Intraoral radiographs for the diagnosis, treatment, and follow-up of periodontal disease: a position paper from the Canadian Dental Hygienists Association

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ABSTRACT

Objective: This position paper assessed, through a systematic review, the role of intraoral radiographs as the standard of care for assessing and diagnosing periodontal disease while also informing treatment planning, intervention delivery and the evaluation of periodontal care. **Methods:** This review adhered to PRISMA guidelines and was registered under the protocol nº CRD42024579081. Searches were conducted through Ovid MEDLINE, Ovid Embase, Web of Science and the Cochrane Library, with additional screening of grey literature and reference lists. Studies evaluating intraoral radiographs for diagnostic accuracy and treatment-planning effectiveness for periodontal disease among adults were included. Risk of bias was assessed using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool. **Results:** Thirty studies involving 1,645 adult patients (mean age 35 to 59 years), were included. Intraoral radiographs demonstrated a moderate to high sensitivity (60–90%) compared to direct measurement (flap surgery) or clinical attachment level measurements for assessing periodontitis and peri-implantitis bone loss. A moderate association (r = 0.5–0.8 across 13 studies) was observed between clinical measurements and intraoral radiographs of alveolar bone loss, with radiographs underestimating bone loss by 0.5 to 2.8 mm compared to clinical methods. **Conclusion:** Periapical and bitewing radiographs are tools with moderate to high sensitivity for periodontal assessment, suggesting that they are the most accurate and appropriate tools to be used as an adjunct to clinical evaluation for dental professionals.

RESUME

Objectif: Cet exposé de position a évalué, par le biais d’une revue systématique, le rôle des radiographies intraorales, qui contribue à la planification du traitement, à la mise en œuvre des interventions et à l’évaluation des soins parodontaux, en tant que norme d'évaluation standardisée pour l’évaluation et le diagnostic des maladies parodontales. **Méthodes:** Cette revue a suivi les directives PRISMA et a été enregistrée sous le protocole numéro CRD42024579081. Les recherches ont été effectuées via Ovid MEDLINE, Ovid Embase, Web of Science et la Cochrane Library, complétées par une recherche de la littérature grise et de listes de références. Les études évaluant la précision diagnostique et l'efficacité des radiographies intraorales dans la planification du traitement des maladies parodontales chez les adultes ont été incluses. Le risque de biais a été évalué à l'aide de l'outil QUADAS (*Quality Assessment of Diagnostic Accuracy Studies*). **Résultats:** Trente études, incluant 1 645 patients adultes (âge moyen entre 35 et 59 ans), ont été retenues. Les radiographies intraorales ont démontré une sensibilité modérée à élevée (60–90 %) comparativement aux mesures directes (chirurgie à lambeau) ou aux mesures du niveau d'attache clinique et ce, pour l'évaluation de la parodontite et l'évaluation de la perte osseuse péri-implantaire. Une association modérée (r = 0,5–0,8 dans 13 études) a été observée entre les mesures cliniques et les radiographies intraorales de la perte osseuse alvéolaire, les radiographies sous-estimant la perte osseuse de 0,5 à 2,8 mm par rapport aux méthodes cliniques. **Conclusion:** Les radiographies périapicales et interproximales sont des outils ayant une sensibilité modérée à élevée pour l'évaluation parodontale. Cela suggère que ces outils sont les plus précis et appropriés pour compléter l'évaluation clinique effectuée par les professionnels dentaires.

Keywords (MeSH terms): dental radiography; diagnosis; treatment; periodontal diseases; periodontitis; oral health; radiograph, dental

CDHA Research Agenda category: risk assessment and management

POSITION STATEMENT

This position paper aims to guide dental hygiene clinicians, as well as oral health care providers, educators, policymakers and regulators, by consolidating and presenting the latest evidence on the indispensable role of intraoral radiographs in diagnosing, monitoring and managing periodontal diseases.

INTRODUCTION

Periodontal diseases affect over one billion people worldwide, compromising the periodontal tissues that support teeth.[1] In Canada, the prevalence of severe periodontal disease in people aged 15 years and older has been reported at 24%.[2] Advanced periodontal disease is the leading cause of tooth loss in adults, significantly impacting their overall quality of life.[3] Timely and accurate screening and diagnostic tools are crucial for the early diagnosis and effective management of this disease.[4] The reference standard for diagnosing periodontal and peri-implant diseases relies on clinical evidence of periodontal destruction, with clinical attachment loss serving as the "diagnostic yardstick" for periodontitis.[5,6]

Intraoral radiographs, such as periapicals and bitewings, have been used globally for over 50 years as a valuable supplementary tool for diagnosing and managing periodontal disease.[7–9] They are an accessible and cost-effective assessment tool, recommended by multiple dental professional organizations, including the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases, and supported by the Periodontology specialty.[8–10] Radiographs provide critical information about bone defects, the extent of bone loss, and the severity of periodontal conditions that may not be visible clinically.[8] Radiographs may also help to identify underlying issues such as furcation involvement, caries, root resorption, local irritating factors, and periapical pathology. They therefore assist clinicians in making more accurate diagnoses and informed decisions resulting in improved patient care and safety.[8,11] The American Academy of Periodontology (AAP) classification is widely used in Canada to facilitate the standardized assessment of alveolar bone status over time.[12,13]

In Canada, dental hygienists can, within their scope of practice, assess, formulate a diagnosis, provide treatment and follow-up for non-surgical periodontal disease. However, their scope of practice varies by province and territory, as each is regulated by its respective governing body.[14,15] With access to both extraoral and intraoral dental imaging, oral health care providers, including dental hygienists, can identify when radiographs are indicated. It remains essential to evaluate the evidence supporting the use of intraoral radiographs for the diagnosis, treatment and follow-up of periodontal disease. While advanced technologies for assessing the maxillofacial area, such as Cone-Beam Computed Tomography (CBCT), and emerging technologies like Magnetic Resonance Imaging (MRI), are not recommended for routine periodontal assessments.[5,10] Furthermore, oral health care providers, including dental hygienists, have been guided by the 2012 American Dental Association recommendations for prescribing dental radiographs.[9]

As the national association representing over 33,000 dental hygienists working in Canada, the Canadian Dental Hygienists Association is well-positioned to lead evidence-informed practice in the field. Evidence-based position statements support informed decision making among practitioners, guide dental hygiene curricula, and shape ongoing continuing education. This, in turn, enhances both professional oral healthcare practices and patient outcomes. Through a systematic review, this position paper seeks to evaluate the role of intraoral radiographs as the standard of care for assessing and diagnosing periodontal disease while also informing treatment planning, intervention delivery and the evaluation of periodontal care. The information outlined in this position paper will be essential for clinicians, educators, policy makers, and regulators to stay informed about the latest research on the role of intraoral radiographs in the management of periodontal diseases.

METHODS

Protocol and research question

This systematic review was developed and reported through a collaborative partnership involving the CDHA and an ad-hoc Steering Committee. The team included dental hygienists, oral and maxillofacial radiologists, dental hygiene educators, a periodontist, a librarian, and experts in evidence-based practice. The review was conducted following the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[16] A protocol for the review was registered with the International Prospective Register of Systematic Reviews (PROSPERO) at the University of York, UK (registration number CRD42024579081). The protocol is publicly available at: www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42024579081.

The PIRDS framework[17,18] (P=Participants, I=Index test, R=Reference test, D=Diagnostic, S=Studies) was used to identify eligible articles. The objective was to address the following structured research question: *In adult patients with periodontal disease (**P**), how does the use of intraoral radiographs (**I**) compare to clinical examination alone or along with other radiographic modalities (**R**) in terms of diagnostic accuracy and treatment planning effectiveness (**D**) in observational studies and clinical trials (**S**)?*

Eligibility criteria

Published studies utilizing dental radiographs to assess, diagnose, treat, and follow up on adult patients with periodontal disease, without restrictions on publication year, were included. Studies employing periapical and bitewing radiographs as intraoral imaging modalities, as well as those comparing dental panoramic radiographs (extraoral imaging) with intraoral radiographs, were also considered. The included studies assessed diagnostic accuracy and the association between dental radiographs and standard clinical periodontal evaluations (e.g., periodontal probing and assessment of clinical attachment level (CAL)). Sensitivity and specificity were used as key statistical measures of a diagnostic method's accuracy (e.g., intraoral radiographs) compared to a reference standard (e.g., clinical parameters that would include CAL and intrasurgical CAL).[19] Sensitivity reflects how effectively intraoral radiographs identify adults with periodontal disease, while specificity indicates their ability to classify those without periodontal disease.

Studies that used advanced dental imaging modalities, such as CBCT and MRI, as the exclusive comparison method to intraoral radiographs were excluded. Ex vivo studies, in vitro studies, animal studies, literature reviews, case series, case reports, personal opinions and conference proceedings were also excluded.

Search strategy

In collaboration with the research team, the expert librarian (JYK) designed and conducted comprehensive searches in Ovid MEDLINE, Ovid Embase, Web of Science Core Collection, and the Cochrane Library (via Wiley) on August 2, 2024. The search strategy was developed following guidelines from the Cochrane Handbook and the JBI Institute.[18,20] Relevant keywords and controlled vocabulary were carefully selected to capture all pertinent literature regarding the use of intraoral radiographs for diagnosing, treatment planning, and evaluating outcomes in patients with periodontal disease. Searches were limited to English-language publications.[21] All search results were retrieved and exported to Covidence Software (Veritas Health Innovation, Melbourne, Australia), available at www.covidence.org, for reference management. Duplicate articles were removed using the software and verified by two reviewers. In addition to subscription-based databases, the research team also searched trial registries (e.g., ClinicalTrials.gov) and Google Scholar. A partial grey literature search engine was utilized, including the first 100 relevant results from Google Scholar, selected without filters.[22] These results were screened according to the PRISMA-S guidelines by Rethlefsen et al. (2021).[23] Articles referenced by the field experts were considered. Appendix 1 details each database strategy, word truncations, key search terms and Booleans used (Appendices, Table S1).

Study selection and data extraction

Two independent reviewers (NF and CP) followed a two-phase process. In phase 1, titles and abstracts were screened according to the eligibility criteria. In phase 2, the same reviewers read the full texts. Any reviewer conflicts were reconciled by mutual agreement and discussion with the field expert and project leads (CP-P and FA). The reference lists from the selected studies were reviewed to identify any additional relevant articles.

