SYSTEMATIC REVIEW

Precision of cone beam CT to assess periodontal bone defects: a systematic review and meta-analysis

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Objectives: Evaluate the diagnostic validity of CBCT in measuring periodontal bone defects when compared with the reference standard (*in situ* measurement).

Methods: Studies in which the main objective was to evaluate the diagnostic validity of CBCT in measuring periodontal bone defects when compared with the reference standard were selected. Four databases were searched. The studies were selected by two independent reviewers. The methodology of selected studies was assessed using the 14-item Quality Assessment Tool for Diagnostic Accuracy Studies. The quality of evidence and strength of recommendation was assessed by The Grading of Recommendations Assessment Tool, Development and Evaluation.

Results: Using a selection process in two phases, 16 studies were identified and, in seven articles meta-analysis was performed. The results from these meta-analyses showed that no difference between the measurements of CBCT and *in situ* for alveolar bone loss, and demonstrated a concordance of 82.82% between CBCT and *in situ* for the classification of the degree of furcation involvement.

Conclusions: Based on a moderate level of evidence, CBCT could be useful for furcation involvement periodontal cases, but it should only be used in cases where clinical evaluation and conventional radiographic imaging do not provide the information necessary for an adequate diagnosis and proper periodontal treatment planning.

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Introduction

Periodontitis is an infectious disease caused by bacterial biofilm on the tooth surface.^{1,2} This pathology is very common in the adult population, 10–15% approximately,³ and it is characterized by a combination of gingival inflammation, periodontal pocket formation, attachment loss and alveolar bone resorption.^{4,5}

A correct assessment of the bone condition is critical to the diagnosis, treatment planning and prognosis of periodontitis. The clinical characteristics of gingival tissues associated with the information obtained through radiographs allow for the evaluation of bone height, as well as morphological and pathological changes caused by the disease.^{6–8}

The most used radiographs to complement periodontal diagnosis are periapical, bitewing and panoramic radiographs.^{6,7,9–11} However, conventional radiographs only demonstrate loss of alveolar bone

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when 30 to 50% of bone mineral in a specific area is destroyed.¹² In addition, these types of radiographs have limitations such as overlapping of anatomical structures,^{12–16} difficulty of standardization^{7,17–20} and underestimation of periodontal bone defects measurements.²⁰ Such characteristics contest the use of conventional radiographs for the diagnosis of periodontitis.

Recently, CBCT has been used when conventional radiographic examination does not provide the required information for periodontal therapy.^{21,22} CBCT has no geometric overlapping of anatomical structures, it is relatively accessible and its radiation dose is lower as compared with medical CT.^{21,23–28} When compared with conventional radiography, CBCT radiation dose is equivalent to a full-mouth series and approximately three to seven times the dose of a panoramic radiograph, depending on the setting used.²⁹ Furthermore, the ability to view the alveolar bone in three dimensions and to make measurements at any location could significantly improve periodontal diagnosis.³⁰

Additionally, different studies^{19,31,32} comparing the use of CBCT vs conventional two-dimensional imaging in artificial bone defects have shown that CBCT has a sensitivity between 80 and 100% for the detection of bone defects, while intraoral radiographs have a sensitivity between 63 and 67%.^{19,31,32} When comparing CBCT with periapical and panoramic radiography the former showed no distortion, no overlapping images and real size compatibility.^{15,19,31,32} However, despite the inherent advantages of CBCT, according to the Sedentext, 2012 guidelines³³ this exam is not indicated as a routine method for the diagnosis of alveolar bone loss.

In view of the abovementioned aspects and the absence of a systematic review that compares *in situ* direct periodontal measurements with measurements from CBCT reconstructions, this review aimed to: evaluate the diagnostic validity of 3D CBCT generated measurements in the evaluation of periodontal bone defects comparing them to the current reference standard (*in situ* measurement).

Methods and materials

This systematic review was written in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist.³⁴

Protocol registration

The systematic review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) under number CRD42016037087.³⁵

Eligibility criteria

Inclusion criteria:

- Studies in which the objective was to evaluate the validity of CBCT in measuring periodontal defects in

humans (*in vivo*, cadavers or dry skulls).

- All studies must have an *in situ* measurement regarded as reference standard for assessment of periodontal bone defects and furcation involvement (FI).^{36,37}
- Regarding periodontal bone defects studies evaluating horizontal and vertical bone loss were considered. Only studies that classified FI according to the system proposed by Hamp *et al*³⁸ were included.
- Studies published in any language were considered.

