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Review Article

Comparative diagnostic accuracy of CBCT and intraoral imaging for peri-implant bone defect assessment: A systematic review

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Abstract

Introduction: Dental implants are widely used, but their success relies on healthy peri-implant bone. Peri-implantitis can cause bone loss and implant failure, making early detection crucial. Intraoral radiography is commonly used due to its convenience and low cost but lacks accuracy in detecting certain defects. CBCT offers detailed 3D imaging and better detection of bone changes but raises concerns over cost, radiation, and image artefacts. A systematic review is needed to compare the diagnostic accuracy of CBCT and intraoral imaging, helping clinicians choose the best method for managing peri-implant bone health.

Materials and Methods: The study protocol was registered on PROSPERO database. The PROSPERO registration number for protocol for this study is CRD42024510593.

The focused PICO question was: Is there a Difference between the diagnostic accuracy of CBCT and intraoral imaging for peri-implant bone defect.

Results: Electronic search of PubMed (including MEDLINE), COCHRANE CENTRAL, and science direct search engines for articles published from 01/07/2006 to 01/07/2022 was conducted.

The terms mentioned in the concept table were used to formulate a search strategy.

Discussion: Imaging alone cannot fully capture peri-implant bone conditions; clinical data such as probing depth, bleeding, and suppuration are essential for early detection and management of peri-implant diseases. While intraoral (IO) radiography remains the standard for long-term follow-up, it lacks the ability to accurately assess buccal and lingual bone levels. CBCT offers three-dimensional insights and may aid in complex cases, but its current limitations—such as image artifacts, especially from metal implants, and overestimation of bone density—restrict its use. Studies show mixed findings: CBCT may outperform IO imaging in detecting specific defects found IO radiographs more reliable. Future research should focus on optimizing low-dose, artifact-free CBCT protocols tailored to clinical needs, following ALARA and ALADIP principles.

Keywords: One-piece dental implants, Two-piece dental implants, Clinical outcomes.

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1. Introduction

Dental implants are widely used in restorative dentistry because of their durability and effectiveness in replacing missing teeth. Their long-term success, however, depends on the maintenance of healthy peri-implant bone. Bone loss around implants, known as a peri-implant defect, can compromise stability. If not detected and treated in time, it may eventually lead to implant failure. Early and accurate detection of these defects is therefore essential for implant longevity and patient outcomes. Peri-implantitis is a pathological inflammatory condition. It is characterized by progressive bone resorption that goes beyond the normal physiological remodeling around implants.[1,2]

Diagnosis is based on both clinical and radiographic findings. These include bleeding on probing, suppuration, and radiographic evidence of bone loss exceeding one-third of the implant's height.[3] Accurate assessment of peri-implant bone status is crucial for identifying disease in its early stages during routine follow-up.[4] Imaging methods are particularly important, as they complement clinical examination and aid in timely management.[5]

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Conventional intraoral imaging methods, such as periapical and panoramic radiographs, have long been used to assess peri-implant bone levels. They are accessible, affordable, and capable of producing high-resolution images. However, these two-dimensional techniques are limited. They cannot reliably detect or differentiate buccal and lingual defects. As a result, they may underestimate or misrepresent the true extent of bone loss.[6,7]

To overcome such limitations, Mozzo et al. introduced cone-beam computed tomography (CBCT) in 1998–1999.[8] CBCT provides three-dimensional visualization of maxillofacial structures with high spatial resolution. Unlike conventional radiographs, it reduces geometric distortion and eliminates anatomical overlap. This allows better detection of subtle peri-implant bone changes.[9-11]

Despite these advantages, CBCT is not free from drawbacks. Concerns exist regarding radiation exposure, cost, and the influence of metal artifacts on image quality[8,12] Patient movement and technical factors may further reduce precision. Current evidence is mixed. Some studies report that intraoral radiography is more reliable in certain conditions. Others demonstrate the superior diagnostic value of CBCT in classifying and measuring peri-implant defects.[13-15]

In view of these uncertainties, there is a strong rationale for systematically evaluating the evidence. This systematic review aims to compare the diagnostic accuracy of CBCT and intraoral radiography in the detection of peri-implant bone defects. It highlights their respective strengths and limitations and informs clinicians on the most appropriate imaging method for clinical use.

Following the PICOS framework, the review focuses on patients with dental implants (Population). It evaluates CBCT (Intervention) in comparison with intraoral radiography (Comparison). The outcome of interest is diagnostic accuracy in detecting peri-implant bone defects (Outcome). Eligible evidence includes randomized controlled trials, clinical studies, case reports, case series, and animal studies (Study design).