A standardized form was used to collect key features from the included articles. This form captured information such as the country and year of publication, sample size and reasons for using intraoral radiographs, type of intraoral radiograph, radiographic acquisition parameters (e.g., kilovoltage peak, milliamperes, type of receptor), features of the comparator group, criteria used to define the clinical assessment, methods for assessing the craniofacial area, and the main results. Data extraction was performed by two reviewers (NF and CR). When data was missing or unclear, attempts were made to contact the corresponding authors via email to retrieve the necessary information.

Risk of bias (RoB) assessment

The RoB assessment was conducted independently and in duplicate by two reviewers (NF and CP). Any disagreements were resolved through discussion with a third investigator. The reviewers were not blinded to the authors or research results, and the assessment was carried out following the calibration of both reviewers. In this phase, each reviewer evaluated ten papers.

Each study was scored through the Quality Assessment of Diagnostic Accuracy Studies-C (QUADAS-C) and Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2), as appropriate for the study type.[24,25] The quality assessment judgments were not used as a threshold for inclusion but rather as a possible explanation for differences in results.

Data synthesis and quantitative analysis

Due to methodological heterogeneity, such as variations in imaging acquisition receptors and modalities, age groups, clinical assessment methods, and statistical approaches used to assess accuracy, a quantitative analysis (i.e., meta-analysis) could not be performed.

RESULTS

Study selection

A total of 11,089 citations were retrieved from the databases. Of these, 4,285 duplicates were excluded. The titles and abstracts of the remaining 6,804 studies were screened based on the eligibility criteria, leading to the selection of 87 studies for full-text assessment. From these, 57 studies were excluded for failing to meet the eligibility criteria in terms of population (n = 3), intervention (n = 10), comparator (n = 6), outcomes (n = 27), or study design (n = 11) as defined in the protocol (Appendices, Table S2). Ultimately, 30 studies met the eligibility criteria and were included. Figure 1 provides a summary of the selection process for this review.

Study characteristics and synthesis of results

A total of 1,645 adult patients, with a mean age ranging from 35 to 59 years, were assessed across the included studies. Analog periapical radiographs, where images are captured using radiographs, were the most commonly used intraoral imaging modality, and were most often compared to direct surgical measurements or clinical attachment levels/loss. Some studies (n = 8) also compared intraoral radiographs and clinical periodontal assessments to dental panoramic radiographs,[26–29] CT scans[30] and CBCT scans.[31–33]

The included studies have been published between 1990–2022, were developed in fourteen countries, including Belgium,[34–36] Germany,[26,37] Greece,[27] India,[30,38–41] Iran,[42] Italy,[43] Malaysia,[31] Saudi Arabia,[44] Spain,[45] Sweden,[28,46] Switzerland,[47] Taiwan,[48] Turkey[29] and the USA.[11,12,32,33,49–53]

Among the included studies, 24 studies were observational (15 cross-sectional studies [11,27,29,32,34–36,38,40–42,45] and nine cohort studies [26,30,39,43,46–49,52]) and six were interventional studies, including four randomized controlled trials (RCT)[12,31,33,50] and two non-randomized controlled trials (N-RCT).[28,53] Also, regarding the type of intraoral radiographs used, 20 studies used only periapicals,[11,26,27,30,31,33–36,38–47,53] five studies used only bitewings,[12,37,48,50,52] and five studies used both periapical and bitewings.[28,29,32,49,51] Twenty studies specified the use of the paralleling technique[26–28,31–36,38–40,42–47,49,51] and five studies did not report the intraoral technique. [11,29,30,41,53]

The use of intraoral radiographs to assess alveolar bone loss in patients with suspected periodontitis was investigated in 22 studies. Of these, three studies focused on the accuracy of intraoral radiographs,[31,34,49] nine studies examined the association between intraoral radiographs and clinical measurements,[12,32,40,42,44,47,48,50,51] two studies assessed the reliability of intraoral radiographs compared to clinical measurements,[26,34] and nine studies compared the statistical differences between measurements from intraoral radiographs and clinical assessments, without assessing their association.[11,27–30,37–39,52]

Additionally, six studies explored using intraoral radiographs to assess bone loss in patients with suspected peri-implantitis. Of these, one study investigated the accuracy of intraoral imaging,[34] two studies examined the association between intraoral radiographs and clinical measurements via regression analysis,[36,41] and five studies compared the differences between measurements from intraoral radiographs and clinical assessments.[35,36,43,45,46]

The use of intraoral radiographs to assess treatment outcomes of periodontal therapy was evaluated in six studies.[29,33,35,48,49,53] Of these, two studies focused on the accuracy of intraoral radiographs,[35,49] one examined the association or correlation between intraoral radiographs and clinical measurements,[48] one investigated the reliability of intraoral radiographs compared to clinical measurements,[34] and one compared the differences between measurements from intraoral radiographs and clinical assessments.[29]

Table 1 summarizes the key features of the included studies and Figure 2 presents a summary of study characteristics.

Results of individual studies

Alveolar bone loss among adults with suspected periodontitis

A total of 22 studies evaluated the use of intraoral radiographs to assess alveolar bone loss in patients with suspected periodontitis. Thirteen studies assessed the accuracy of alveolar bone loss assessment between intraoral radiographs and direct periodontal probing during flap surgery,[11,26–31,34,37–39,42,48] and nine studies compared the accuracy of alveolar bone loss in intraoral radiographs and clinical periodontal probing.[12,32,40,44,47,49–52]

When comparing the intraoral radiographs alveolar bone loss measurements to intrasurgical periodontal probing, an underestimation of bone loss was observed in intraoral radiographs, varying from 0.6–2.8 mm.[11,27–30,37–39] Two studies assessed and reported positive association, varying from 0.24–0.88 ($p<.001$),[42,48] and two studies assessed and reported a sensitivity ranging from 0.59–0.66 when comparing both methods.[31,34] One study assessed and reported an agreement of 0.54 between tests used.[26] Additionally, two studies assessed panoramic radiograph accuracy along with intraoral radiographs and surgical measurements, in which intraoral radiographs presented less underestimation of the alveolar bone loss.[27,28] One study assessed Computed Tomography accuracy along with intraoral radiographs and surgical measurements, in which intraoral radiographs presented a comparable level of alveolar bone loss underestimation;[30] and another study compared the accuracy of intraoral radiographs to

CBCT, in which the same magnitude of sensitivity was observed (CBCT = 0.62 and intraoral radiographs = 0.59).[31]

When comparing the intraoral radiographs alveolar bone loss measurements to clinical periodontal probing, six studies assessed and reported a weak (r = 0.03)[50] to moderate (r = 0.5–0.67)[32,40,44,47,51] overall association between both methods. Contrasting association values were also observed in one study, depending on the teeth assessed: probing on lingual sites of mandibular molars showed a weaker association (r = 0.23) than buccal sites of maxillary molars (r = 0.57).[51] One study assessed and reported a positive association between measurements,[12] another reported a high sensitivity (0.87) and low specificity (0.17) between measurements.[49] Another study found 54% accuracy while comparing periodontal probing to a specific radiographic subtraction evaluation.[52] Two studies assessed the association between CBCT measurements with clinical and intraoral radiograph evaluations, showing no statistical differences between CBCT and intraoral radiographs.[32,51]

Alveolar bone loss among adults with suspected peri-implantitis

Six studies evaluated the use of intraoral radiographs to assess bone loss among patients with suspected peri-implantitis. When comparing the intraoral radiographs alveolar bone loss measurements to intrasurgical periodontal probing, all five studies assessed and reported an underestimation ranging from 0.5–2.7 between methods, in which a range of 0 to 8 mm of underestimation was observed across studies.[35,36,43,45,46] Two studies assessed and reported an association varying from 0.34–0.65, in which the measurement of mesial alveolar bone defects showed a lower association than distal alveolar bone defects.[43,46] One study reported a sensitivity of 0.80 and a specificity of 0.62 when comparing both methods.[35]

When comparing the intraoral radiographs alveolar bone loss measurements to clinical periodontal probing, one study observed a negative correlation (r = -0.74) between the keratinized gingiva width and the radiographic bone loss (p<.0001).[41]

Alveolar bone loss among adults under periodontal therapy

Six studies evaluated the use of intraoral radiographs to assess treatment outcomes of periodontal therapy. All six studies included patients with periodontitis and used intraoral radiograph parameters to follow up with patients after non-surgical [48,53] and surgical periodontal therapy (e.g., subgingival curettage, bone grafting).[29,33,35,49,53] Three studies compared intraoral radiographs to intrasurgical clinical measurements,[33,35,48] and three others compared intraoral radiographs to periodontal probing measurements.[29,49,53]

When intraoral radiographs were used to evaluate alveolar bone loss measurements against intrasurgical periodontal probing, two studies found a weak to moderate correlation while monitoring patients after non-surgical periodontal therapy (r = 0.26),[48] and surgical periodontal therapy, (i.e., bone grafting; r = 0.53).[33] One study reported an underestimation of 2.5 mm between methods.[35] One study also compared the use of CBCT in addition to intraoral radiographs and clinical surgical measurements while following up with patients with generalized periodontitis after surgical periodontal therapy, in which CBCT (r = 0.89) showed a higher correlation to surgical measurements than intraoral radiographs (r = 0.53).[33]

When comparing the intraoral radiographs alveolar bone loss measurements to clinical periodontal probing, one study observed an underestimation of 1.20 mm from bitewing radiographs and an underestimation of 1.5 mm from periapical radiographs using paralleling technique, one year after periodontal surgery.[29] One study reported a correlation of 0.40 when comparing both methods in a group of patients with a history of surgical and non-surgical periodontal therapy in the previous 12 months.[53] One study assessed the presence of radiographic crestal lamina dura as a predictor of clinical periodontitis disease-activity and stability, observing a positive association between both (OR = 2.6, p = .0004).[49]

Figure 3 presents a summary of main findings regarding the performance of intraoral radiographs in the assessment of periodontal diseases.

Risk of bias

The overall RoB varied significantly across studies, with most categorized as unclear.

The QUADAS-C tool was applied to nine studies, among which five studies presented an unclear RoB,[27,28,30,33,51] two studies presented a high RoB,[29,32] and two studies presented a low RoB.[26,31] The main issues leading to this classification were patient selection and index (i.e., data from intraoral radiographs methodology) domains (Figure 4).