Exclusion criteria:

- Reviews, case reports, retrospective studies, letters and personal opinions.
- Studies that only evaluated other methods such as intraoral radiographs, panoramic radiograph, fan beam CT or micro-CT.
- Studies that did not compare the measurements from CBCT reconstruction to the reference standard.

Information sources and search

Detailed individual search strategies for each of the following electronic databases were performed: LILACS, PubMed, Scopus and Web of Science. A gray literature search on Open Grey, ProQuest, Google Scholar and the reference lists of selected articles were reviewed to add any references that could have been missed during the electronic database searches. The database search was updated until 23 January 2017. EndNote Basic® (Thomson Reuters, New York, NY) software was used to remove duplicates.

Appropriate truncation and word combinations were selected with the support of a Health Sciences librarian and were adapted to each database search (Appendix A).

Study selection

The selection of articles was carried out in two phases. In Phase 1, two authors, one experienced in oral radiology (LFH) and the other experienced in periodontics (GZ) independently reviewed the titles and abstracts of all references. All studies that did not meet the inclusion criteria were excluded. In Phase 2, full texts were read independently by the same authors, and the studies that fulfilled all inclusion criteria were selected. When mutual agreement between the two reviewers was not reached, a third author with expertise in oral radiology (MC) was involved to make a final decision.

Data collection process and data items

The following study characteristics were recorded for all included studies: study characteristics (authors, year of publication, country), sample characteristics (size, type, defect and dental group), observer's characteristics (number, type and calibration), characteristics of assessment methods (instrument used for *in situ* measurement and CBCT image acquisition protocol), statistical analysis and main results. An author (LFH) extracted the data required from the selected studies. A second author

(GZ) cross-checked all the retrieved information. Again, the discrepancies between both reviewers were discussed and a third author (MC) made a final decision.

The authors of the articles that did not show all data to perform the meta-analysis were contacted by e-mail three times with an interval of 1 week.

Quality assessment

The methodological quality of the selected studies was evaluated using QUADAS-2 which is a revised tool for quality assessment of diagnostic accuracy studies.³⁹ Two authors (LFH, GZ) scored independently each data item as “yes”, “no”, “unclear”, “low” or “high”. The third author (MC) was in charge of deciding any disagreement between the authors. The QUADAS-2 tool scoring was made using Review Manager® (RevMan) 5.2.

Synthesis of results: Two proportion meta-analyses were performed. The first analysis verified the mean difference between CBCT reconstructions and *in situ* assessment of alveolar bone loss measurements using the software Review Manager (RevMan), v. 5.3 (The NordicCochrane Centre, Copenhagen, Denmark). The second analysis examined the level of agreement between CBCT reconstruction and *in situ* assessment of the degree of FI using the software MedCalc (MedCalc Software, Ostend, Belgium). The significance level was 5%.

Grading the “body of evidence”: The Grading of Recommendations Assessment, Development and Evaluation (GRADE)⁴⁰ system was used to evaluate the quality of evidence. Two authors (LFH, GZ) rated the quality of the evidence as well as the strength of the recommendations according to the following aspects: risk of bias, inconsistency, indirectness, imprecision, publication bias, large effect, plausible confounding and dose response gradient.

The option involving intervention/treatment studies was used in the GRADE tool since it is the only one that allows to assess the results based on outcomes. Despite being a diagnostic study, it is not possible to use the diagnosis specific option since measurement of only diagnostic validity data does not generate the other required diagnostic data such as sensitivity and specificity, positive predictive value and negative predictive value.

Results

Study selection

In Phase 1, 922 articles were selected from four electronic databases. After removal of duplicates, 543 different citations remained. Following a detailed evaluation of abstracts, only 23 articles were selected for Phase 2. The limited search performed on Open Grey resulted in one study, two on ProQuest and five studies on Google Scholar. Additionally, one study was identified from the reference list.

Therefore, 29 articles were retrieved for full-text reading. 13 of them were later excluded. Reasons for the exclusion can be found in Appendix B. Thus, only 16 studies fulfilled the eligibility criteria and were finally included. A flowchart of the complete selection process is shown in Figure 1.

Study characteristics

The amount of evaluated periodontal areas ranged from 28⁴¹ to 8964.⁴² Most studies evaluated the periodontal bone defects in patients,^{4,36,41,43–46} others in dry skulls^{19,30,32,47–49} and only one in a macerated mandible.⁵⁰ Only one study was published in Chinese.⁴² A summary of the descriptive characteristics of included articles is provided in Table 1.

Quality assessment

Although the included studies were methodologically homogeneous and had high methodological quality, none of the studies fulfilled all of the QUADAS-2 methodological quality criteria. More information about the risk of bias assessment can be found in Appendix C and Figure 2.