2. Materials and Methods

2.1. Protocol and registration

This systematic review was carried out following established guidelines for diagnostic accuracy studies. The study protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO) with the registration number CRD42024510593. The registration ensured transparency of the review process and avoided duplication of ongoing systematic reviews.

2.2. Eligibility criteria

The eligibility of studies was defined using the PICOS framework. The population of interest included patients or animals with dental implants evaluated for peri-implant bone defects. The intervention was the use of cone-beam computed tomography (CBCT), while intraoral radiography, including periapical and panoramic imaging, served as the comparator. The primary outcome of interest was diagnostic accuracy in detecting, classifying, or measuring peri-implant bone defects. Eligible study designs included randomized controlled trials, clinical studies, case reports, case series, and animal studies.

Exclusion criteria were applied to maintain methodological rigor. In vitro studies, studies conducted on non-living samples, reports not meeting inclusion criteria, and articles without clearly defined outcome measures were excluded. Only articles published in English between July 1, 2006, and July 1, 2022 were considered. Grey literature was not included in this review.

2.3. Information sources

A comprehensive literature search was performed across three electronic databases: PubMed (including MEDLINE), Cochrane Central Register of Controlled Trials (CENTRAL), and ScienceDirect. These sources were selected for their relevance and coverage of clinical and experimental studies in dentistry. To ensure completeness, manual searches were also conducted using printed journals available in the institutional library. The final search was conducted on July 1, 2022.

2.4. Search strategy

The search strategy was developed in accordance with the PICOS framework. Both controlled vocabulary and free-text terms were applied. Medical Subject Headings (MeSH) were identified through the MeSH database, while additional free-text terms were derived from previous literature, dictionaries, and thesauri. Boolean operators such as AND, OR, and NOT were used in combination with phrase searching, truncation, wildcards, and proximity operators.

A concept table (**Table 1**) was designed to guide the search process. This table summarized the PICOS elements: patients with dental implants as the population, CBCT as the intervention, intraoral radiography as the comparator, and diagnostic accuracy as the outcome. The same structured approach was applied consistently across all three databases.

2.5. Study selection

The process of study selection was conducted in two stages. First, two independent reviewers screened titles and abstracts obtained from the electronic searches. In the second stage, the full texts of potentially relevant studies were retrieved and assessed for eligibility. In cases where disagreement arose regarding study inclusion, resolution was achieved by discussion. When necessary, a third reviewer was consulted. After applying the inclusion and exclusion criteria, a total of six studies were found eligible and included in the review.

2.6. Data collection process

Data were extracted using pre-designed Excel-based forms. Two reviewers independently performed the extraction to ensure accuracy and consistency. The extracted data included details of study identification, design, number of patients or samples, number of implants, implant type and site, defect induction (where applicable), imaging modalities, reference standards, and number of observers. Measures of intra- and inter-rater reliability, when reported, were also recorded. Any discrepancies between reviewers were resolved through consensus.

2.7. Data items

The specific variables extracted from each study included the author and year of publication, study design, sample size, number of implants, type or brand of implant, and implant site. Additional data items included the imaging modality employed, the reference standard used for validation (such as histology or micro-CT), and diagnostic performance outcomes such as sensitivity, specificity, and accuracy. Where available, technical details of CBCT systems, such as voxel size and artifact influence, were also collected to provide a comprehensive comparison.

2.8. Risk of bias in individual studies

The methodological quality of the included studies was assessed using the QUADAS-2 tool (Quality Assessment of Diagnostic Accuracy Studies 2). This tool evaluates risk of bias in four domains: patient selection, index test, reference standard, and flow and timing. Each domain was also examined for its applicability to clinical practice. One reviewer independently performed the risk of bias assessment, which was repeated for verification. The results were then cross-checked by a second reviewer. Any disagreements were resolved by discussion.

To strengthen the quality assessment, complementary tools such as the Methodological Index for Non-Randomized Studies (MINORS) and the Institute of Health Economics quality assessment tool were also used where appropriate. Despite extensive efforts to minimize selection bias, certain limitations remained, including the exclusion of grey literature and restriction to English-language publications.

3. Results

3.1. Study characteristics

Six studies were included in this review, comprising experimental animal and bovine models that evaluated the diagnostic accuracy of cone-beam computed tomography (CBCT) compared to intraoral radiography or periapical radiography for peri-implant bone defect detection. The sample characteristics, intervention details, imaging modalities, and gold standards used are summarized in **Table 1**. Across the studies, the number of implants ranged from 15 to 80, with both naturally induced and mechanically created peri-implant defects being evaluated. Histology and micro-CT served as the reference standards in selected studies, while others relied solely on comparative imaging.