The QUADAS-2 tool was applied to 21 studies, of which nine studies presented an unclear RoB,[11,34–36,38,39,41,52,53] four presented a high RoB,[37,40,42,46] and eight studies presented a low RoB.[12,43–45,47–50] The main issues contributing to this classification were patient selection (Figure 5).

DISCUSSION

Through a systematic review, this position paper explores the most current evidence regarding the role of intraoral radiographs as the standard of care for assessing and diagnosing periodontal disease among adults. The included studies evaluated the diagnostic potential of intraoral radiographs in three independent scenarios: assessment of alveolar bone loss in adults with suspected periodontitis, assessment of alveolar bone loss in adults with suspected peri-implantitis, and alveolar bone loss in adults under periodontal therapy (all phases, including follow-up). This review showed that intraoral radiographs presented a moderate to high 60–90% sensitivity, when compared to either intrasurgical and clinical attachment level measurements in both assessments of periodontitis and peri-implantitis bone loss. Furthermore, this review reported a moderate (r = 0.5 - 0.8 across 13 studies) association between clinical and intraoral radiographs alveolar bone loss measurements and an underestimation varying from 0.5 to 2.8 mm in intraoral radiographs measurements when comparing both methods. When compared to other imaging modalities, intraoral radiographs presented the same level of accuracy between CBCTs (CBCT = 0.62 and intraoral radiographs = 0.59)[31] and less underestimation of alveolar bone loss when compared to panoramic radiographs (intraoral radiographs underestimation = 13%, panoramic underestimation = 24%) among the included studies.

The moderate to high sensitivity of periapical radiographs in assessing alveolar bone loss for periodontitis, peri-implantitis, and adults undergoing non-surgical periodontal therapy supports a current position paper in the *Journal of Periodontology*, which recommends using intraoral radiographs for periodontal disease assessment.[5] This review suggests that alveolar bone loss measurements via intraoral radiographs is comparable to clinical measurements in positive cases of periodontitis and peri-implantitis. Additionally, these findings support the American Dental Association guidelines for radiographs and align with the Entry-to-Practice Canadian Competencies for Dental Hygienists to obtain radiographs as needed for patient care, in this case periodontal disease.[6,9,54] Beyond the scientific evidence supporting the diagnostic accuracy of intraoral radiographs, it is essential to prioritize minimizing ionizing radiation while ensuring accessible and effective diagnostic methods. When interpreting radiographic findings, dental hygienists must assess whether bone loss is severe or if other complexities warrant referral and possible postponement of clinical intervention.[55] Our findings reinforce the importance of prescribing and selecting radiographs based on comprehensive evaluation including clinical examinations, medical history, and previous imaging.

Clinical translation of our results

Clinical processes and intraoral radiographs likely complement each other in assessing and monitoring periodontal status. In our review, both direct surgical measurement and periodontal probing and tactile assessment of CAL were compared to intraoral radiographs as the reference standard. Intraoral radiographs presented less underestimation when compared to periodontal probing and assessment of CAL than direct surgical measurements.

While the superior diagnostic value of the paralleling technique over the bisecting angle technique for assessing bone loss is well documented,[4,6] half of the studies included in this review did not specify the imaging technique employed. They also overlooked the benefits of vertical bitewings, which gained recognition for bone assessment in the early 2000s.[4] This lack of methodological detail limits our ability to compare outcomes and may contribute to clinically significant discrepancies in bone loss measurements reported across studies, methods potentially confounding the results.

Research during this period demonstrated that vertical bitewings offer superior visualization of interproximal bone loss compared to horizontal bitewings, making them valuable for diagnosing and monitoring periodontal disease.[4,56] Vertical bitewings improve the likelihood of seeing both mandibular and maxillary bone levels with known or suspected moderate to advanced bone loss, presenting a better accuracy in detecting furcation involvement and alveolar bone loss than horizontal bitewings.[57] However, some patients might be less tolerant to vertical bitewings and sometimes report being more uncomfortable when compared to horizontal bitewings.[4,57]

Interestingly, mandibular central incisors showed less underestimation and higher association with actual bone loss, likely due to the imaging technique and acquisition angulation.[44]

Considering that intrasurgical measurements do not represent a routine diagnostic technique, intraoral radiographs are a suitable adjunct to periodontal probing and assessment of CAL assessment method for dental clinicians to assess periodontal status in adults.

Also, among the studies that assessed peri-implantitis, all reported an underestimation of alveolar bone loss when compared to CAL intrasurgical assessment. It has been suggested that demineralization and loss of the alveolar ridge in peri-implantitis cases could negatively influence the accuracy of the radiographic measurements.[46] In this regard, a recent narrative review highlighted that while 2D intraoral radiographs remain essential for assessing alveolar and peri-implant bone, their diagnostic accuracy can be affected by high-density potentially obscuring marginal bone levels.[13] Moreover, although CBCT provides 3D imaging, scientific evidence also points its limitations in evaluating peri-implants bone loss, largely due to significant artifacts-related issues. Therefore, intraoral radiographs continue to be the most appropriate imaging modality for this purpose. However, they should be considered an adjunct rather than a stand-alone diagnostic tool in the comprehensive assessment of periodontal and peri-implant diseases.[13]

Dental hygienists are educated to use radiographs in clinical practice.[14] Previous studies conducted in the United States have supported the use of radiographs in the assessment of periodontal disease and the adherence to the periodontal disease diagnostic guidelines proposed by the AAP in 2018.[58,59] The results of this systematic review align with the competencies and current practices of dental hygienists, suggesting the essential clinical applicability of intraoral radiographs on periodontal assessment performed by dental hygienists.

It is important to incorporate these results in the clinical practice of Canadian dental hygienists. Across the ten provinces and three territories of Canada, seven dental hygiene governing bodies (or licensing authorities) (i.e., Alberta, British Columbia, New Brunswick, Nova Scotia, Newfoundland and Labrador, Prince Edward Island, and Northwest Territories) include the prescription of radiographs within the scope of practice for dental hygienists.[60–66]

Dental hygienists in all jurisdictions across Canada make clinical decisions based on radiographic information. The interpretation of intraoral radiographs remains an essential component of informing dental hygiene process of care decisions within one's scope of practice regardless of who prescribes them.

Extraoral imaging (panoramic radiographs) and advanced imaging

In this review, intraoral radiographs are more accurate than panoramic radiographs for the assessment of periodontal bone loss. Studies have reported that panoramic radiographs can be used in periodontitis case screening but not to replace clinical examinations and comprehensive clinical periodontal assessments.[67,68] Panoramic radiographs have limitations compared to intraoral radiographs including increased magnification, superimposition and reduced spatial resolution.[67] They are therefore less effective than intraoral radiographs for assessing periodontal conditions, especially in the early disease stages. As diagnosis and management could be compromised by using panoramic images as the primary imaging choice for periodontal assessment, intraoral radiographs remain the preferred imaging modality for periodontal assessment in adults.[69]

Although this review did not include studies that exclusively compared intraoral images with advanced imaging, we came across studies that used CBCT as a second method of comparison. Notably, these studies showed that CBCTs present the same level of accuracy as intraoral radiographs for the assessment of periodontal disease. While CBCT has the advantage of representing structures in true dimensions (without superimposition or magnification), it is also subject to beam hardening artifacts and scattering radiation, which can impact the image quality. Not to mention its higher radiation doses compared to 2D imaging, which limits its justification for routine periodontal diagnosis and monitoring.[70] While systematic reviews suggest that advanced imaging offers high accuracy for periodontal assessment compared to surgical measurements, they recommend its use only when intraoral radiographs fail to provide adequate diagnostic information.[68] Our review, however, indicates that intraoral radiographs matches CBCT accuracy to measuring alveolar bone loss while exposing patients to significantly lower radiation doses. To date there is insufficient evidence to support CBCT use and implementation for routine periodontal treatment planning, with experts suggesting CBCT having value only in the management of patients with selected periodontitis scenarios.[13] Additionally, CBCT's resolution limitations and artifacts can impair the visualization of small structures like the alveolar bone crest and thin/limited bone widths.

Intraoral radiographs therefore remain the preferred imaging modality for periodontal assessment in adults compared to CBCT.

Dental hygiene scope of practice and radiographic interpretation

Our findings underscore the critical role of intraoral radiographs in periodontal assessment, not only for diagnostic purposes but also for guiding appropriate planning, therapeutic interventions, and evaluation. Interventions such as non-surgical periodontal therapy, periodontal debridement, scaling and root planning require the dental hygienist to make individualized clinical decisions based on periodontal assessments and diagnoses, which are informed by both clinical and radiographic assessments. However, it is essential to consider the scope of practice for dental hygienists, particularly in Canada, where variations exist across provinces and territories. Nationally, all dental hygienists must determine the need for radiographs, then acquire, develop and interpret them; however, only certain provinces permit dental hygienists to prescribe radiographs and operate their own radiographic equipment. Even so, radiographic competency is a standard requirement on the National Dental Hygiene

Certification Examination.[71] These regulatory differences may impact the extent to which dental hygienists can fully integrate radiographic findings into clinical decision-making and periodontal care. While radiographs are invaluable for identifying periodontal risk factors, such as calculus, bony defects, furcations, bone loss and interproximal restorative defects, they also aid in detecting pathology that may necessitate treatment modifications, postponement, or referral. Understanding these regulatory nuances is crucial when considering the role of radiographs in periodontal treatment planning.

Given the demonstrated importance of proper interpretation in ensuring accurate assessments, these restrictions highlight a potential gap in practice that may affect patient outcomes. Future policy considerations should address the need for expanded training and scope of practice for all Canadian dental hygienists, enabling them to effectively utilize radiographic tools as a component of best practice in managing periodontal care for patients.