Synthesis of results

Only seven^{4,36,37,44–46,49} out of the studies included were considered for the meta-analysis. The others did not have enough appropriate data for analysis. Although some authors were contacted by e-mail, no new data were retrieved. These seven articles resulted in two meta-analyses: (1) mean difference of alveolar bone loss between CBCT reconstruction and *in situ* measurements^{4,37,44,46,49} and (2) agreement on the classification of the degree of FI between CBCT reconstruction and *in situ* assessment.^{36,45}

The results of the meta-analysis suggested no difference between the measurements of CBCT reconstruction and *in situ* for alveolar bone loss [−0.10, 95%CI (−0.39 to 0.19); Figure 3], however, it is not possible to infer equality between the two methods of measuring alveolar bone loss. In relation to FI the results showed a significant concordance of 82.82% [95% CI (75.84–88.84); *n* = 126; Figure 4] between CBCT and *in situ* for the classification of the degree of FI.

Grading the “body of evidence”

The analysis of the level of quality of evidence found by the GRADE tool (Table 2) indicated that there is moderate evidence to support the use of CBCT to provide periodontal bone defect linear measurements and evaluation of FI.

Discussion

Summary of evidence

Alveolar bone loss is one of the consequences of periodontitis. Bone loss can occur in the mesio-distal

Figure 1 Flow diagram of literature search and selection criteria.

and/or bucco-lingual tooth aspects, which limits the use of conventional 2D radiographs when measuring bucco-lingual periodontal defects.^{4,18,51}

Meanwhile, 3D imaging can potentially add important information to the clinician. However, the last guideline published in 2012 by the European Commission, considers that there is no consistent scientific evidence to support its use as a routine in periodontal evaluation.³³

The current systematic review suggests with a moderate level of evidence (Table 2) that CBCT can be a precise imaging method for the measurement

of periodontal bone defects and evaluation of FI. However, CBCT should not be the first imaging choice in periodontal assessment.

There is no consensus among the studies regarding the comparison between the measurements of alveolar bone loss by means of CBCT compared with *in situ* measurements. Some studies report that there is no statistical difference between CBCT and *in situ* measurements,^{19,41,43,46,47,50} however, others report a statistical significant difference.^{4,43,49}

Studies also report that CBCT may underestimate or overestimate the values of alveolar bone loss

Table 1 Summary of descriptive characteristics of included studies (n = 16)

Studies characteristics			Intervention		Outcomes	
Author, year	Country	Population Sample (size/type/defect/dental group)	Observers (number/type calibration)	Instrument for measuring <i>in situ</i>	Image acquisition protocol -CBCT unit, FOV (cm), voxel (mm), Kv, mA, s	Findings overall
Banodkar et al, 2015	India	15 patients; 100 sites; Horizontal and vertical defects; Dental Group: U.	1 examiner (<i>in situ</i> and image); Calibration: Y.	Digital vernier caliper.	Promax 3D ^a . FOV: 4 × 4 cm; voxel: 0.4 mm; 90kV; 10mA; 13 s.	CBCT was 100% accurate in identifying the type of defect in all the patients. When the correlation between horizontal and vertical defects was compared with the horizontal defect correlation was higher than the vertical defects.
Deng et al, 2015	China	75 patients; 8,964 sites; Horizontal and vertical defects; Incisor, canine, premolars and molars. ^b	2 residents (<i>in situ</i>); 2 radiologists (image); Calibration: Y.	Manual periodontal probe.	Vatech. ^c FOV: U; voxel: U; 90 kV; 7 mA; 24 s.	No significant difference between clinical probing and CBCT. CBCT have the highest consistency with clinical probing in detecting the alveolar bone loss in chronic periodontitis.
Feijó et al, 2012	Brazil	6 patients; 72 sites; Horizontal; Upper molars.	1 professional (<i>in situ</i>); 1 radiologist (image); Calibration: U.	Manual periodontal probe.	i-CAT ^d . FOV: U; voxel: 0.2 mm; kV: U; mA: U; 40 s.	There was no statistically significant difference between clinical and CBCT measurements. There was a statistical difference between the CBCT and surgical measurements on the palatal surfaces and vestibular.
Fleiner et al, 2013	Belgium	1 dry skull; 72 sites; Circumferential bone level, infrabony crater; Upper and lower premolars and molars.	3 observers (<i>in situ</i> and image). Calibration: Y.	Manual periodontal probe.	Promax 3D ^e FOV: 8 × 8 cm; voxel: 0.16 mm; 80 kV; 12 mA; 12 and 22 s.	The CBCT showed accurate measurements of periodontal bone circumferential level as compared with the gold standard and 100% of the detected furcation.

