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Review Article

Comparative Evaluation of 2D Digital Intraoral Radiography and Cone Beam Computed Tomography (CBCT) in Assessing Peri-Implant Marginal Bone Loss: A Clinical and Diagnostic Accuracy Study

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Abstract

Periodic measurement of MBL allows for the timely recognition and treatment of peri-implantitis. Despite the wide availability of two-dimensional digital intraoral radiography, which also provides a low radiation dose, the impossibility of assessing the buccal and lingual cortical plates is a serious limitation in diagnosing the condition. Cone-beam computed tomography provides a three-dimensional image and gives an opportunity to assess the bone defects in multiple planes. This work evaluates the diagnostic effectiveness, clinical indications, and limitations of the two types of imaging used in the diagnosis of peri-implant bone level. The research is based on data from scientific literature sources available between 2021 and 2026. The results show that CBCT significantly enhances the detection of buccal bone loss and crater lesions in three dimensions in comparison with 2D radiography. However, the presence of artifacts in the titanium structures and radiation exposure limit the use of this technique.

Keywords: peri-implantitis, Cone-beam computed tomography (CBCT), 2D Digital Intraoral Radiography.

1. Introduction

Predictable long-term integration and functional stability still remain the main aims of implant dentistry [1]. Despite more than 95% survival rate during ten years of observation, inflammatory peri-implant diseases have become a new biological threat in daily practice [2]. The disease is characterized by inflammation of peri-implant mucosa along with gradual and irreversible loss of marginal bone support [3]. If left untreated, bone loss will cause instability of the fixture, which eventually leads to loss of the fixture. Thus, proper assessment of marginal bone levels is important.

Alveolar bone levels have traditionally been assessed through clinical probing measurements, bleeding on probing, and intraoral 2D digital radiography, which includes periapical and bitewing images [4]. Intraoral radiographic methods provide good spatial resolution, cost-effectiveness, and low ionizing radiation exposure to the patients. However, 2D imaging techniques are structurally limited due to superimposed anatomy, where the buccal and lingual plates of cortical bone overlap, making it impossible to identify 3D bone defects if the cancellous bone is covered with cortical bone [5].

The introduction of CBCT has changed the field of diagnostic radiology of the maxillofacial region by introducing isotropic volumetric imaging [6]. Multiple cross-sectional images allow the evaluation of the peri-implant tissues on the sagittal, coronal,

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and axial planes [7]. Regardless of such obvious benefits, the question of whether to use 3D or 2D imaging is still clinically challenging. This paper aims to evaluate the diagnostic efficacy, accuracy of measurements, and technical constraints of 2D imaging compared to CBCT in assessing peri-implant bone loss based on scientific literature from 2021 to 2026.

2. Literature Review and Conceptual Framework

Evaluating peri-implant bone resorption requires differentiation between physiological bone resorption within the first year post-loading and subsequent pathological bone resorption due to peri-implantitis [8]. In accordance with consensus statements of international associations of dentists, it is recommended that the radiographic assessment should define baseline bone levels immediately after the placement of implants and prostheses.

Several comparative radiologic investigations published in the period from 2021 to 2026 have shown that the two-dimensional intraoral radiographs consistently underreport the actual circumference of peri-implant bone resorption [9]. Even though mesial and distal bone resorption can be estimated using the parallel periapical technique, early bone intrusions and buccal dehiscences might not be revealed on two-dimensional radiographs. It is precisely where CBCT provides an advantage in terms of cross-sectional bone measurements [10].

However, guidelines in radiology focus on compliance with the ALARA (As Low as Reasonably Achievable) approach [11]. Since CBCT involves higher amounts of radiation compared with periapical radiography, there is no need to take three-dimensional scans in stable cases with implants. Moreover, due to the high density of the materials used (titanium/zirconia), metal artifacts become evident [12].

3. Methodological Comparison and Diagnostic Metrics

The evaluation of certain diagnostic criteria is required in order to determine the accuracy of imaging techniques, which include spatial resolution, ability to identify defects, radiation dose, and susceptibility to image distortion.

3.1 2D Digital Intraoral Radiography

Digital intraoral sensors (CCD, CMOS, PSP) have high line-pair resolution values exceeding 15-20 lp/mm, making them an efficient tool for identifying fine trabeculae at the mesial and distal areas of the roots [13]. Film holders fitted with beam aligners eliminate geometrical distortions, thus providing standardized placement in longitudinal follow-up studies.