Recommendations

Although the strength of evidence varies across the literature addressing the proposed question, the following recommendations are offered based on the current data to assist dental hygienists in making informed decisions about their practice, while ensuring the safety of both their patients and themselves:

- Our findings align with current guidelines, which recommend intraoral radiographs (bitewing (horizontal or vertical) and periapical (paralleling technique)) for assessment of periodontal disease in all stages.[6,9,14] Image prescription, including the image modality, number, type and location, should be individualized and guided by each patient's medical history, past dental history, signs and symptoms and clinical examination, as well as a review of intraoral radiographs

- This position paper emphasizes that intraoral radiographs are superior to panoramic radiographs for assessing periodontal disease. As such, extraoral radiographs should not be the primary imaging choice for this purpose
- Moreover, while intraoral radiographs showed similar results to CBCT, the potential unknown risks of ionizing radiation exposure associated with CBCT compared to intraoral radiographs, as well as CBCT's higher cost and potential artifacts make CBCT unsuitable for routine periodontal assessment

Strengths, limitations and future directions

The systematic review supporting this position paper has strengths and limitations. To our knowledge, a key strength is that this is the first systematic review to comprehensively evaluate the accuracy of intraoral radiographs for periodontal disease assessment, encompassing diagnostic, therapeutic and follow-up phases. However, the review is limited to adult populations, preventing the generalization of findings to pediatric patients. Additionally, most included studies were assessed as having an unclear risk of bias due to missing information, particularly regarding patient selection, information regarding the use of vertical bitewings and the lack of identification of what intraoral technique was used. This issue may stem from the fact that many methodological guidelines for conducting observational and diagnostic studies were only established after 2010,[72,73] while half of the studies included in this review were published before that period.

A possible consequence associated with the lack of standardization was the observed variability in imaging protocols adopted by the included studies. We attempt to minimize the impact of such variability by clearly defining the inclusion criteria. Additionally, our RoB assessment accounted for study setting and standardization of imaging protocols, which helped ensure consistency across diverse study populations.

The least distorted images of teeth and periodontal structures occur when the image receptor is placed as parallel to the long axis of the teeth as possible. The paralleling periapical technique is therefore preferred compared to the bisecting angle technique.[4] Interproximal images (horizontal or vertical bitewings) provide the most accurate distance between the CEJ and the crest of the alveolar bone, with vertical bitewings being particularly useful when there is suspected or known moderate to advanced bone loss.[4] Regarding the known diagnostic value of paralleling over bisecting angle technique for measuring bone loss, few studies (n = 5) did not mention the specific technique used, limiting our capability to analyse this aspect further. This difference in image accuracy between techniques is often overlooked and could be the reason why some studies found a clinically significant discrepancy on measurements. Consequently, the absence of detailed information hampers a definitive assessment of potential biases in the included studies.

Future studies should more clearly outline the techniques and image receptors used. Additionally, this study's findings identified a lack of standardization in defining bone loss landmarks and measurement techniques. This inconsistency poses a challenge when assessing the correlation between radiographic bone loss and clinical attachment levels. Establishing standardized criteria for bone loss assessment in future research would enhance the reliability of findings and improve the ability to draw meaningful conclusions. Standardization would also facilitate comparisons across studies, ultimately strengthening the evidence base for the use of radiographs in periodontal evaluation.

Practical implications of this research findings

The dental hygiene process of care (namely assessment, dental hygiene diagnosis, planning, implementation and evaluation) guides practitioners in delivering client-centred care. The reliance on using available assessments to inform the dental hygiene diagnosis, the determination of the classification of periodontal and peri-implantitis diseases according to the 2018 AAP Classification.[10] Also, to support individualized and appropriate care planning. Radiographic assessments provide essential subgingival information that cannot be obtained through clinical examination alone. Without access to radiographic data, dental hygienists risk making critical errors in patient records, diagnosis, treatment planning and care evaluation. This can result in incomplete or inaccurate diagnoses that potentially overlook oral health issues. Intraoral radiography enables dental hygienists to assess disease progression and activity, calculus formation, root morphology, bony defects, furcation involvement, restorative defects, apical findings and other pathologies. Without this adjunct diagnostic tool, dental hygienists may compromise both their professional responsibility and patient safety by failing to detect crucial oral health conditions. In summary, intraoral radiographs, such as periapical and bitewing images, are essential tools that enable practitioners to provide comprehensive, safe and effective dental hygiene care.

CONCLUSION

This systematic review showed that intraoral radiographs, including periapical and bitewing radiographs, represent a tool with moderate to high sensitivity for periodontal assessment, suggesting they are the most appropriate imaging tool to be used as an adjunct to clinical evaluation for dental professionals. This paper confirms the recommendations of existing guidelines regarding periodontal assessment with intraoral radiographs. Lastly, this review provides an update for dental hygienists regarding the best and most up-to-date clinical evidence on this subject.

ACKNOWLEDGEMENTS

We sincerely thank the CDHA Steering Committee for their valuable contributions, enriched discussions and clarifications. In particular, we acknowledge Sylvie Martel, Kelly Turner, Helen Symons, Veronique Benhamou, Margaret Kreutziger, Kim Haslam and Juliana Jackson - your input was essential for this work. We also extend our appreciation to Carlos Flores-Mir and Graziela De Luca Canto for serving as evidence-based consultants providing their methodological expertise, which greatly contributed to the methodological rigor of this study. We also thank Camila Paiva for contributing as reviewer in the selection and data analysis phase of this review. Finally, we are grateful to Nathalia Fagundes for her dedication and arduous commitment as a lead research associate, whose contributions were integral to this project.

FIGURES AND LEGENDS

Figure 1 - PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources

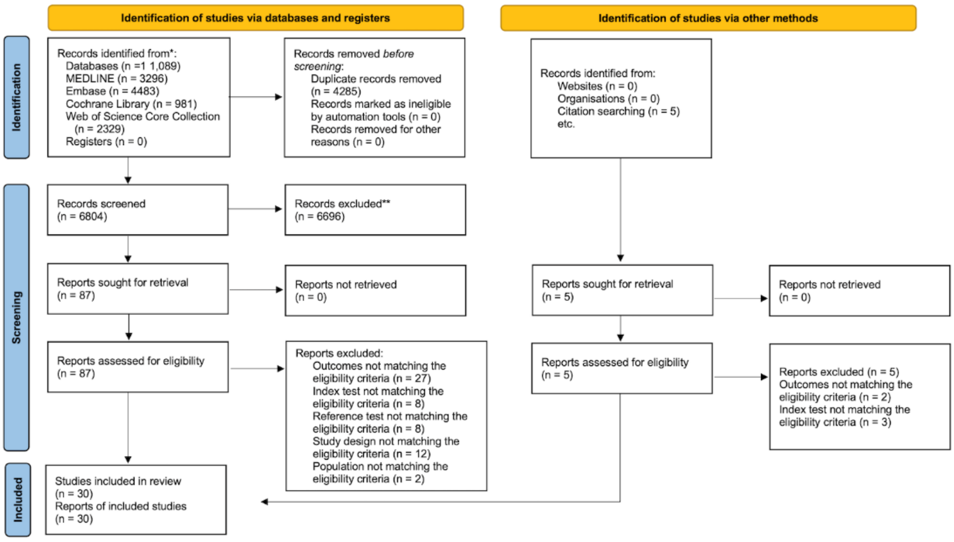

Figure 2 - Main characteristics of included studies

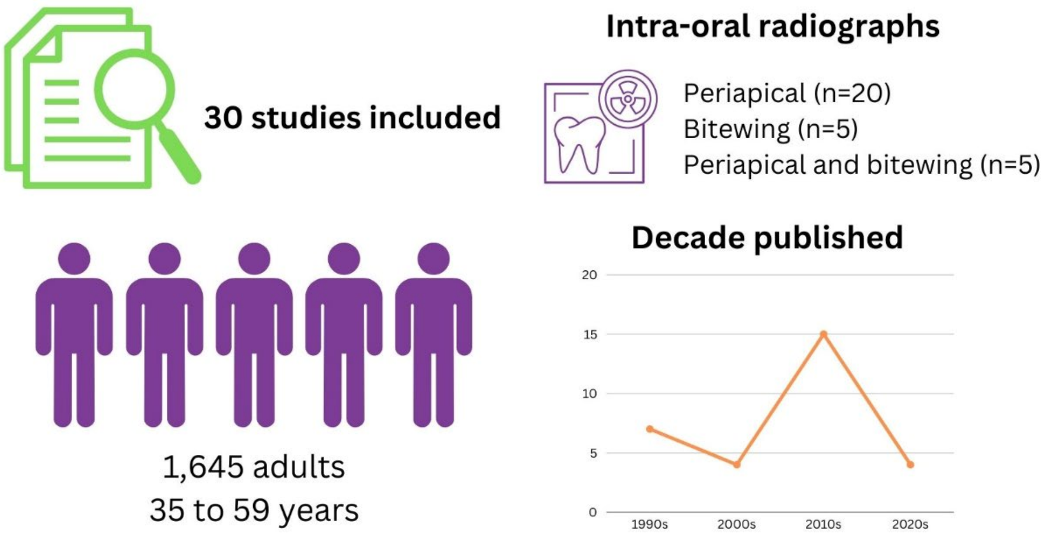

Figure 3 - Summary of main findings regarding the performance of intraoral radiographs in the assessment of periodontal disease