(Continued)

Table 1 (Continued)

Studies characteristics		Population		Intervention		Outcomes	
Author, year	Country	Sample (size/type/defect/dental group)	Observers (number/type/calibration)	Instrument for measuring <i>in situ</i>	Image acquisition protocol-CBCT unit, FOV (cm), voxel (mm), Kv, mA, s	Statistical analysis	Findings overall
Grimard et al, 2009	USA	29 patients; 33 sites; Infrabony defects; Upper and lower teeth.	2 Periodontics – Board Certified Periodontists (<i>in situ</i>); 1 author (image); Calibration: U.	Manual periodontal probe.	3DX Accuitomo ^c , FOV: U; voxel: 0.125 mm; kV: U; mA: U; 18 s.	Pearson product-moment correlation coefficients; Spearman rank-order correlation coefficients; paired <i>t</i> -test; McNemar.	None of the differences between surgical cemento-enamel junction to alveolar crest measurements and the CBCT were statistically significant.
Haghgoo et al, 2014	Iran	Patients; U; 50 sites; Interproximal defects; Anterior and posterior teeth ^b .	2 clinicians (<i>in situ</i> and image). Calibration: Y.	Manual periodontal probe and digital caliper.	Newtom 3G ^f , FOV: 6 × 6 cm; voxel: 0.2 mm; 110 kV; 10.65 mA; s: U.	Paired <i>t</i> -test.	The accuracy of CBCT in evaluating vertical dimension of periodontal bony defects was high.
Li, Jia and Ouyang, 2015	China	44 patients; 44 sites; Infrabony defects; Anterior tooth, premolars and molars ^b .	1 periodontist (<i>in situ</i>); 1 radiologist (image). Calibration: Y.	Manual periodontal probe.	Newtom VG ^f , FOV: U; voxel: 0.125 mm; 110 kV; 12 to 17 mA; s: U.	Paired <i>t</i> -test.	CBCT measurements for the bucco-lingual width and mesio-distal width of the defect were similar to the intrasurgical measurements. CBCT for the cemento-enamel junction to bone loss and the depth of the defect were significantly underestimated in respect to the intrasurgical measurements.
Leung et al, 2010	USA	13 dry skulls 446 sites; Bone height; Upper and lower molars, premolars, canine and incisors.	1 operator (<i>in situ</i> and image); Calibration: Y.	Digital caliper.	CBCT ^g , FOV: 12 × 12 cm; voxel: 0.38 mm; 110 kV; 2 mA; s: 9.6.	Two-tailed paired <i>t</i> -test, The CBCT measurements were essentially equal to the direct measurements. The correlation between CBCT and direct method was high.	

(Continued)

Table 1 (Continued)

Studies characteristics			Population		Intervention		Outcomes	
Author, year	Country	Sample (size/type/defect/dental group)	Observers (number/type calibration)	Instrument for measuring <i>in situ</i>	Image acquisition protocol-CBCT unit, FOV (cm), voxel (mm), Kv, mA, s	Statistical analysis	Findings overall	
Misch, Yi and Sarment, 2006	USA	2 dry skulls; Site: U; Infrabony buccal, lingual, and interproximal defects; Lower premolar and molar.	3 examiners (<i>in situ</i> and image); Calibration: Y.	Periodontal probe (direct measurements) and electronic caliper (indirect measurements).	i-CAT [®] . FOV: U; voxel: 0.4 mm; 120 kV; 47.74 mA; 20 s.	Pearson correlation coefficients and two-way ANOVA.	All infrabony defects were detected using CBCT and the probe and the results of measures were not statistically different.	
Mol and Balasundaram, 2008	USA	5 dry skulls; 146 sites; Horizontal and vertical defects; Upper and lower molar, premolar and anterior.	1 examiner (<i>in situ</i>); 4 board-certified oral and maxillofacial radiologists (image); 1 oral and maxillofacial radiology resident (image), and 1 periodontist (image); Calibration: Y.	Digital caliper.	NewTom 9000 [®] . FOV: U; voxel: 0.3 mm; kV: U; mA: U; s: U.	ANOVA and Tukey's honestly significant difference <i>post hoc</i> test.	The diagnostic accuracy of CBCT was lower for anterior teeth than for molars and premolars.	
Qiao et al, 2014	China	15 patients; 51 furcation involvement; Upper molars.	2 periodontists (pre-surgical clinical measurements); 2 periodontists (intrasurgical clinical measurements); 2 radiographers (image); Calibration: Y.	Pre-surgical clinical measurements: XYZ Intrasurgical clinical measurements: curved probe and manual periodontal probe.	3D Accutomo 60, XYZ Slice View Tomograph [®] . FOV: 4 × 4 – 6 × 6 cm; voxel: 0.125 mm; 74–90 kV; 5–8 mA; s: U.	Paired <i>t</i> -test.	CBCT confirmed 82.4% of surgical measurements performed, indicating a high degree of accuracy of CBCT. CBCT underestimated measurements in 11.8% of furcation lesions analysed and overestimated in 5.9% of cases.	
Raichur et al, 2012	India	7 patients; 28 sites; Infrabony defects; Dental Group: U.	Observers: U; Calibration: U.	Manual periodontal probe.	Planmeca Prostyle Intra [®] . FOV: 50 × 37 mm; voxel: U; 70–74 kV; 10 mA; 10.8 s.	One-way ANOVA; Newman Keuls multiple differences were observed between digital volume tomography and direct surgical measurements.	No significant differences were observed between digital volume tomography and direct surgical measurements.	
Takeshita et al, 2015	Brazil	10 macerated human mandibles; Site: U; Proximal alveolar bone loss; Lower teeth.	1 radiologist (<i>in situ</i> and image); Calibration: Y.	Digital caliper.	i-CAT [®] . FOV: 6 × 6 cm; voxel: 0.125 mm; kV: U; 36.2 mA; s: U.	ANOVA and Tukey's test.	The values of CBCT were the closest to the control method.	