3.2 CBCT Volumetric Assessment

The CBCT scanner uses a cone-beam shaped X-ray source along with a flat panel detector to gather volume information in a single rotation cycle [14]. The size of the reconstructed voxel can range anywhere from 0.075 mm to 0.2 mm. This facilitates high-resolution spatial reconstruction. Measurements of the distance between the implant shoulder and the first bone contact at each quadrant can be made using cross sections.

Table 1: Comparative Diagnostic Parameters of 2D Digital Radiography vs. CBCT in Peri-Implant Bone Evaluation

Parameter	2D Digital Intraoral Radiography	Cone-Beam Computed Tomography (CBCT)	Citation
Spatial Resolution	Very High (>15 lp /mm	Moderate to High (2-4 lp/mm)	[13, 14]
Dimensionality	Two-Dimensional (2D) Projection	Three-Dimensional (3D) Volumetric	[5, 7]
Buccal/Lingual Defect Detection	Poor (Masked by superimposition)	Excellent (Multiplanar views)	[9, 15]
Intrabony Crater Evaluation	Underestimated / Incomplete	Precise volumetric mapping	[10, 16]
Metal Artifact Susceptibility	Low (Minor blooming effect)	High (Beam hardening and streak artifacts)	[12, 16]
Effective Radiation Dose	Minimal (1-6 micro Sv)	Low to Moderate (30-300 microSv)	[11, 14]

4. Clinical Accuracy and Diagnostic Performance

There are a variety of experimental and clinical studies comparing radiographic measurements to direct measurements performed during open flap reentry, where there are obvious discrepancies in the diagnostic accuracy between different imaging techniques [17].

When discussing two-dimensional bone loss of the mesial and distal sides, it was found that two-dimensional intraoral periapical radiographs have high diagnostic accuracy, where the measurement error is less than 0.5 mm under conditions of orthogonal positioning [18]. However, in practice, cases of two-dimensional bone loss are extremely rare; peri-implantitis usually appears in the form of a three-dimensional circumferential bone defect or infrabony pocket.

In the case of three-dimensional bone defects, cone beam computed tomography (CBCT) is more accurate [19]. The cross-sectional imaging allows diagnosis of thin buccal bone plates, which are crucial for good esthetics in the anterior maxilla region. Studies show that the sensitivity of CBCT in detecting buccal dehiscence and fenestration is more than 88%, while in periapical radiography it is less than 35% [20].

5. Technical Bottlenecks and Radiographic Artifacts

Although it offers various advantages, the use of CBCT scanning around dental implants is compromised by the existence of some inherent technical challenges caused by the physical interaction of radiation.

5.1 Beam Hardening and Metal Artifacts

The metallic dental implants contain a high atomic number and density [21]. During passage of the polychromatic X-ray through a metallic dental implant, the lower-energy photons get preferentially absorbed. This results in two kinds of image artifacts:

1. **Dark bands and cupping artifacts**: False low-density regions that appear immediately next to the implant threads resembling bone resorption around the implant.
2. **Streak artifacts**: Appearance of bright and dark streaks from the center of the implant, thereby obliterating the bone trabeculae surrounding the implant [22].

5.2 Radiation Dose and Patient Risk

Though CBCT results in a significantly lower radiation dose compared to MDCT, it still provides a higher dose than regular intraoral radiographs [23]. Randomly employing CBCT to monitor the condition of healthy implants is nothing but an unnecessary increase in radiation dose with no diagnostic advantage at all.

6. Future Directions and Optimization Protocols

Current technological innovations strive to minimize the effects of image distortion and exposure to radiation without compromising the quality of diagnosis [24]:

1. **Advanced Metal Artifact Reduction (MAR) Algorithms**: Current-generation reconstruction methods use deep learning algorithms to detect and eliminate metallic artifacts in the raw data before volumetric reconstruction [24].
2. **Ultra-Low Dose Protocols**: Through optimization of imaging parameters such as reduction in milliampere-seconds (mAs) and use of limited FOV settings, it is possible to achieve local high-resolution images at radiation doses comparable to those of standard 2D radiography [25].

7. Conclusion

Intra-oral 2D digital radiography is still the most frequently utilized imaging tool for evaluation of peri-implant bone level, due to its good spatial resolution, affordability, and low radiation exposure. On the other hand, if the patient suffers from peri-implantitis or has deep intrabony pockets and there is suspicion of perforation of the buccal cortical plate, conventional 2D imaging will be insufficient. For these purposes, Cone Beam Computed Tomography provides valuable 3D information. Use of three-dimensional imaging should be considered, taking into account its clear advantages and possible problems with artifacts and radiation exposure.

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