured as the internal angle formed between the root surface and the

adjacent bony defect wall. Linear measurements are expressed in millimetres and the angular measurement in degrees.

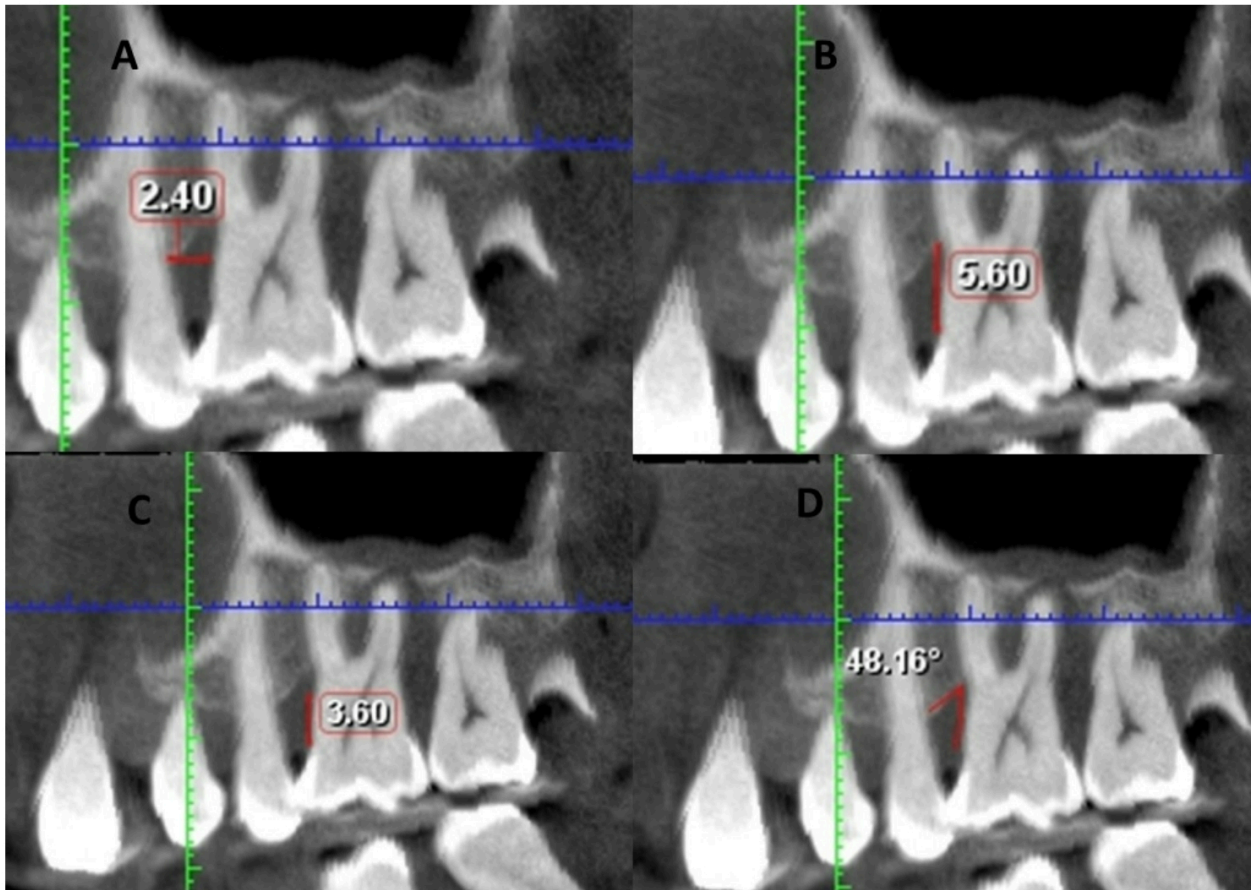


Figure 2

Measurement of intrabony periodontal defect dimensions on cone-beam computed tomography.