(Continued)

Table 1 (Continued)

Studies characteristics		Population		Intervention		Outcomes	
Author, year	Country	Sample (size/type/defect/dental group)	Observers (number/type calibration)	Instrument for measuring <i>in situ</i>	Image acquisition protocol -CBCT unit, FOV (cm), voxel (mm), Kv, mA, s	Statistical analysis	Findings overall
Vandenbergh, Jacobs and Yang, 2007	Belgium	2 skulls, a cadaver head and a dry skull; 30 sites; Linear defects, three-dimensional craters; Dental Group: U.	3 postgraduate students at the Oral Imaging Centre (<i>in situ</i> and image); Calibration: Y.	Digital sliding caliper.	i-CAT ^d . FOV: U; voxel: 0.4 mm; 120 kV; 23.87 mA; s: U.	Kruskal Wallis; Friedman ANOVA test; Wilcoxon Signed Rank test, and Mann Whitney.	The linear measurement deviations of periodontal bone levels from the gold standard ranged from 0.13 to 1.67 mm for CBCT.
Vandenbergh, Jacobs and Yang, 2008	Belgium	2 skulls; 71 sites; Linear defects, three-dimensional craters; Molar region of the upper and lower jaws.	3 observers (a Medical Imaging Master and PhD student, and 2 radiology faculty members, Temple University, School of Dentistry, Philadelphia, PA) (<i>in situ</i> and image); Calibration: Y.	Digital sliding caliper.	i-CAT ^d . FOV: 6 × 2 cm; voxel: 0.4 mm; 120 kV; 23.87 mA; 20 s.	Wilcoxon Signed Rank test; Mann Whitney, and Kruskal-Wallis.	No statistical difference between the CBCT and <i>in situ</i> measurements.
Walter, Weiger and Zitzmann, 2010	Switzerland	14 patients; 75 furcation involvement; Upper molars.	2 periodontists (<i>in situ</i> and image); Calibration: Y.	Curved scaled probe.	3D Accutomo 60, XYZ Slice View Tomograph ^e . FOV: 4 × 4 – 6 × 6 cm; voxel: 0.08–0.25 mm; 74–90 kV; 5–8 mA; s: U.	Weighted k.	Overall, 84% of the CBCT data were confirmed by the intrasurgical findings. However, 14.7% of the cases were underestimated (CBCT less than surgical value) and 1.3% revealed an overestimation in the CBCT as compared with the surgical analysis.

FOV, field of view; kV, kilovolt; mA, milliseconds; s, seconds; U, unclear; Y, yes.

^aPlanmeca Oy, Helsinki, Finland.^bAbsence of information whether it is upper or lower teeth.^cVatch, E-WOO Technology Co, Ltd. Republic of Korea.^dImaging Sciences International, Hatfield, PA.^eJ. Morita, Kyoto, Japan.^fQR-NIM s.r.l., Verona, Italy.^gCB MercuRay, Hitachi Medical Systems American, Twinsburg, Ohio.