3.2. Results of individual studies

The diagnostic outcomes varied among the included studies (**Table 3**). Dave et al. (2012)[17] reported that long cone periapical radiographs (LCPAs) were superior to CBCT in detecting peri-implant defects at smaller defect widths (0.35 mm, $p < 0.02$), with higher negative predictive values and greater examiner consistency. Ritter et al. (2014)[10] found no significant difference between digital intraoral radiographs and CBCT in assessing mesial and distal bone levels, although CBCT provided additional structural information despite being susceptible to artifacts.

Corpas et al. (2011)[14] observed no significant correlation between CBCT, intraoral radiographs, and histology, though intraoral radiographs were more sensitive to subtle bone changes after healing. Eskandarloo et al. (2018)[18] demonstrated that the NewTom CBCT system had the highest sensitivity (75.81%) and specificity (100%) for detecting fenestrations, highlighting variability among CBCT devices. Saberi et al. (2019)[19] showed that oblique periapical radiographs improved detection of fenestration and dehiscence compared to conventional parallel projections, with CBCT exhibiting the highest sensitivity for dehiscence defects. Song et al. (2021)[20] concluded that CBCT had significantly higher diagnostic accuracy than intraoral radiographs in detecting and classifying peri-implant defects, with stronger correlation to the micro-CT gold standard.

3.3. Risk of bias in included studies

Risk of bias assessment was performed across four domains: patient selection, index test, reference standard, and flow/timing. The domain-wise judgments are illustrated in **Figure 1**, and overall bias distribution is summarized in **Figure 2**. Patient selection presented the highest risk of bias, particularly in studies using animal or bovine models. The index test and reference standards showed some concerns in several studies. Overall, one study demonstrated high risk of bias, three presented some concerns, and two were judged as low risk.

3.4. Synthesis of results

Due to methodological heterogeneity, including variability in defect induction, imaging devices, and outcome measures, a quantitative meta-analysis was not feasible. Instead, a qualitative synthesis was undertaken. Across studies, CBCT consistently demonstrated superior diagnostic accuracy compared with intraoral radiographs when evaluating defect classification, depth, and width. However, periapical radiographs showed better performance for detecting very small peri-implant spaces and demonstrated higher intra-examiner reproducibility.

Table 1: Study characteristics

Pico	Population	Intervention	Comparison	Outcome
1	Population with dental implants.	Peri-implant bone defects	Peri-implant bone defects with CBCT versus various intraoral imaging	Difference in between diagnostic accuracy

Table 2:

Author (Year)	Study Design	Samples (n)	Implants (n)	Defect Induction	3D Imaging	2D Imaging	Gold Standard	Observers	Reliability
Corpas et al (2011)[14]	Minipig model	10	80	No	CBCT	IO	Histology	Not clear	✗
Dave et al (2013)[17]	Bovine ribs	4	15	Yes (mechanical)	CBCT	IO	–	9	IO ✓ CBCT ✗
Ritter et al (2014)[10]	Dog model	12	26	Yes	CBCT	IO	Histology	3	✓
Eskandarloo et al (2018)[18]	Bovine ribs	62	31	Yes	CBCT	IO	–	2	✓
Saberi et al (2019)[19]	Bovine ribs	10	40	Yes	CBCT	IO (PA & OPA)	–	2	✓
Song et al (2021)[20]	Dog model	54	16	No	CBCT	IO	Micro-CT	3	✓