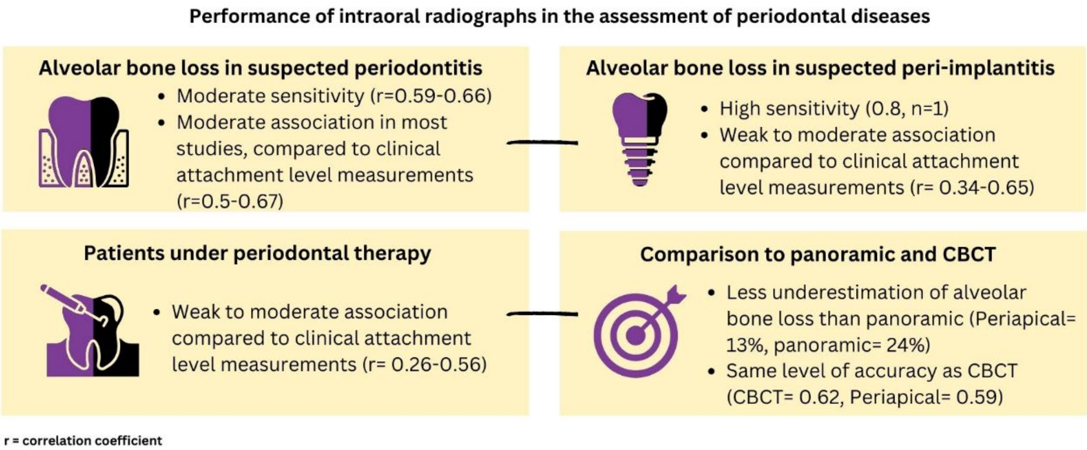

Figure 4 - Assessment of individual risk of bias using QUADAS-C tool

Figure 5 - Assessment of individual risk of bias using QUADAS-2 tool

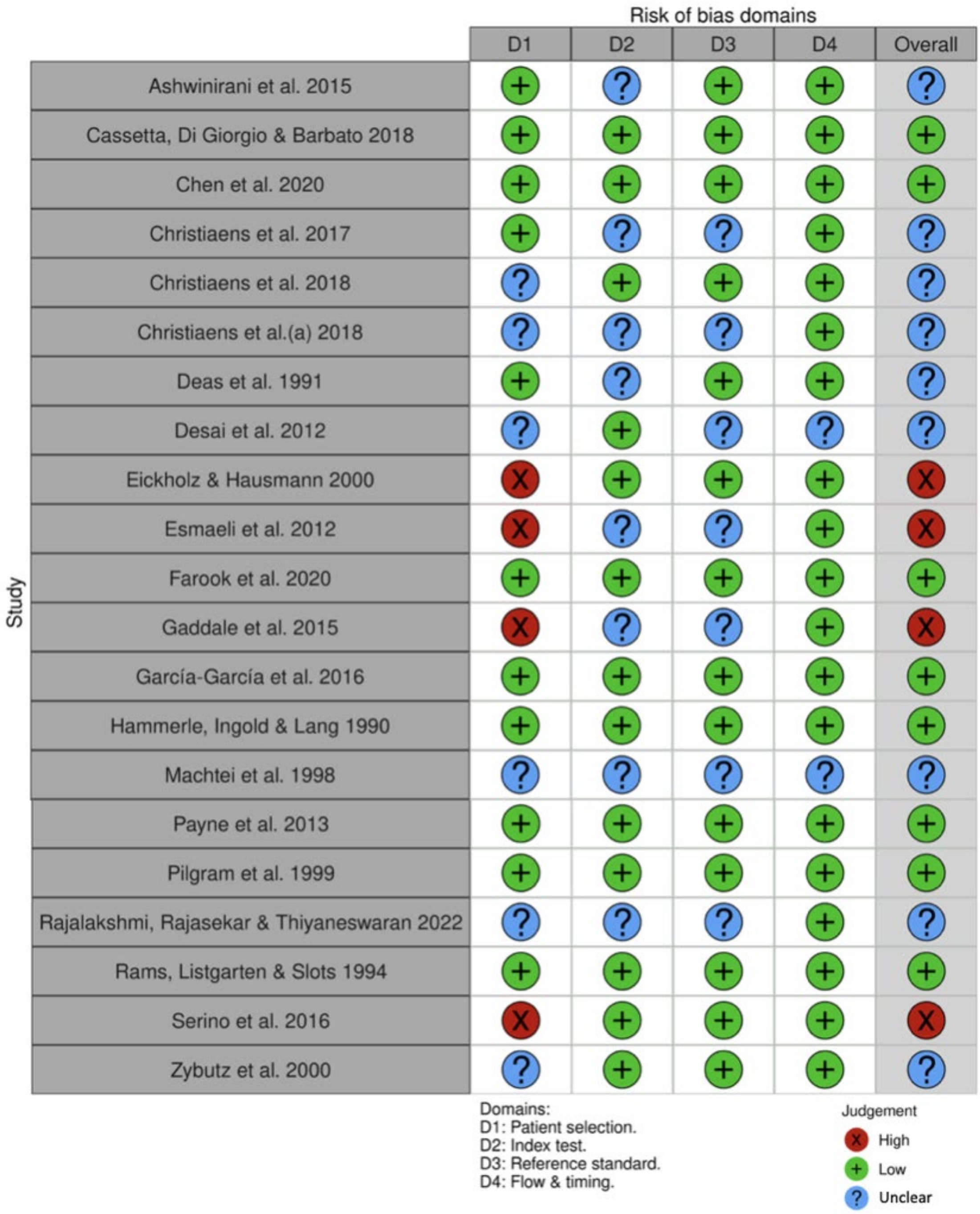

Table 1. Summary characteristics of included studies

Author/ Year/ Country	Study design	Sample		Intraoral radiograph		Comparison	Main results
		N	Timing **	Type	Assessment		
Akesson et al. 1992 Sweden	Non-RCT	23 (237 sites)	1	PA & BTW	Vertical bone loss (occlusal level and the most apical level of the marginal bone).	Probing depth, direct surgical measurements (deepest bone pocket) and panoramic radiographs (same as PA assessment)	PA showed the least underestimation of bone loss, with an average deviation of 13% from the true value, while panoramic radiographs exhibited an average underestimation of 24%.
Ashwinirani et al. 2015 India	Cross-sectional	30 (60 sites)	1	PA	Distance from alveolar crest and base of defect at both mesial and distal sides.	Direct surgical measurements (periodontal probing at mesial and distal sides)	PA underestimated bone loss compared to direct surgical measurements by 2.24 ± 1.14 mm.
Cassetta, Di Giorgio & Barbato 2018 Italy	Prospective cohort	142 (268 implants)	2	PA	Measurement of bone level using a digital system.	Direct surgical measurements	PA showed a correlation= 0.53 for mesial site and 0.34 for distal site ($p < 0.0001$). intraoral radiographs measurements were 0.50± 1.5mm higher than surgical ($p < 0.0001$).
Chen et al. 2020 Taiwan	Prospective cohort	39	1,3	BTW	Distance between root surface and the bone defect surface.	Direct surgical measurements (probing depth, gingival recession, and CAL)	The radiographic defect angle showed a correlation= 0.26 with clinical periodontal parameters for initial CAL and r = 0.24 for final CAL.
Christiaens et al. 2017 Belgium	Cross-sectional	23 (50 implants)	2	PA	Deepest interproximal bone level to the implant-abutment interface	Periodontal probing (vertical distance between implant/abutment interface and the pocket bottom)	PA showed a 2.3 mm mean underestimation compared to intra-surgical. Variability among the examiners varied from 1.4-3.8 mm.
Christiaens et al. 2018 Belgium	Cross-sectional	23 (50 implants) / 17 (49 teeth)	1,2	PA	Goldman and Cohen classification of bone defect	Direct surgical measurements (Goldman and Cohen classification of bone defect)	Sensitivity of PA for bone defect was 0.66 (95% Cl: 0.58, 0.74), and specificity was 0.60 (95% Cl: 0.51, 0.70). Sensitivity of PA for bone defects around implants 0.80 (95% Cl: 0.76, 0.85), and specificity 0.62 (95% Cl: 0.54, 0.70).
Christiaens et al.(a) 2018 Belgium	Cross-sectional	17 (50 interdental sites)	3	PA	Distance from the deepest interdental bone level to the metal wire placed in occlusal level during image taking.	Direct surgical measurements (vertical relative probing attachment level)	The mean underestimation of the bone level was 2.7 mm (± 3.1 mm) for analog radiographs and 2.5 mm (± 2.8 mm) for digital. The analysis revealed that the underestimation was greater in premolar and molar regions.
Deas et al. 1991 USA	Prospective cohort	21 (2,094 sites)	1	BTW	Subtraction of average gray levels of all 2 x 2-pixel areas in the baseline and experimental images.	Periodontal probing (CAL)	21% of radiographic complexes showed an attachment loss equal to or greater than 2 mm, and of those, 32 (or 54%) demonstrated loss of bone density.

Author/ Year/ Country	Study design	Sample		Intraoral radiograph		Comparison	Main results
		N	Timing **	Type	Assessment		
Desai et al. 2012 India	Prospective cohort	78 (120 sites)	1	PA	CEJ to alveolar crest, CEJ to apical extension of the bony defect, furcation fornix to interradicular bone level.	Periodontal probing (pocket depth and CAL)	In maxillary and mandibular molars, a positive association between radiographic bone defect height at the mesiobuccal and distobuccal site was observed in the interdental region.
Eickholz & Hausmann 2000 Germany	Cross-sectional	22 (34 sites)	1	BTW	Distance between CEJ and the most apical extension of the bony defects.	Periodontal probing at 6 sites per tooth. Probing depth and vertical attachment levels. Direct surgical measurements.	The radiograph underestimated interproximal bone loss by an average of 1.4 mm with a standard deviation of ± 2.6 mm when compared to the direct surgical measurement.
Esmaeli et al. 2012 Iran	Cross-sectional	NI (20 defects)	1	PA	Linear measurements of defect depth, defect width and defect angle.	Direct surgical measurements (assessment of depth, angle, and width of interproximal bone defects)	High correlation ($r= 0.88$, $p < 0.001$) was detected between radiographic and clinical measurements. Small discrepancies were observed between methods, with an average of 1.41 mm for the angle, 0.24 mm for depth, and 0.42 mm for width.
Farook et al. 2020 Saudi Arabia	Cross-sectional	104 (880 sites)	1	PA	Distance between the apical part of alveolar crest to CEJ	Periodontal probing (CAL)	A correlation of 0.5 was detected between clinical and intraoral radiographs for assessing alveolar bone level in PA. A moderate reliability (ICC=0.68) was observed between CAL and PA.
Gaddale et al. 2015 India	Cross-sectional	40	1	PA	Distance from CEJ to the alveolar crest)	Periodontal probing (probing depth and CAL).	The correlation between probing depth and the crestal bone level was moderate ($r=0.67$).
García-García et al. 2016 Spain	Cross-sectional	25 (55 implants)	2	PA	Intra-bony and supracrestal components of the defect, total vertical radiographic bone level, defect width.	Periodontal probing (Measurement of intra-bony and supracrestal components of the defect, Total vertical intra-operative bone level, Defect width).	Significant difference between radiographic and surgical bone loss ($p = 0.014$).
Gedik, Marakoglu & Demirer 2008 Turkey	Cross-sectional	21 (21 teeth)	1,3	PA & BTW	Distance from the CEJ to the alveolar crest.	Periodontal probing (CEJ to alveolar crest, identifying the deepest alveolar defect in first mandibular molars), Panoramic radiographs (CEJ to the alveolar crest).	BTW had the highest accuracy 2.34 ± 0.98 mm before surgery and 2.11 ± 1.06 mm after (an average 0.22 ± 0.87 mm, $p < 0.05$), when compared to performances of panoramic and PA.
Graetz et al. 2014 Germany	Retrospective cohort	215 (834 molars)	1	PA	Assessment of furcation involvement (Hamp classification)	Periodontal probing, Panoramic radiographs. Direct surgical measurements (Furcation involvement assessed by Hamp et al. classification),	The agreement of surgical measurement and radiographs was k= 0.555 for panoramic and k=0.52 for PA.

