Diagnostic Accuracy of Cone Beam Computed Tomography in Identifying Peri-implantitis–Like Bone Defects Ex Vivo

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This pilot study aimed to assess the diagnostic accuracy of CBCT in identifying peri-implantitis–like bone defects in cadavers. Three cadaver dental arches treated with the Thiel embalming method were used. Three different types of peri-implant bone defects (buccal dehiscence, two- to three-wall defects, and circumferential defects) were prepared on 15 implants. Defect depths and lengths were identified clinically using a periodontal probe, radiologically by means of CBCT images, and histologically with a micrometer using an optic microscope. Peri-implant bone defect morphology evaluated using CBCT images matched the clinical defect configuration (100% accuracy). CBCT assessment demonstrated lower values in defect depth and defect length when compared with the clinical evaluation. A statistically significant difference in defect depth (0.35 ± 0.45 mm; P = .037) was recorded between the clinical and CBCT data. Regarding defect length, a statistically significant mean difference of 0.81 ± 0.83 mm (P = .003) was noted between the clinical and CBCT data. Similarly, a mean difference of 1.09 ± 1.52 mm was recorded between the defect length assessed histologically and the CBCT data (P = .031). No statistically significant differences were observed between the other evaluated variables. CBCT is a reliable tool for peri-implantitis diagnosis and treatment planning, though the underestimation of defect severity may affect the prognosis and clinical decision-making. Clinicians need to be flexible in establishing prognoses and treatment based on CBCT assessment.


Peri-implantitis is defined as the progressive breakdown of support bone as the result of an inflammatory reaction to infection.1 This disorder has been shown to follow an accelerating, nonlinear pattern of bone loss.2 In fact, peri-implantitis lesions are commonly more than twice as large as those noted at periodontitis sites.3

Peri-implant defect morphology, among other features, plays a pivotal role in interventions seeking to arrest and manage peri-implantitis. Generally speaking, reconstruction of infrabony defects has been recommended, whereas the supracrestal components are more prone to resolution by adopting resective approaches. Given the importance of defect morphologic characteristics in accurate treatment planning, it is advisable to map out the bone defect preoperatively.4

The use of intraoral radiography (IR) is common in daily practice, but it is a two-dimensional (2D) image limited to two planes; this fact together with superimpositioning may mask the peri-implant marginal bone levels.5 Moreover, the absence of 3D information in IR impairs evaluation of the buccal and lingual bone plates and peri-implant bone defects.6 In contrast, CBCT may overcome these limitations, as 3D images are generated and can assist in evaluating the buccolingual cortical...
plates and assessing the orthogonal planes. Moreover, as nongeometric distortion is inherent in CBCT images, this technique allows for undistorted determination of bony defects, unlike IR and panoramic radiography. For the assessment of peri-implant bone defects, better performance of IR was reported in the past. Nevertheless, recent data seem to indicate that CBCT images outperform evaluation with 2D radiographic techniques. As an example, Pelekos et al showed that IR’s diagnostic accuracy was affected by defect morphology, exposure time, bone wall thickness, and examiner experience, whereas the diagnostic accuracy of CBCT images was > 96% for all types of defects, regardless of the examiner. Pelekos et al stated that CBCT is a tool with excellent to good diagnostic accuracy in detecting circumferential intrabony and fenestration-type peri-implant defects, but it has limited accuracy for dehiscence defects. Based on that, no evidence was found to recommend CBCT as a standard diagnostic tool for detection and measurement of peri-implant bone loss.

The present ex vivo pilot study in humans was performed to shed light on the diagnostic accuracy of CBCT in identifying peri-implantitis–like defects when compared to histomorphometric and intrasurgical assessments.

Materials and Methods

Three cadaver heads treated with the Thiel embalming method were used in the study. Because the study involved surgical procedures of cadaver samples without personal private information, ethics committee approval was not required, though the study was conducted under the permission and supervision of the Department of Anatomy and Pathology of the University of Extremadura (Badajoz, Spain).

Characterization of Peri-implantitis Defect Morphology

A carbide bur was used on the edentulous alveolar ridges of three jaws to even the plateau. Conventional drilling at 900 rpm was performed to prepare the implant sites. Subsequently, three different types of peri-implant bone defects were prepared (Fig 1) using carbide burs, complying with the radiographic case definition of peri-implantitis, as follows: buccal dehiscence (Class Ia), two- to three-wall defects (Class Ib), and circumferential defects (Class Ic). The severity of the peri-implant bone defects was estimated to be similar across the study. Fifteen implants (10 in the mandible, 5 in the maxilla) were then placed (3.3 × 8 mm; InHex TiCare, Mozo Grau).