Figure 2 Criteria met, according to the QUADAS tool.

measurements,^{4,43} as well as in cases of FI.^{36,45} One potential justification for these differences would be the voxel size used.⁴⁹ Nevertheless, when defining accuracy in terms of clinical impact, certainly a discrepancy in the range of 0.5–1 mm between actual bone level and estimated bone level on radiographs should normally be considered clinically acceptable. It may be more likely that small or large errors in locating the CEJ and the AC (landmark location errors) can respectively lead to a more significant under- and over-estimation of disease prevalence.^{32,47,48,52,53}

Other factors that explain the differences found in CBCT measurements with those detected by probing

in situ, are the variables such as: probing force,⁴⁸ probe diameter and the presence of granulation tissue in defect base.⁴ Additionally, access and visualization are often difficult in conventional real-life clinical assessment and can affect this measurement.³⁶

However, a systematic review recently published by Walter *et al*⁵⁴ shows that CBCT is particularly useful in cases of FI in molars, as it provides high accuracy for detecting the degree of FI and morphology of surrounding periodontal tissues. The authors reported that CBCT can improve diagnosis validity and periodontal treatment planning optimization, especially in cases of FI in molars.

Figure 3 Mean difference between the CBCT and *in situ* evaluation for the measurement of alveolar bone loss. Sample = 632.

Figure 4 Forest plot for the concordance between CBCT and *in situ* for the classification of the degree of furcation involvement. Sample = 126.

Table 2 Summary of findings (GRADE 2014) for the measurements of CBCT compared with *in situ* measurements

Outcome	Impact	N° of participants (sites) (studies)	Quality
Measures fixed reference point— Alveolar crest	There was no statistical difference between the CBCT and <i>in situ</i> measurements in the studies: Banodkar et al, 2015; Deng et al, 2015; Feijó et al, 2012; Grimard et al, 2009; Leung et al, 2010; Misch, Yi and Sarment, 2006; Raichur et al, 2012; Takeshita et al, 2015; Vandenbergh et al., 2008. In the study by Mol and Balasundaram, 2008 the average difference between CBCT and <i>in situ</i> measurements was −0.23 mm. In the study by Vandenbergh, Jacobs and Yang, 2007 the average was between −1 and 1 mm CBCT and <i>in situ</i> measurements, with an underestimation of the measures of CBCT. Study by Fleiner et al, 2013, CBCT and <i>in situ</i> measurements varied 0.36 and 0.69 mm, in which 83% of all results were < 0.5 mm.	9962 (12 observational studies)	⊕⊕⊕○ MODERATE
Measures fixed reference point – Base of the defect	There was no statistical difference between the CBCT and <i>in situ</i> measurements in the studies: Banodkar et al, 2015; Misch, Yi and Sarment, 2006. There was statistical difference between the CBCT and <i>in situ</i> measurements in the studies: Grimard et al, 2009; Haghighi et al, 2014; Li, Jia and Ouyang, 2015; Raichur et al, 2012.	255 (6 observational studies)	⊕⊕⊕○ MODERATE
Concordance of FI classification according to Hemp et al (1975)	Qiao et al, 2014: 82.4% of the CBCT measurements were confirmed <i>in situ</i> . Underestimated: 11.8%. Overestimation: 5.9%. Walter, Weiger and Zitzmann, 2010: 84% of the CBCT measurements were confirmed <i>in situ</i> . Underestimated: 14.7%. Overestimation: 1.3%.	126 (2 observational studies)	⊕⊕⊕○ MODERATE

FI, furcation involvement; GRADE, grading of recommendations assessment, development and evaluation.

In cases of furcation, 3D reconstructions become more important because the correct classification of the FI degree directly affects treatment approaches. This becomes more relevant in the case of Grade II where treatments, especially regenerative therapies, show higher success rates in relation to Grade III of FI.⁵⁵ In addition, Qiao et al³⁶ also suggested that CBCT provides important additional imaging data on the morphology of the bifurcation and on the severity of the lesion.

However, just like any other radiographic examination, indicating 3D images must be justified and the ionizing radiation dose should be considered. The problem with CBCT imaging lies in its image resolution (voxel size). Not all machines produce voxel sizes that may have a diagnostic value for this specific problem. In addition, smaller voxel sizes are usually linked to increased imaging exposure time and ionizing radiation concomitantly.

The effective radiation dose of CBCT varies according to the brand and the selected exposure parameters during acquisition of the image, such as size of the field of view (FOV) and voxel, exposure time, kilovoltage and milli-ampereage.^{56–59} When compared with the conventional radiography, the CBCT radiation dose is equivalent to a full-mouth series and approximately three to seven times the dose of a panoramic radiograph depending on the setting in use.²⁹

Therefore, CBCT imaging should not be the first choice to measure bone periodontal defects. Its use should be preferably for cases where clinical and conventional images are insufficient or unclear for diagnosis and treatment decision. In addition, it is fundamental to choose the correct FOV size and exposure parameters in order to reduce the amount of radiation dose absorbed by the patient. This philosophy supports the ALARA (As Low As Reasonably Achievable)⁶⁰ principle.