Table 3: Study characteristics

Author & Year	Title	Intervention	Comparison	Methodology	Outcome Assessed	Key Results	Conclusion
Corpas et al. 2011[14]	Peri-implant bone tissue assessment by IO radiograph and CBCT vs histology	Detection using intraoral radiography	CBCT	Minipig model; 80 implants in 10 animals; Spearman correlation with histology	Diagnostic accuracy of osseointegration	1. Deviations from histology: IO = 1.17 mm, CBCT = 1.20 mm 2. No significant correlations in fractal analysis 3. IO detected marginal bone changes after 3 months	IO radiographs detect small bone changes in short term. CBCT unreliable for density but may aid trabecular structure assessment
Dave et al. 2012[17]	A comparison of CBCT and conventional periapical radiography at detecting peri-implant bone defects	Detection using periapical radiography (LCPA)	Detection using CBCT (Accuitomo, i-CAT)	RCT on fresh bovine ribs; implants placed at osteotomy sites; imaging with LCPA, small-FOV CBCT, large-FOV CBCT	Presence/absence of peri-implant radiolucency	1. LCPAs more effective for 0.35 mm defects (p < 0.02) 2. No significant difference between 3 techniques 3. LCPA had higher negative predictive value than i-CAT 4. LCPAs had better intra/inter-examiner reliability	LCPAs are dependable and accurate for circumferential peri-implant defects, outperforming CBCT in consistency
Ritter et al. 2014[10]	Accuracy of peri-implant bone evaluation using CBCT, digital intraoral radiographs, and histology	Detection using intraoral radiography (CR)	CBCT	Dog model; 4 implants per specimen; blocks fixed, defects induced randomly; CR using HELIODENT PLUS	Diagnostic accuracy of osseointegration	1. Mesial bone: CR 0.84 mm vs CBCT 0.72 mm (p=0.54) 2. Distal bone: CR 0.82 mm vs CBCT 0.84 mm (NS) 3. Mesio-distal direction significant (p<0.01) though t-test NS	CBCT provides extra info but affected by metal artifacts. Accuracy similar between CR and CBCT; limited clinical generalization

Eskandarloo et al. 2018[18]	Diagnostic accuracy of 3 CBCT systems and periapical radiography for fenestration detection	Detection using periapical radiography	CBCT (NewTom, others)	Bovine ribs with 31 implants; fenestrations artificially created; PA & CBCT taken before/after	Detection of fenestration	1. No differences among systems for defect-free sites 2. Significant differences in detecting defects (p<0.05) 3. NewTom highest sensitivity (75.8%) and specificity (100%)	Differences in diagnostic accuracy due to detector type & voxel size. NewTom most reliable
Saberi et al. 2019[19]	Detection of peri-implant bone defects using CBCT and digital periapical radiography (parallel & oblique)	Detection using IO radiography (PPA, OPA)	CBCT	Bovine ribs; 40 implants (30 with angular, fenestration, or dehiscence defects; 10 controls); CBCT, PPA, OPA	Detection of various defect types	1. All modalities effective for angular defects 2. CBCT & OPA comparable for fenestration 3. CBCT most sensitive for dehiscence, then OPA, then PPA	OPA with PPA improves fenestration/dehiscence detection. CBCT best overall but costly and higher radiation
Song et al. 2021[20]	Diagnostic accuracy of CBCT vs intraoral imaging for peri-implant bone defects	Detection using IO radiography	CBCT and micro-CT (gold standard)	Beagle dog model; 54 mandible blocks; 16 samples assessed via micro-CT in 3 defect categories (dehiscence, infrabony, crater-like)	Classification and measurement of defects	1. CBCT superior in classifying defects 2. IO failed to identify vestibular dehiscence 3. CBCT had stronger correlation with micro-CT for defect depth/width	CBCT adds valuable diagnostic info, particularly for complex defects, beyond IO imaging

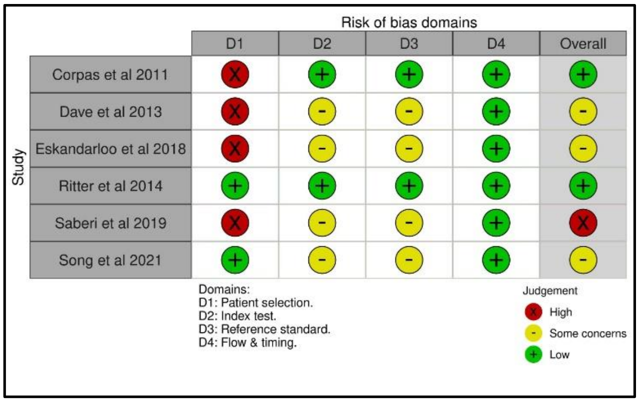

Figure 1: Risk of bias assessment of included studies across four QUADAS-2 domains. Green circles indicate low risk of bias, yellow circles indicate some concerns, and red circles indicate high risk of bias.

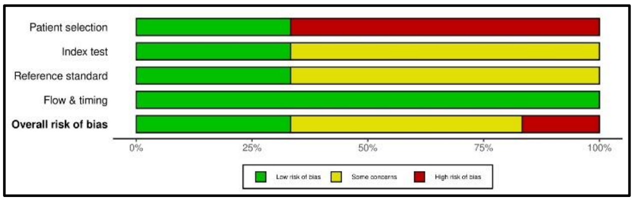

Figure 2: Summary of overall risk of bias across studies, presented as a proportion of judgments for each domain. Green represents low risk of bias, yellow represents some concerns, and red represents high risk of bias.