Assessment of Bone Defects

Clinical assessment

Defect depth and length were assessed in millimeters using a North Carolina Probe (Hu Friedy) at the mesial, distal, buccal, and lingual aspects of Class Ib and Ic defects, while only the buccal site was assessed for Class Ia defects. Defect length was defined as the linear measurement from the base of the bone defect up to the implant shoulder. Defect depth was defined as the linear distance from the proximal bone defect wall (mesial, distal, buccal, or lingual) to the implant surface (Fig 1).

Radiographic assessment

Images of the dental arches were acquired using a CBCT system (i-CAT 17-19, Imaging Sciences International). The imaging parameters were set at 120 kVp, 18.66 mAs, scan time 20 seconds, 0.4-mm voxel size, and a field of view that varied according to the scanned region. The peri-implant defect depth and length of each implant were determined on a slice, crossing the implant central axis in a buccolingual plane, and measured using the DICOM (Digital Imaging and Communications in Medicine) Osirix viewer (Pixmeo) by a previously calibrated examiner (A.I.; intraexaminer cohens kappa index > 85%) who was blinded to the clinical morphologic defects created in each implant.

Histomorphometric assessment

In brief, the alveolar ridges were dissected and stored in 10% formaldehyde solution. The implant and hard tissue samples were fixed with 4% buffered formaldehyde. Then, samples were dehydrated in an ascending alcohol and xylene series and embedded in methyl methacrylate (Technovit 9100 NEW, Heraeus Kulzer). Nondecalcified sections were prepared by sawing and grinding.
Three cadaver dental arches:
- 15 implants
- 15 peri-implantitis–like defects

Class I defect configuration (intraosseous defect type)

Class 1a: Dehiscence defect
Class 1b: Two- to three-wall defect
Class 1c: Circumferential defect

Defect length
Defect depth

Clinical assessment
CBCT assessment
Histomorphometric assessment

Fig 1 Research protocol of the present study, including the different peri-implantitis–like bone defects and the different assessment methodologies tested.

Samples were then cut following the axis of the implant on the buccolingual plane. The central section was harvested and set to a final thickness of 40 µm. Finally, sections were stained with Masson-Goldner trichrome stain and McNeal stain. Codified specimens were studied and measured by a pathologist using an optic microscope with a micrometer at ×4, ×10, ×40, and ×100 magnifications. The areas of interest were recorded, imported, and analyzed using NIS-Elements AR (Nikon Instruments) and ImageJ (National Institutes of Health) software. This allowed the assessment of defect length and depth.
Statistical Analysis

The statistical analysis involved calculation of the mean, SD, and 95% confidence interval (95% CI) for each item. Repeated-measures t test was applied to CBCT data vs data from the reference methods in order to validate the radiologic measurements. A simple linear regression model with CBCT data as a dependent variable and clinical or histologic data as an independent variable was generated. Pearson linear correlation coefficient between methods was also estimated. The significance level was \( P \leq .05 \). Statistical packages SPSS (version 23, IBM) and Microsoft Excel 2010 were used for data analysis.

**Results**

**Peri-implant Bone Defect Morphologic Features**

Three implants were discarded during the histologic procedures, and radiologic data from one of these implants were not used for statistics. The data of the defect configurations are shown in Tables 1 and 2. Figure 2 illustrates the three types of peri-implantitis–like bone defects as assessed with CBCT. Table 3 shows the data used for statistical analysis. The mean clinical defect depth was 1.65 ± 0.57 mm, whereas the mean clinical defect length was 2.66 ± 0.81 mm. Regarding the histologic measurements, defect depth and length were 1.09 ± 0.56 mm and 2.87 ± 1.45 mm, respectively. Radiographic defect depth and length were 1.26 ± 0.50 mm and 1.90 ± 0.60 mm, respectively.

**Accuracy of CBCT in Identifying Peri-implant Bone Defect Morphology**

CBCT was seen to have an accuracy of 100% in diagnosing peri-implantitis bone defect morphology (Fig 3). Thus, no differences were noted among the three different defect types evaluated.