Author/ Year/ Country	Study design	Sample		Intraoral radiograph		Comparison	Main results
		N	Timing **	Type	Assessment		
Grimard et al. 2009 USA	RCT	29 (35 bone defects)	3	PA	Distance between CEJ to alveolar crest and distance from CEJ to base of the defect	Direct surgical measurements and CBCT (Distance between CEJ to alveolar crest; CEJ to base of the defect).	The difference between surgical and PA measurements were overestimated (1.5 – 2.3 mm, p<0.05). Differences in defect fill between surgical and PA measurements were not statistically significant.
Hammerle, Ingold & Lang 1990 Switzerland	Prospective cohort	68	1	PA	Distance from the CEJ to the marginal alveolar crest	Periodontal probing (pocket probing depth and CAL - Ramfjord 1959 methodology).	The comparison of the different clinical and radiographic parameters showed the best correlations between the various radiographic measurements of bone heights (r=0.87; r=0.86).
Machtei et al. 1998 USA	Non-RCT	108	3	PA	Measurement of alveolar crestal height	Periodontal probing (probing depth, relative attachment level, CAL, distance from the CEJ to clinical base of the pocket)	For percentile of gaining sites, a positive (r= 0.40, p = 0.0001) correlation was observed between alveolar gain detected from intraoral radiographs and periodontal probing.
Pahwa et al. 2015 India	Prospective cohort	15 (31 defects)	1	PA	Distance from CEJ to the base of defect, and CEJ to alveolar crest.	Surgical periodontal probing (CEJ to alveolar crest, CEJ to base of defect) and CT (most coronal aspect of the defect-associated alveolar crest, most apical point from base of defect)	In vertical defects, 96% of intraoral radiographs showed underestimation, while 71% of defects measured with CT overestimated in the maximum percentage of sites.
Payne et al. 2013 USA	RCT	117	1	BTW	Subtraction of average gray levels of all 2 x 2 pixel areas	Periodontal probing (CAL)	Baseline relative CAL and PD were positively associated with baseline radiographic alveolar bone height loss (P <0.0001).
Pepelassi et al. 1997 Greece	Cross-sectional	100 (2536 teeth, 5072 sites)	1	PA	Distance between CEJ and alveolar crest; percentage of osseous destruction according to Schei method.	Periodontal probing (pocket depth and CAL). Panoramic radiographs (CEJ to alveolar crest). Surgical measurements (CEJ and the alveolar crest).	The mean difference in osseous destruction between panoramic (0.39 mm) and surgical assessment was statistically significantly higher than the difference between periapical (0.01 mm) and surgical assessment.
Pilgram et al. 1999 USA	RCT	85	1	BTW	Distance from CEJ to the alveolar crest	Periodontal probing (Width of Keratinized gingiva, peri-implant probing depth, CAL).	The correlations between probing attachment changes and radiographic bone changes were very weak for individual measurements (r < .05 in all cases).
Rajalakshmi, Rajasekar & Thiyaneswaran 2022 India	Cross-sectional	35	2	PA	Distance from the alveolar bone margin and the abutment's coronal portion	Periodontal probing (probing depth and recession) at 6 sites per tooth: mesial edge, midtooth, and distal edge on both facial and lingual sides.	There was a negative correlation between the keratinized gingiva width and he radiographic bone loss (p<0.0001, r= -0.74)

Author/ Year/ Country	Study design	Sample		Intraoral radiograph		Comparison	Main results
		N	Timing **	Type	Assessment		
Rams, Listgarten & Slots 1994 USA	Retrospective cohort	51 (1809 sites)	1,3	PA & BTW	Presence of absence of intact crestal lamina dura	Periodontal probing (Probing depth and relative attachment level measured at mesial, distal, vestibular and oral surfaces.	Absence of detectable crestal lamina dura on baseline radiographs exhibited relatively high sensitivity (87-100%), but low specificity (17%) and low positive predictive values (0.8-3.2%), for localized periodontitis disease recurrence.
Serino et al. 2016 Sweden	Retrospective cohort	24 (46 implants)	2	PA	Distance from fixture–abutment junction to the bone level.	Periodontal probing (bone loss at implants after open flap peri-implant-surgery).	intraoral radiographs measurements had a moderate correlation with the clinical bone loss as (r=0.55-0.65). A difference of about 1–2 mm in the estimation of radiographic bone loss was observed.
Yusof et al. 2021 Malaysia	RCT	22	1	PA	Vertical bone loss, CAL, root trunk, and furcation width.	Intrasurgical and CBCT measurements (horizontal and vertical bone loss, CAL, root trunk, and furcation width	The sensitivity for CBCT measurements was 62.8% and the sensitivity for periapical radiograph was 56.9%.
Zhang, Rajani & Wang 2017 USA	Cross-sectional	80	1	PA & BTW	CEJ–crest distances for mesial and distal sites	Periodontal probing (probing depth, free gingival margin to CEJ, CAL), CBCT (CEJ–crest distance in both the buccal and lingual/palatal sides)	Spearman's correlation analysis revealed highly significant positive correlations between CBCT and CAL, CBCT and PA/BTW, and CAL and PA/BTW.
Zhang, Foss & Wang 2018 USA	Cross-sectional	51	1	PA & BTW	Triangular radiolucency at the furcation area, and/or alveolar bone level	Molar furcation involvement (modified Glickman's classification).	There were weak to moderate correlations between clinical detection and intraoral radiographs, clinical detection and CBCT, as well as intraoral radiographs and CBCT at all the measured sites (r values range between 0.230 to 0.644, p<0.05).
Zybutz et al. 2000 USA	Cross-sectional	29 (57 deffects)	1	PA	Surgical and clinical measurements (CEJ or another fixed reference to the bottom of the defect, and distance from bone crest to the bottom of the defect).	Probing depth, probing attachment level, at the deepest site (from CEJ or other fixed reference point); relative attachment level.	intraoral radiographs underestimate bone level and defect depth by 1.4 mm. The interpretation of periodontal changes between baseline and 12 months after treatment by probing to bone, or PAL measurements, or from radiographic images yield almost identical results.

SD= Standard deviation, NI= Not informed, PA= periapical radiograph, BTW= bitewing radiograph, CBCT= Cone-beam computed tomography, CT= Computed Tomography, CEJ= Cemento Enamel Junction; CAL= Clinical Attachment Level.
****Timing:** 1- Assessment (periodontitis), 2-Assessment (peri-implantitis), 3-Treatment outcomes.

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APPENDICES

Table S1: Search strategies adopted in each database

Database	**Search Strategy**
MEDLINE Ovid MEDLINE(R) ALL 1946 to Aug 01, 2024	1. radiography, dental/ or radiography, bitewing/ or radiography, dental, digital/ or radiography, panoramic/ 2. (dental radiograph* or dental radiolog*).mp. 3. ((intraoral or intra-oral or periapical) adj (digital or radiograph* or radiology or radiologic* or imag* or x-ray* or xray*)).mp. 4. ((bitewing or bite-wing) adj (digital or radiograph* or radiology or radiologic* or imag* or x-ray* or xray*)).mp. 5. ((digital or panoramic) adj (radiograph* or radiology or radiologic* or x-ray* or xray*)).mp. 6. or/1-5 7. exp Periodontal Diseases/di, dg, th [Diagnosis, Diagnostic Imaging, Therapy] 8. periodont*.tw,kf. 9. paradont*.mp. 10. (gingivitis or gingiva*).mp. 11. exp Alveolar Bone Loss/ 12. ((dental or alveolar) adj3 bone loss).mp. 13. or/7-12 14. 6 and 13 15. exp Artificial Intelligence/ or (AI or "artificial intelligence" or AIVI or "classification algorithm*" or "computer heuristic*" or "convolutional network*" or DALL-E or "decision support system*" or "decision tree" or DeepAI or "deep learning" or "data science" or "feature detection" or "generative pre-trained transformer" or "generative pretrained transformer" or Invideo or "language learning model*" or "large language model*" or "learning algorithm*" or "machine learning" or (Markov adj3 model*) or Midjourney or ((multifactor* or multicriteria) adj3 ("decision analysis" or "decision making")) or "natural language process*" or "nearest neighbo*" or "neural network*" or "outlier detection" or "pattern recognition" or Perplexity or "probability tree" or "random forest" or "representation learning" or Runway AI or Runway Gen-1 or "Stable Diffusion" or "support vector machine*" or "transfer learning" or "Bing chat" or ChatGPT* or "Chat GPT" or "Google* Bard" or "Google* Gemini" or "IBM Watson" or "Microsoft* Bing" or "Microsoft* Copilot" or OpenAI or "Open AI" or PathAI or "Path AI").mp. 16. animals/ not (animals/ and humans/) 17. exp models animal/ 18. (veterinary or rabbit or rabbits or animal or animals or mouse or mice or rodent or rodents or rat or rats or murine or hamster* or pig or pigs or piglets or swine or porcine or horse* or equine or cow or cows or cattle or bovine or goat or goats or sheep or lambs or ovine or monkey or monkeys or trout or marmoset$1 or canine or dog or dogs or feline or cat or cats or zebrafish or case report or case series).ti.