CBCT systems differed in sensitivity and specificity, reflecting variations in voxel size, detector type, and kVp settings.

Overall, CBCT provides valuable additional diagnostic information compared to intraoral imaging, but its superiority is not absolute. Factors such as radiation dose, cost, and susceptibility to artifacts must be considered in clinical decision-making.

4. Discussion

The findings of this review suggest that intraoral radiography continues to serve as the standard modality for routine peri-implant bone defect assessment due to its accessibility, cost-effectiveness, and low radiation exposure.[21-23] However, the two-dimensional nature of this technique limits its diagnostic accuracy, particularly in detecting buccal and lingual bone changes, which are often obscured in radiographs.[24] As highlighted by several studies, intraoral radiographs are generally restricted to detecting horizontal and one-wall vertical defects in the mesiodistal direction.[28] In contrast, CBCT provides detailed three-dimensional information, allowing more precise assessment of volumetric and morphological changes. Song et al.[20] demonstrated that CBCT showed greater reliability and diagnostic accuracy in detecting and classifying peri-implant bone defects compared to intraoral radiographs. Similar findings were reported[28] and Kuhl et al.,[23] who found CBCT to be highly sensitive in identifying peri-implant defects. Nonetheless, the limitations of CBCT must be acknowledged. Corpas et al.[14] reported that CBCT was less accurate than intraoral radiography and histological analysis in assessing bone density. Dave et al.[17] further demonstrated that LCPA exhibited superior sensitivity and specificity in detecting simulated peri-implant defects compared to CBCT. Ritter et al.[10] attributed inaccuracies in CBCT imaging to artifacts generated by metallic components of implants, and other studies have emphasized the need for improved algorithms to reduce artifacts and overcome beam-hardening issues.[25,26] Taken together, these results indicate that intraoral imaging should remain the first-line tool for monitoring peri-implant bone, while CBCT should be reserved as a complementary technique in complex or ambiguous cases.[20,27,28]

Despite these findings, the evidence included in this review has several limitations. Many studies were based on experimental models involving animals such as minipigs, dogs, or bovine jaws, which restricts generalisability to human clinical practice.[14,17,20] Small sample sizes and heterogeneity in imaging devices, voxel sizes, and reference standards further complicated direct comparisons across studies. Moreover, incomplete reporting of outcomes in some studies raised concerns about selective reporting bias. In addition, CBCT itself carries inherent technical limitations, as image quality and measurement precision are strongly influenced by blooming artifacts, beam hardening, and implant material design.[10,14,29,30] These factors undermine the accuracy of linear measurements and should be carefully considered when interpreting results.

The review process also carries limitations. The literature search was restricted to English-language publications, which may have excluded relevant studies in other languages, introducing language bias. Grey literature was not included, increasing the possibility of publication bias. Although multiple databases and manual searches were conducted, some relevant studies may have been missed. Furthermore, the included studies encompassed heterogeneous designs, many of which were not randomized or clinical human trials, which lowers the overall strength of the evidence base.

The implications of these findings are important for clinical practice, policy, and future research. Clinically, intraoral radiography should remain the preferred method for routine monitoring of peri-implant bone health, owing to its reliability, affordability, and lower radiation dose.[22,23] CBCT should not be used for evaluating bone density,[21] but may be indicated in complex or doubtful cases where three-dimensional visualization is required.[20,27,28] Clinicians should follow the ALARA and ALADIP principles to minimize radiation exposure, tailoring protocols to patient-specific needs. [21] From a policy perspective, guidelines should emphasize indication-based use of CBCT to balance diagnostic benefits with patient safety, and standardization of imaging protocols would improve the comparability of future studies. For research, there is a clear need for large-scale, well-designed clinical trials in human populations, with standardized reference standards and outcome reporting, to confirm diagnostic accuracy. Technological improvements in CBCT, including artifact-reduction algorithms and optimized low-dose protocols[25-28] should also be prioritized to strengthen its role in peri-implant assessment.

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5. Conclusion

This systematic review evaluated the diagnostic accuracy of CBCT compared with intraoral imaging for detecting peri-implant bone defects. The findings indicate that while CBCT offers greater reliability, sensitivity, and diagnostic detail, particularly for classifying complex defects, it is not yet suitable as the standard imaging method due to artifacts and limitations in bone density assessment. Intraoral radiography remains the most practical tool for routine monitoring, with CBCT reserved for complex clinical situations requiring three-dimensional evaluation.

6. Source of Funding

None.

7. Conflict of Interest

None.

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