Limitations

The main methodological limitations identified in the selected studies were heterogeneity between the examiners and the protocols for the acquisition of 3D images. Some studies were not clear or did not report whether the examiners of the images were radiologists and whether examiners who performed *in situ* measurement were periodontists.

In addition, acquisition protocols (FOV and voxel) of the images were very heterogeneous among included studies. The larger the FOV the greater the amount of noise in the image. On the other hand, the smaller the size of the voxel, the best spatial resolution of the image, which allows visualization of the bone tissue in areas with smaller thicknesses or lower bone density, *e.g.* on the base of defects containing demineralized bone tissue.

Another point that interferes with the diagnostic process performed on CBCT is the presence of metallic

materials in the oral cavity. Only four studies^{4,36,46,47} excluded teeth with restorations or metal crowns, and teeth with endodontic fillings. The artefacts created by these objects are also defined as “missing value artefacts”, and they reduce image quality.⁶¹ That is, the parameters for the acquisition of CBCT are directly related to the quality of the images and their diagnostic ability.

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Appendix A: Search strategy in databases

1. LILACS

((furcation AND defect*) OR (alveolar AND bone AND loss) OR (periodontal AND bone AND loss) OR (alveolar AND loss) OR (interproximal AND bone AND loss) OR (periodontal AND bone AND resorption) OR (alveolar AND bone AND resorption) OR (periodontal AND bone AND defect*) OR (alveolar AND bone AND defect*) OR (infrabony AND defect*) OR (intrabony AND defect*) OR (defeito AND furca) OR (perda AND óssea AND alveolar) OR (perda AND óssea AND periodontal) OR (reabsorção AND óssea AND periodontal) OR (reabsorção AND óssea AND alveolar) OR (reabsorção AND periodontal) OR (defeito AND infraósseo) OR (defeito AND intraósseo)) AND ((cone-beam AND computed AND tomography) OR (cone beam AND computed AND tomography) OR (cone AND beam AND computed AND tomography) OR (tomografia AND computadorizada AND de AND Feixe AND cônico))

2. PubMed

((((((((((("furcation defects"[MeSH Terms] OR ("furcation"[All Fields] AND "defects"[All Fields]) OR "furcation defects"[All Fields])) OR ("alveolar bone loss"[MeSH Terms] OR ("alveolar"[All Fields] AND "bone"[All Fields] AND "loss"[All Fields]) OR "alveolar bone loss"[All Fields])) OR ("alveolar bone loss"[MeSH Terms] OR ("alveolar"[All Fields] AND "bone"[All Fields] AND "loss"[All Fields]) OR "alveolar bone loss"[All Fields]) OR ("periodontal"[All Fields] AND "bone"[All Fields] AND "loss"[All Fields]) OR "periodontal bone loss"[All Fields])) OR (alveolar[All Fields] AND loss[All Fields]) OR (interproximal[All Fields] AND ("bone diseases, metabolic"[MeSH Terms] OR ("bone"[All Fields] AND "diseases"[All Fields] AND "metabolic"[All Fields]) OR "metabolic bone diseases"[All Fields] OR ("bone"[All Fields] AND "loss"[All Fields]) OR "bone loss"[All Fields])))) OR (periodontal[All Fields] AND ("bone resorption"[MeSH Terms] OR ("bone"[All Fields] AND "resorption"[All Fields]) OR "bone resorption"[All Fields])) OR (alveolar[All Fields] AND ("bone resorption"[MeSH Terms] OR ("bone"[All Fields] AND "resorption"[All Fields]) OR "bone resorption"[All Fields])) OR ("alveolar bone loss"[MeSH Terms] OR ("alveolar"[All Fields] AND "bone"[All Fields] AND "loss"[All Fields]) OR "alveolar bone loss"[All Fields] OR ("periodontal"[All Fields] AND "resorption"[All Fields]) OR "periodontal resorption"[All Fields])) OR (periodontal[All Fields] AND ("bone and bones"[MeSH Terms] OR ("bone"[All Fields] AND "bones"[All Fields]) OR "bone and bones"[All Fields] OR "bone"[All Fields]) AND ("abnormalities"[Subheading] OR "abnormalities"[All Fields] OR "defects"[All Fields])) OR (alveolar[All Fields] AND