Representative multiplanar reconstructed CBCT images illustrating: **(A)** defect width, measured as the maximum horizontal dimension of the defect; **(B)** defect height, measured from the alveolar crest to the base of the defect; **(C)** defect depth, measured from the cemento-enamel junction to the deepest point of the defect; and **(D)** defect angle, measured as the internal angle formed between the root surface and the adjacent bony defect wall. Measurements were performed on the multiplanar reconstructed section demonstrating the maximum extent of the defect. Linear measurements are expressed in millimetres and the angular measurement in degrees.

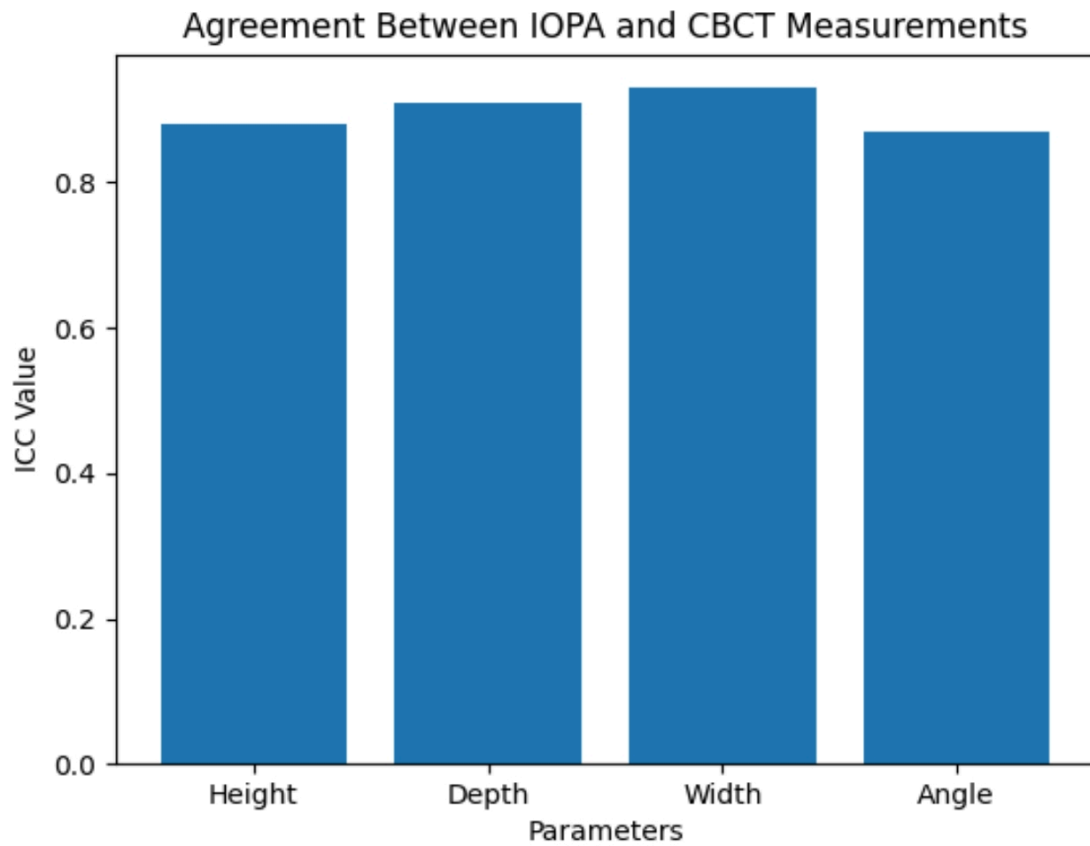


Figure 3

Agreement between IOPA and CBCT measurements based on ICC values

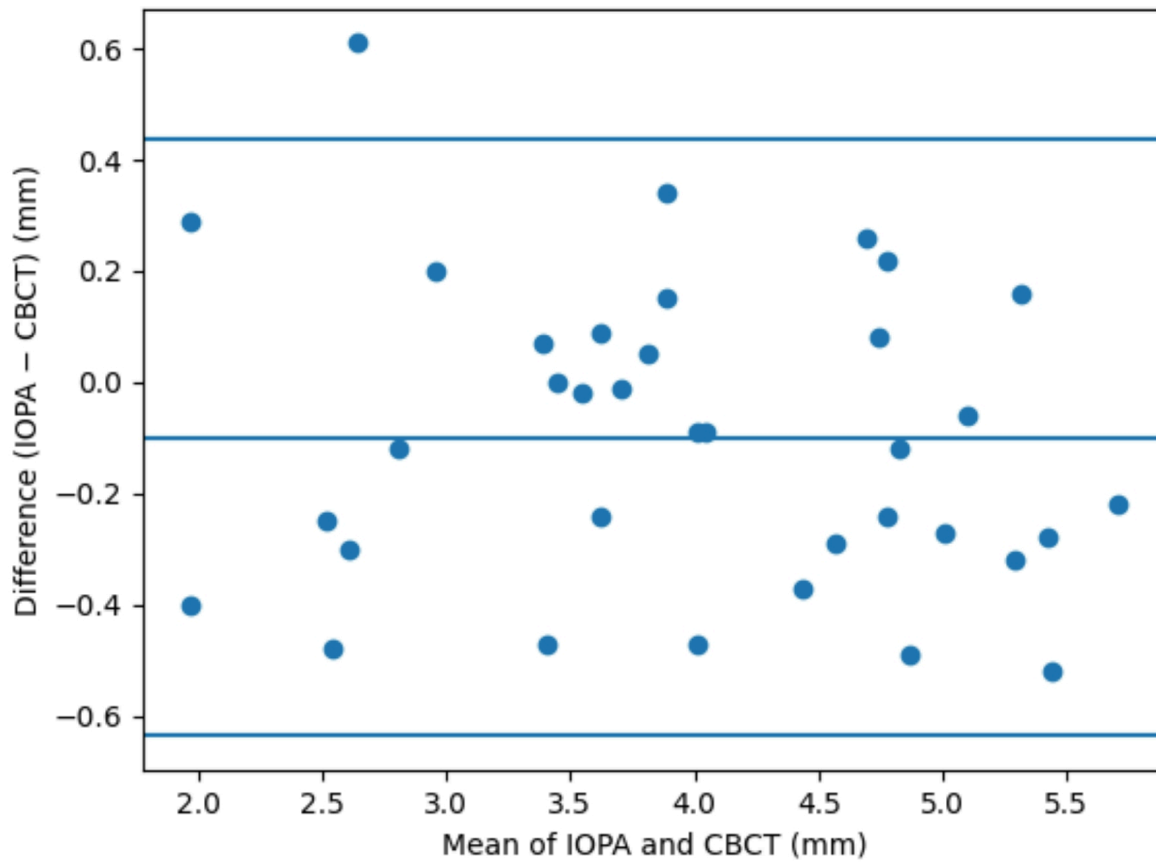


Figure 4

Bland–Altman plot for defect height measurements