**Accuracy of CBCT in Identifying Peri-implant Bone Defect Length/Depth**

A statistically significant mean difference of 0.35 ± 0.45 mm (\( P = .037 \)) was recorded between the

*Table 1 Horizontal (Depth) and Vertical (Length) Defects Measured Clinically and Radiologically*

<table>
<thead>
<tr>
<th>Site</th>
<th>Buccal depth</th>
<th>Lingual depth</th>
<th>Mesial depth</th>
<th>Distal depth</th>
<th>Buccal defect depth</th>
<th>Lingual defect depth</th>
<th>Mesial defect depth</th>
<th>Distal defect depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical</td>
<td>1.65 ± 0.57</td>
<td>0.95 ± 0.55</td>
<td>1.55 ± 0.36</td>
<td>1.65 ± 0.94</td>
<td>2.4 ± 0.54</td>
<td>0.94 ± 0.36</td>
<td>1.65 ± 0.36</td>
<td>3.35 ± 1.49</td>
</tr>
<tr>
<td>CBCT</td>
<td>1.05 ± 0.28</td>
<td>0.92 ± 0.32</td>
<td>1.29 ± 0.36</td>
<td>0.97 ± 0.22</td>
<td>4.45 ± 1.03</td>
<td>0.94 ± 0.68</td>
<td>0.59 ± 0.69</td>
<td>2.17 ± 0.58</td>
</tr>
</tbody>
</table>

Data are presented in millimeters as mean ± SD.

*Table 2 Horizontal (Depth) and Vertical (Length) Defects Measured Histologically and Radiographically on the Buccolingual Implant Plane*

<table>
<thead>
<tr>
<th>Defect depth</th>
<th>Defect length</th>
<th>Defect depth</th>
<th>Defect length</th>
<th>Defect depth</th>
<th>Defect length</th>
<th>Defect depth</th>
<th>Defect length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buccal site</td>
<td>1.09 ± 0.56</td>
<td>2.84 ± 1.52</td>
<td>0.63 ± 0.38</td>
<td>1.68 ± 1.04</td>
<td>1.26 ± 0.50</td>
<td>1.90 ± 0.69</td>
<td>0.98 ± 0.69</td>
</tr>
<tr>
<td>Lingual site</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Data are presented in millimeters as mean ± SD.
clinical and CBCT data in regard to defect depth. In the case of defect length, a statistically significant difference of $0.81 \pm 0.83$ mm ($P = .003$) was recorded between the clinical and CBCT data. Similarly, a mean difference of $1.09 \pm 1.52$ mm was seen between the defect length assessed at the histologic level and the CBCT image ($P = .031$). In contrast, when the defect depth was evaluated at the histologic level, a mean difference of $-0.09 \pm 0.57$ mm was recorded ($P = .618$) compared to the value yielded by CBCT.

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**Table 3** Horizontal (Depth) and Vertical (Length) Defects Measured by Clinical, Histologic, and Radiologic Methods

<table>
<thead>
<tr>
<th>Clinical assessment</th>
<th>Histologic assessment</th>
<th>Radiographic assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defect depth</td>
<td>Defect length</td>
<td>Defect depth</td>
</tr>
<tr>
<td>$1.65 \pm 0.57$</td>
<td>$2.66 \pm 0.81$</td>
<td>$1.09 \pm 0.56$</td>
</tr>
</tbody>
</table>

Data are presented in millimeters as mean ± SD.
CIs of these comparisons are shown in Fig 2.

Two simple linear regression models were calculated using the mean CBCT values as the dependent variable, and the gold standard (clinical and histomorphometric assessments) as the independent variable. Analysis of the defect depth determined by CBCT vs the clinical depth defect yielded a Pearson coefficient ($r$) of 0.675. Similarly, weak correlations with limited agreement were recorded upon comparing CBCT vs clinical defect length, CBCT vs histologic defect depth, and CBCT vs histologic defect length ($r = 0.415$, $r = 0.383$, and $r = 0.069$, respectively) (Fig 4).

## Discussion

CBCT plays a notorious role in diagnosis and treatment planning in peri-implantitis. The present ex vivo study has demonstrated the great accuracy of CBCT in identifying a range of peri-implantitis–like bone defect configurations. Nevertheless, the technique demonstrated shortcomings in precise diagnosis of bone defect severity. In effect, the linear regression analyses showed that CBCT generally tended to underestimate the bone defects, particularly defect length, when compared to the clinical and histologic findings. Interestingly, the larger the defect, the greater the observed underestimation. In relation to defect depth, however, CBCT was seen to afford a more accurate prediction, as the mean difference with respect to the histologic outcomes was only about 0.17 mm.