	19. limit 14 to (case reports or clinical conference or clinical trial, veterinary or clinical trial protocol or comment or congress or editorial or letter) 20. limit 14 to "books and documents" 21. or/15-20 [Exclude] 22. 14 not 21 23. limit 22 to english language
Embase Ovid Embase 1974 to 2024 Aug 01	1. tooth radiography/ or panoramic radiography/ 2. (dental radiograph* or dental radiolog*).mp. 3. ((intraoral or intra-oral or periapical) adj (digital or radiograph* or radiology or radiologic* or imag* or x-ray* or xray*)).mp. 4. ((bitewing or bite-wing) adj (digital or radiograph* or radiology or radiologic* or imag* or x-ray* or xray*)).mp. 5. ((digital or panoramic) adj (radiograph* or radiology or radiologic* or x-ray* or xray*)).mp. 6. or/1-5 7. exp periodontal disease/di, rt, th [Diagnosis, Radiotherapy, Therapy] 8. periodont*.tw,kw. 9. paradont*.mp. 10. (gingivitis or gingiva*).mp. 11. exp Alveolar Bone Loss/ 12. ((dental or alveolar) adj3 bone loss).mp. 13. or/7-12 14. 6 and 13 15. exp artificial intelligence/ or exp deep learning/ or exp machine learning/ or (AI or "artificial intelligence" or AIVI or "classification algorithm*" or "computer heuristic*" or "convolutional network*" or DALL-E or "decision support system*" or "decision tree" or DeepAI or "deep learning" or "data science" or "feature detection" or "generative pre-trained transformer" or "generative pretrained transformer" or Invideo or "language learning model*" or "large language model*" or "learning algorithm*" or "machine learning" or (Markov adj3 model*) or Midjourney or ((multifactor* or multicriteria) adj3 ("decision analysis" or "decision making")) or "natural language process*" or "nearest neighbo*" or "neural network*" or "outlier detection" or "pattern recognition" or Perplexity or "probability tree" or "random forest" or "representation learning" or Runway AI or Runway Gen-1 or "Stable Diffusion" or "support vector machine*" or "transfer learning" or "Bing chat" or ChatGPT* or "Chat GPT" or "Google* Bard" or "Google* Gemini" or "IBM Watson" or "Microsoft* Bing" or "Microsoft* Copilot" or OpenAI or "Open AI" or PathAI or "Path AI").mp. 16. animal/ not (animal/ and human/) 17. exp animal model/ 18. (veterinary or rabbit or rabbits or animal or animals or mouse or mice or rodent or rodents or rat or rats or murine or hamster* or pig or pigs or piglets or swine or porcine or horse* or equine or cow or cows or cattle or bovine or goat or goats or sheep or lambs or ovine or monkey or monkeys or trout or marmoset$1 or canine or dog or dogs or feline or cat or cats or zebrafish or case report or case series).ti. 19. limit 14 to (books or chapter or conference abstract or conference paper or editorial or letter or note)

	20. limit 14 to (book or book series or conference proceeding) 21. limit 14 to conference abstracts 22. or/15-21 [Exclude] 23. 14 not 22 24. limit 23 to english language
Cochrane Library via Wiley	#1 [mh "radiography, dental"] or [mh "radiography, bitewing"] or [mh "radiography, dental, digital"] or [mh "radiography, panoramic"] #2 dental NEXT radiograph* or dental NEXT radiolog* #3 ((intraoral or intra-oral or periapical) NEAR/1 (digital or radiograph* or radiology or radiologic* or imag* or x-ray* or xray*)) #4 ((bitewing or bite-wing) NEAR/1 (digital or radiograph* or radiology or radiologic* or imag* or x-ray* or xray*)) #5 ((digital or panoramic) NEAR/1 (radiograph* or radiology or radiologic* or x-ray* or xray*)) #6 12-#5 #7 MeSH descriptor: [Periodontal Diseases] explode all trees and with qualifier(s): [therapy - TH, diagnostic imaging - DG, diagnosis - DI] #8 periodont* #9 paradont* #10 gingivitis or gingiva* #11 [mh "Alveolar Bone Loss"] #12 ((dental or alveolar) NEAR/3 bone loss) #13 5-#12 #14 #6 AND #13 #15 [mh "Artificial Intelligence"] or (AI or "artificial intelligence" or AIVI or (classification NEXT algorithm*) or (computer NEXT heuristic*) or (convolutional NEXT network*) or DALL-E or (decision support NEXT system*) or "decision tree" or DeepAI or "deep learning" or "data science" or "feature detection" or (pre-trained NEXT transformer*) or (pretrained NEXT transformer*) or (hybrid NEXT protocol*) or Invideo or (language learning NEXT model*) or (large language NEXT model*) or (learning NEXT algorithm*) or "machine learning" or (Markov NEAR/3 model*) or Midjourney or ((multifactor* or multicriteria) NEAR/3 ("decision analysis" or "decision making")) or (natural language NEXT process*) or (nearest NEXT neighbo*) or (neural NEXT network*) or "outlier detection" or "pattern recognition" or Perplexity or "probability tree" or "random forest" or "representation learning" or "Runway AI" or "Runway Gen-1" or "Stable Diffusion" or (support vector NEXT machine*) or "transfer learning" or "Bing chat" or ChatGPT* or "Chat GPT" or (Google* NEXT Bard) or (Google* NEXT Gemini) or "IBM Watson" or (Microsoft* NEXT Bing) or (Microsoft* NEXT Copilot) or OpenAI or "Open AI" or PathAI or "Path AI") #16 [mh animals] NOT ([mh animals] AND [mh humans]) #17 (veterinary or rabbit or rabbits or animal or animals or mouse or mice or rodent or rodents or rat or rats or murine or hamster* or pig or pigs or piglets or swine or porcine or horse* or equine or cow or cows or cattle or bovine or goat or goats or sheep or lambs or ovine or monkey or monkeys or trout or marmoset* or canine or dog or dogs or feline or cat or cats or zebrafish or case report or case series):ti

	#18 {OR #15-#17} #19 #14 NOT #18 Limit: English Language
Web of Science Core Collection	(TS=("dental radiograph*" or "dental radiolog*" or ((intraoral or intra-oral or periapical) NEAR/1 (digital or radiograph* or radiology or radiologic* or imag* or x-ray* or xray*)) or ((bitewing or bite-wing) NEAR/1 (digital or radiograph* or radiology or radiologic* or imag* or x-ray* or xray*)) or ((digital or panoramic) NEAR/1 (radiograph* or radiology or radiologic* or x-ray* or xray*))) AND TS=(periodont* or paradont* or gingivitis or gingiva* or ((dental or alveolar) NEAR/3 bone loss))) NOT (TS=(AI or "artificial intelligence" or AIVI or "classification algorithm*" or "computer heuristic*" or "convolutional network*" or DALL-E or "decision support system*" or "decision tree" or DeepAI or "deep learning" or "data science" or "feature detection" or "generative pre-trained transformer" or "generative pretrained transformer" or Invideo or "language learning model*" or "large language model*" or "learning algorithm*" or "machine learning" or (Markov NEAR/3 model*) or Midjourney or ((multifactor* or multicriteria) NEAR/3 ("decision analysis" or "decision making")) or "natural language process*" or "nearest neighbo*" or "neural network*" or "outlier detection" or "pattern recognition" or Perplexity or "probability tree" or "random forest" or "representation learning" or Runway AI or Runway Gen-1 or "Stable Diffusion" or "support vector machine*" or "transfer learning" or "Bing chat" or ChatGPT* or "Chat GPT" or "Google* Bard" or "Google* Gemini" or "IBM Watson" or "Microsoft* Bing" or "Microsoft* Copilot" or OpenAI or "Open AI" or PathAI or "Path AI") OR TI=(veterinary or rabbit or rabbits or animal or animals or mouse or mice or rodent or rodents or rat or rats or murine or hamster* or pig or pigs or piglets or swine or porcine or horse* or equine or cow or cows or cattle or bovine or goat or goats or sheep or lambs or ovine or monkey or monkeys or trout or marmoset* or canine or dog or dogs or feline or cat or cats or zebrafish or case report or case series) Refined by: English language Exclude: Document Types - Proceeding Paper, Meeting Abstract, Editorial Material, Letter, Note
Google Scholar (sorted "by relevance") Without filters	("dental radiography" OR "dental radiological" OR intraoral imaging OR intra-oral x-rays OR bitewing radiographs OR panoramic radiology) AND (periodontal OR paradontal OR gingivitis OR gingiva OR alveolar bone loss) -artificial intelligence -deep learning -AI

Table S2- Articles excluded after full-text evaluation, with reasons (n=57)

Article excluded	**Reason**[a]
Alazmi SO, Almutairi FJ, Alresheedi BA. Comparison of Peri-Implant Clinicoradiographic Parameters among Non-Smokers and Individuals Using Electronic Nicotine Delivery Systems at 8 Years of Follow-up. Oral Health Prev Dent. 2021 Sep 30;19:511-516.	1
Albandar JM, Abbas DK, Waerhaug M, Gjermo P. Comparison between standardized periapical and bitewing radiographs in assessing alveolar bone loss. Community Dent Oral Epidemiol. 1985 Aug;13(4):222-5.	1
Alberti A, Morandi B, Frascolino C, Cavalli N, Francetti L, Corbella S. The Morphology of Peri-Implantitis Bone Defects: A Retrospective Study on Periapical Radiographs. Int J Dent. 2024 Apr 30;2024:4324114.	1
Alharthi SS, BinShabaib MS, Ahmed HB, Mehmood A, Khan J, Javed F. Comparison of peri-implant clinical and radiographic inflammatory parameters among cigarette and waterpipe (narghile) smokers and never-smokers. J Periodontol. 2018 Feb;89(2):213-218.	2
Bishop K, Dummer PM, Kingdom A, Newcombe RG, Addy M. Radiographic alveolar bone loss from posterintraoral radiographs teeth in young adults over a 4-year period. J Clin Periodontol. 1995 Nov;22(11):835-41.	3
Brägger U, Hugel-Pisoni C, Bürgin W, Buser D, Lang NP. Correlations between radiographic, clinical and mobility parameters after loading of oral implants with fixed partial dentures. A 2-year longitudinal study. Clin Oral Implants Res. 1996 Sep;7(3):230-9.	1
Chan M, Dadul T, Langlais R, Russell D, Ahmad M. Accuracy of extraoral bite-wing radiography in detecting proximal caries and crestal bone loss. J Am Dent Assoc. 2018 Jan;149(1):51-58.	3
Corpas Ldos S, Jacobs R, Quirynen M, Huang Y, Naert I, Duyck J. Peri-implant bone tissue assessment by comparing the outcome of intra-oral radiograph and cone beam computed tomography analyses to the histological standard. Clin Oral Implants Res. 2011 May;22(5):492-9.	4
de Faria Vasconcelos K, Evangelista KM, Rodrigues CD, Estrela C, de Sousa TO, Silva MA. Detection of periodontal bone loss using cone beam CT and intraoral radiography. Dentomaxillofac Radiol. 2012 Jan;41(1):64-9.	1
de Paula-Silva FW, Wu MK, Leonardo MR, da Silva LA, Wesselink PR. Accuracy of periapical radiography and cone-beam computed tomography scans in diagnosing apical periodontitis using histopathological findings as a gold standard. J Endod. 2009 Jul;35(7):1009-12.	4
Duinkerke AS, Van de Poel AC, Purdell-Lewis DJ, Doesburg WH. Estimation of alveolar crest height using routine periapical dental radiographs. Oral Surg Oral Med Oral Pathol. 1986 Nov;62(5):603-6.	2
French D, Grandin HM, Ofec R. Retrospective cohort study of 4,591 dental implants: Analysis of risk indicators for bone loss and prevalence of peri-implant mucositis and peri-implantitis. J Periodontol. 2019 Jul;90(7):691-700.	1
Fukuda CT, Carneiro SR, Alves VT, Pustiglioni FE, De Micheli G. Radiographic alveolar bone loss in patients undergoing periodontal maintenance. Bull Tokyo Dent Coll. 2008 Aug;49(3):99-106.	3
Furkart AJ, Dove SB, McDavid WD, Nummikoski P, Matteson S. Direct digital radiography for the detection of periodontal bone lesions. Oral Surg Oral Med Oral Pathol. 1992 Nov;74(5):652-60.	2
Galal A, Manson-Hing L, Jamison H. A comparison of combinations of clinical and radiographic examinations in evaluation of a dental clinic population. Oral Surg Oral Med Oral Pathol. 1985 Nov;60(5):553-61	5
Green PT, Mol A, Moretti AJ, Tyndall DA, Kohltfarber HB. Comparing the diagnostic efficacy of intraoral radiography and cone beam computed tomography volume registration in the detection of	2