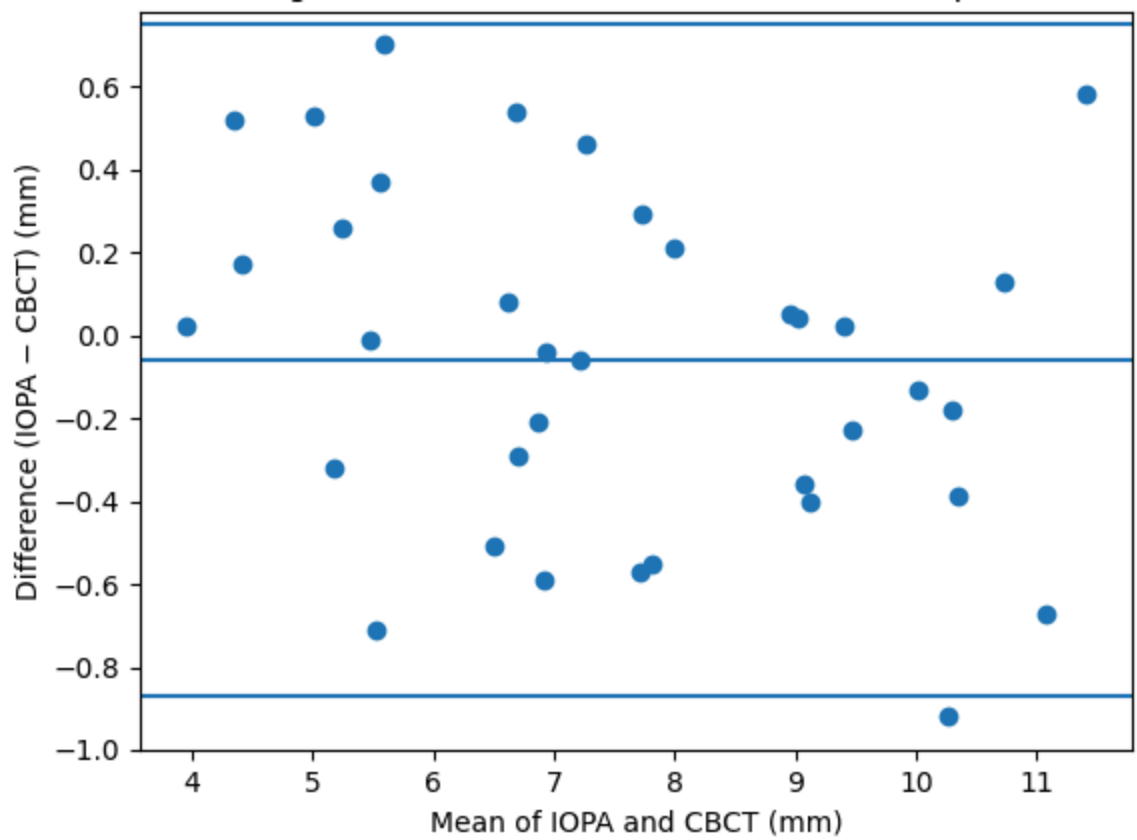


Figure 5

Bland–Altman plot for defect depth measurements

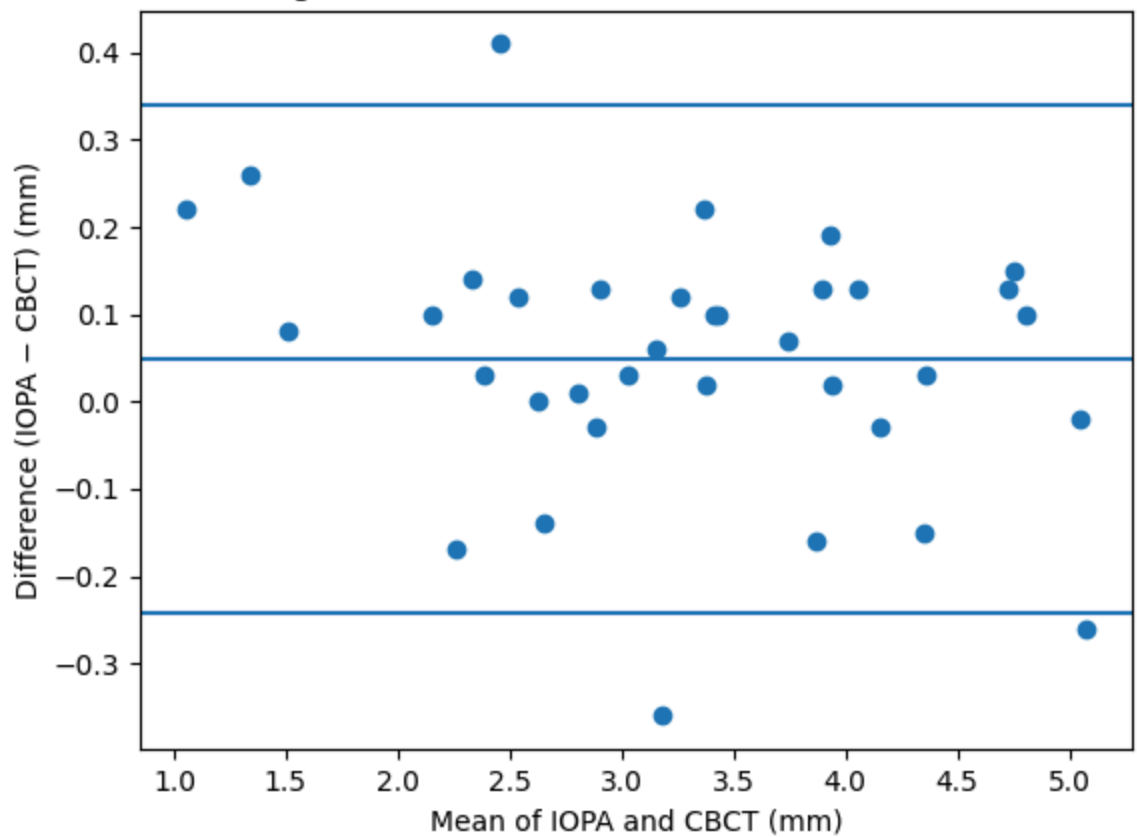


Figure 6

Bland–Altman plot for defect width measurements

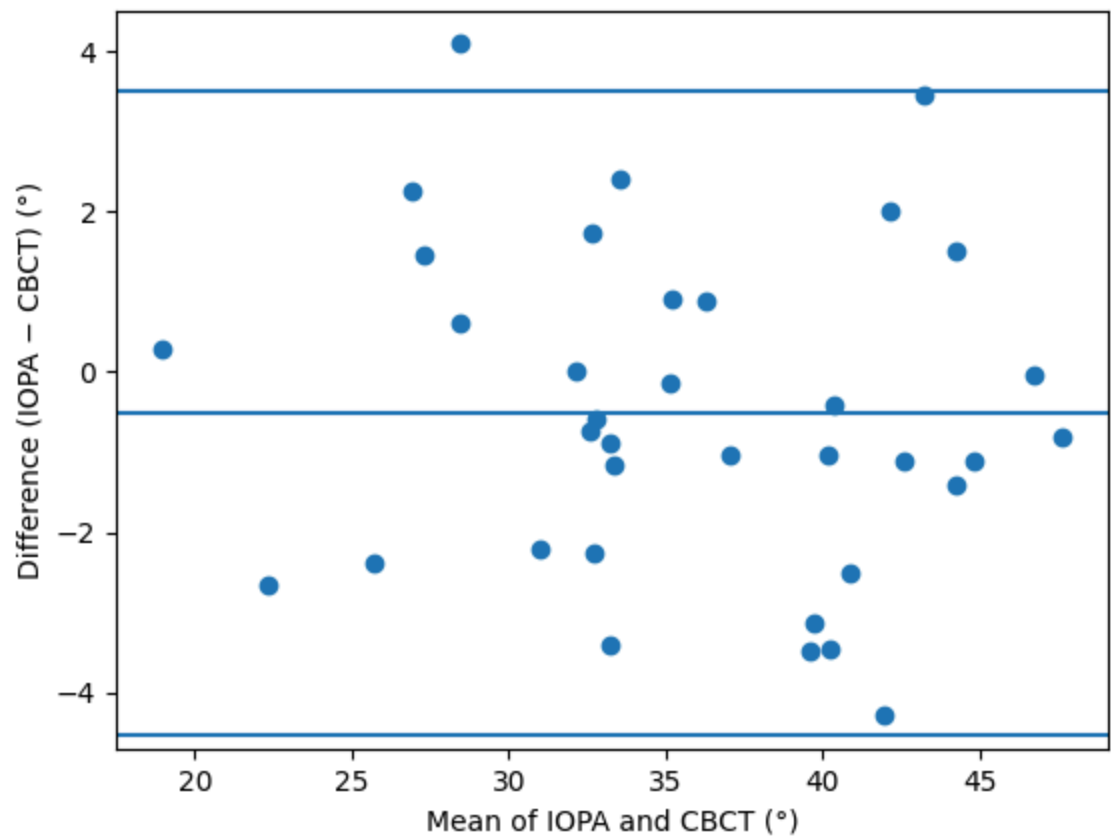


Figure 7

Bland–Altman plot for defect angle measurements