Several studies have investigated the most suitable radiographic tool for establishing an accurate diagnosis of peri-implantitis, but quorum on their reliability has not yet been reached. Kühl et al evaluated CBCT, intraoral radiography (IR), digital panoramic radiographs, and computed tomography (CT) of the human cadaver head to assess peri-implant bone loss. IR showed the highest sensitivity and specificity, and it was recommended as the standard method for evaluating peri-implant bone loss. IR showed the highest sensitivity and specificity, and it was recommended as the standard method for evaluating peri-implant bone loss. It was concluded that CBCT should be used when specifically indicated in a concrete clinical case. In fact, CBCT was shown to outperform the other tested tools in detecting defects $< 1$ mm deep (68%), while IR was found to be the best tool in application to 3-mm deep defects.

![Fig 3 95% confidence intervals (95% CI) of the differences between clinical, radiologic (CBCT), and histologic assessments.](image-url)
contrast, Schwindling et al reported that both low- and high-definition CBCT provide additional morphologic information on the defects compared with the basic information afforded by IR. In this regard, a significant correlation was observed between the histologic bone level around implants placed in minipigs and the bone level reported on CBCT images and IR. Radiographic images consistently reported lower values of the defect size than the histologic images. In this regard, underestimations of 1.17 mm and 1.20 mm were reported for IR and CBCT images, respectively. Moreover, the authors recorded greater deviations in CBCT images in relation to defects > 1.5 mm (2.16 mm) vs defects < 1.5 mm (0.04 mm). More recently, Pelekos et al reported better diagnostic accuracy in the detection of peri-implant defects in porcine ribs using CBCT vs IR images, which was in accordance with a recent animal study. Thus, the present results generally agree with those reported in the literature: In comparison of clinical and histologic findings, CBCT was found to be accurate in identifying peri-implant bone morphology, but less accurate in interpreting the severity of bone loss.

However, across the literature, CBCT has been reported to offer lower performance in identifying peri-implant defects due to a poor resolution or the presence of artifacts. These observations could explain why a few studies have found IR to outperform CBCT. In addition, CBCT has some limitations in clinical use attributable to limited resolution, precluding the routine achievement of accuracies of under 0.5 mm. Furthermore, it has been seen that CBCT may underestimate the thickness of bone measuring less than 1 mm, and that it might not be a suitable tool for measuring bone structures of less than 0.5 mm. Indeed, CBCT may underestimate buccal bone walls of less than 0.3 mm due to direct blooming artifacts.

Certain shortcomings inherent to the study design require caution in interpreting the obtained results. Firstly, mention must be made of the small sample size (three human jaws with 15 implants), which could condition the findings. In addition, it must be noted that the soft tissues of the head were previously removed in order to operate within the alveolar crests, place the implants, and outline the bone defects. This may have improved the contrast in the present CBCT images compared with those obtained in a real-life clinical setting. Moreover, the defects were created artificially, and their edges could be sharper than the more subtle and diffuse edges found in naturally occurring peri-implantitis bone defects. On the other hand, the study contrasted histologic and radiologic images, and this involved intrinsic shortcomings,
especially when matching the same slices with both methods. Another study limitation is related to the presence of artifacts caused by the implant metal and the use of CBCT, as scientific evidence shows beam-hardening artifacts to be present near implants, irrespective of their position in the arches. Also, it should be noted that the present study was conducted using a specific CBCT (i-CAT). Therefore, the results might not be extrapolated generically to other CBCT devices with different resolutions or parameters.

The results of the present study suggest that CBCT is a viable and reliable tool for diagnosis and treatment planning in peri-implantitis. Nonetheless, given the underestimation of the technique in relation to defect length (severity), clinicians need to be flexible in (1) establishing prognoses based on CBCT assessment, and (2) clinical intraoperative decision-making when surgically managing the disorder.

Conclusions

The present ex vivo study shows the potential benefit of using CBCT to diagnose peri-implantitis–like bone defects and distinguish morphologic bone patterns. However, CBCT displayed low precision in accurately estimating bone defect severity.

Acknowledgments

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This study involved surgical procedures performed on cadaver samples without sharing of the cadavers’ personal information, so formal consent was not required.

Author contributions: A.I. and A.M.: Performed surgeries, collected data, and wrote the paper. J.A.G., Y.G., and Y.M.: Analyzed data and wrote the paper. M.R.: Critically assessed the manuscript.

References