mandibular alveolar bone defects. Oral Surg Oral Med Oral Pathol Oral Radiol. 2019 Aug;128(2):176-185	
Griffiths GS, Brägger U, Fourmousis I, Sterne JA. Use of an internal standard in subtraction radiography to assess initial periodontal bone changes. Dentomaxillofac Radiol. 1996 Apr;25(2):76-81.	2
Gröndahl K, Sundén S, Gröndahl HG. Inter- and intraobserver variability in radiographic bone level assessment at Brånemark fixtures. Clin Oral Implants Res. 1998 Aug;9(4):243-50.	1
Hausmann E, Allen K, Clerehugh V. What alveolar crest level on a bite-wing radiograph represents bone loss? J Periodontol. 1991 Sep;62(9):570-2.	2
Hong RY, Kwon S, Steffensen B, Jain S, Levi PA Jr. Diagnosing periodontal and dental indicators with horizontal and vertical bitewing radiographs. J Dent Educ. 2020 May;84(5):552-558.	5
Hou GL, Hung CC, Yang YH, Chen YC, Tsai CC, Shieh TY. Periodontal bone loss in Chinese subjects with untreated early-onset and adult periodontitis: a cross-sectional study using digital scanning radiographic image analysis. Kaohsiung J Med Sci. 2002 Oct;18(10):500-7.	1
Jenkins WM, Brocklebank LM, Winning SM, Wylupek M, Donaldson A, Strang RM. A comparison of two radiographic assessment protocols for patients with periodontal disease. Br Dent J. 2005 May 14;198(9):565-9; discussion 557; quiz 586.	5
Joly JC, Palioto DB, de Lima AF, Mota LF, Caffesse R. Clinical and radiographic evaluation of periodontal intrabony defects treated with guided tissue regeneration. A pilot study. J Periodontol. 2002 Apr;73(4):353-9	1
Kattimani VS, Bajantai NV, Sriram SK, Sriram RR, Rao VK, Desai PD. Observer strategy and radiographic classification of healing after grafting of cystic defects in maxilla: a radiological appraisal. J Contemp Dent Pract. 2013 Mar 1;14(2):227-32.	3
Khocht A, Janal M, Harasty L, Chang KM. Comparison of direct digital and conventional intraoral radiographs in detecting alveolar bone loss. J Am Dent Assoc. 2003 Nov;134(11):1468-75.	1
Kim DM, Badovinac RL, Lorenz RL, Fintraoral radiographsellini JP, Weber HP. A 10-year prospective clinical and radiographic study of one-stage dental implants. Clin Oral Implants Res. 2008 Mar;19(3):254-8.	1
Kim TS, Obst C, Zehaczek S, Geenen C. Detection of bone loss with different X-ray techniques in periodontal patients. J Periodontol. 2008 Jul;79(7):1141-9.	1
Komšić S, Plančak D, Kašaj A, Puhar I. A Comparison of Clinical and Radiological Parameters in the Evaluation of Molar Furcation Involvement in Periodontitis. Acta Stomatol Croat. 2019 Dec;53(4):326-336.	5
Korkmaz MZ, Altin A, Günaçar DN, Köse TE. Comparison of trabecular bone structure in individuals with healthy periodontium and stage III/IV, grade C periodontitis by fractal analysis. Oral Surg Oral Med Oral Pathol Oral Radiol. 2023 Mar;135(3):427-432.	5
Lam J, Yeung AWK, Acharya A, Fok C, Fok M, Pelekos G. Comparison between Conventional Modality Versus Cone-Beam Computer Tomography on the Assessment of Vertical Furcation in Molars. Diagnostics. 2023; 13(1), 106.	3
Latcham NL, Powell RN, Jago JD, Seymour GJ, Aitken JF. A radiographic study of chronic periodontitis in 15 year old Queensland children. J Clin Periodontol. 1983 Jan;10(1):37-45.	3
Mahasneh SA, Goodwin M, Pretty I, Cunliffe J. The use of radiographs to assess the impact of the distance between the contact area and the crest of the bone to predict the presence or absence of interdental papilla: an in vivo study. Br Dent J. 2023 Aug 21.	2
Mailoa J, Arnett M, Chan HL, George FM, Kaigler D, Wang HL. The Association Between Buccal Mucosa Thickness and Periimplant Bone Loss and Attachment Loss: A Cross-Sectional Study. Implant Dent. 2018 Oct;27(5):575-581.	1
Mengel R, von Rosen CS, Mogk M, Thöne-Mühling M. Correlation between crestal bone loss and PPD at teeth and implants: a 5- to 20-year long-term cohort study in patients with treated periodontal disease. Quintessence Int. 2023 Sep 19;54(8):612-620.	1

Merchant AT, Pitiphat W, Parker J, Joshipura K, Kellerman M, Douglass CW. Can nonstandardized bitewing radiographs be used to assess the presence of alveolar bone loss in epidemiologic studies? Community Dent Oral Epidemiol. 2004 Aug;32(4):271-6.	5
Natto ZS, Olwi A, Abduljawad F. A comparison of the horizontal and vertical bitewing images in detecting approximal caries and interdental bone loss in posterintraoral radiographs teeth: A diagnostic accuracy randomized cross over clinical trial. J Dent Sci. 2023 Apr;18(2):645-651.	5
Nieri M, Muzzi L, Cattabriga M, Rotundo R, Cairo F, Pini Prato GP. The prognostic value of several periodontal factors measured as radiographic bone level variation: a 10-year retrospective multilevel analysis of treated and maintained periodontal patients. J Periodontol. 2002 Dec;73(12):1485-93.	1
Okano T, Mera T, Ohki M, Ishikawa I, Yamada N. Digital subtraction of radiograph in evaluating alveolar bone changes after initial periodontal therapy. Oral Surg Oral Med Oral Pathol. 1990 Feb;69(2):258-62.	1
Papapanou PN, Lindhe J. Preservation of probing attachment and alveolar bone levels in 2 random population samples. J Clin Periodontol. 1992 Sep;19(8):583-8.	2
Papapanou PN, Wennström JL, Johnsson T. Evaluation of a radiographic partial recording system assessing the extent and severity of periodontal destruction. Community Dent Oral Epidemiol. 1991 Dec;19(6):318-20.	1
Pecoraro M, Azadivatan-le N, Janal M, Khocht A. Comparison of observer reliability in assessing alveolar bone height on direct digital and conventional radiographs. Dentomaxillofac Radiol. 2005 Sep;34(5):279-84.	1
Persson RE, Tzannetou S, Feloutzis AG, Brägger U, Persson GR, Lang NP. Comparison between panoramic and intra-oral radiographs for the assessment of alveolar bone levels in a periodontal maintenance population. J Clin Periodontol. 2003 Sep;30(9):833-9.	1
Pitiphat W, Crohin C, Williams P, Merchant AT, Douglass CW, Colditz GA, Joshipura KJ. Use of preexisting radiographs for assessing periodontal disease in epidemiologic studies. J Public Health Dent. 2004 Fall;64(4):223-30.	3
Ricci G, Aimetti M, Stablum W, Guasti A. Crestal bone resorption 5 years after implant loading: clinical and radiologic results with a 2-stage implant system. Int J Oral Maxillofac Implants. 2004 Jul-Aug;19(4):597-602.	1
Rise J, Albandar JM. Pattern of alveolar bone loss and reliability of measurements of the radiographic technique. Acta Odontol Scand. 1988 Aug;46(4):227-32.	1
Rohlin M, Akesson L, Hakansson J, Hakansson H, Nasstrom K. Comparison between panoramic and periapical radiography in the diagnosis of periodontal bone loss. Dentomaxillofac Radiol. 1989 May;18(2):72-6.	1
Rohlin M, Akesson L, Hakansson J, Hakansson H, Nasstrom K. Comparison between panoramic and periapical radiography in the diagnosis of periodontal bone loss. Dentomaxillofac Radiol. 1989 May;18(2):72-6.	2
Sakka S, Al-ani Z, Kasioumis T, Worthington H, Coulthard P. Inter-examiner and intra-examiner reliability of the measurement of marginal bone loss around oral implants. Implant Dent. 2005 Dec;14(4):386-8.	2
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[a]Reasons for exclusion: 1- Outcomes not matching eligibility criteria, 2- Study design not matching eligibility criteria, 3-Reference test not matching eligibility criteria, 4- Population not matching eligibility criteria, 5-Index test not matching eligibility criteria.