("bone and bones"[MeSH Terms] OR ("bone"[All Fields] AND "bones"[All Fields]) OR "bone and bones"[All Fields] OR "bone"[All Fields]) AND ("abnormalities"[Subheading] OR "abnormalities"[All Fields] OR "defects"[All Fields])) OR (infrabony[All Fields] AND ("abnormalities"[Subheading] OR "abnormalities"[All Fields] OR "defects"[All Fields])) OR (intrabony[All Fields] AND ("abnormalities"[Subheading] OR "abnormalities"[All Fields] OR "defects"[All Fields])) AND ("cone-beam computed tomography"[MeSH Terms] OR ("cone-beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone-beam computed tomography"[All Fields] OR ("cone"[All Fields] AND "beam"[All Fields] AND "computed"[All Fields] AND "tomography"[All Fields]) OR "cone beam computed tomography"[All Fields])

3. Scopus

((("furcation" W/5 "defect*") OR ("alveolar" W/5 "bone" W/5 "loss") OR ("periodontal" W/5 "bone" W/5 "loss") OR ("alveolar" W/5 "loss") OR ("interproximal" W/5 "bone" W/5 "loss") OR ("periodontal" W/5 "bone" W/5 "resorption") OR ("alveolar" W/5 "bone" W/5 "resorption") OR ("periodontal" W/5 "resorption") OR ("periodontal" W/5 "bone" W/5 "defect*") OR ("alveolar" W/5 "bone" W/5 "defect*") OR ("infrabony" W/5 "defect*") OR ("intrabony" W/5 "defect*")) AND ((("cone-beam" W/5 "computed" W/5 "tomography") OR ("cone-beam" W/5 "computed" W/5 "tomography") OR ("cone" W/5 "beam" W/5 "computed" W/5 "tomography"))

4. Web of Science

((("furcation" AND "defect*") OR ("alveolar" AND "bone" AND "loss") OR ("periodontal" AND "bone" AND "loss") OR ("alveolar" AND "loss") OR ("interproximal" AND "bone" AND "loss") OR ("periodontal" AND "bone" AND "resorption") OR ("alveolar" AND "bone" AND "resorption") OR ("periodontal" AND "resorption") OR ("periodontal" AND "bone" AND "defect*") OR ("alveolar" AND "bone" AND "defect*") OR ("infrabony" AND "defect*") OR ("intrabony" AND "defect*")) AND ((("cone-beam" AND "computed" AND "tomography") OR ("cone-beam" AND "computed" AND "tomography") OR ("cone" AND "beam" AND "computed" AND "tomography"))

5. Open Grey and Google Scholar

("furcation defect" OR "alveolar bone loss" OR "periodontal bone loss" OR "alveolar loss" OR "interproximal bone loss" OR "periodontal bone resorption" OR "alveolar bone resorption" OR "periodontal resorption" OR "periodontal bone defect" OR "alveolar bone defect" OR "infrabony defect" OR "intrabony defect") AND ("cone-beam computed tomography" OR "cone beam computed tomography")

6. *ProQuest*

all(("furcation defects")) OR all(("alveolar bone loss" OR "periodontal bone loss")) OR all(("alveolar loss" OR "interproximal bone loss")) OR all(("periodontal bone resorption" OR "alveolar bone resorption")) OR

all(("periodontal resorption" OR "periodontal bone defects")) OR all(("alveolar bone defects" OR "infrabony defects")) OR all("infrabony defects") AND all(("cone-beam computed tomography" OR "cone beam computed tomography"))

Appendix B: Articles excluded and the reasons for exclusion (*n* = 13)

Author	Reasons for exclusion ^a
1. Almeida et al 2014	1
2. Bagis et al 2015	3
3. Cimbaljevic et al 2015	3
4. Darby et al 2015	1
5. De Farias Vasconcelos et al 2012	3
6. Dehghani et al 2011	3
7. Ma et al 2015	3
8. Marinescu et al 2014	3
9. Minami et al 2015	3
10. Noujeim et al 2009	3
11. Rost 2014	3
12. Walter et al 2009	3
13. Zhong et al 2010	3

^a(1) Reviews, case reports, retrospective studies, letters and personal opinions; (2) studies that only evaluated other methods such as intraoral radiographs, panoramic radiograph, fan beam CT or micro-CT; (3) studies that did not compare the measurements from CBCT reconstruction to the reference standard.

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Appendix C: QUADAS-2 criteria fulfilled (*n* = 16)

	<i>Item</i>	<i>Banodkar et al, 2015³⁷</i>	<i>Deng et al, 2015⁴²</i>	<i>Feijó et al, 2012⁴⁶</i>	<i>Fleiner et al, 2013⁴⁷</i>	<i>Grimard et al, 2009⁴³</i>	<i>Haghgoo et al, 2014⁴⁴</i>	<i>Li, Jia and Ouyang, 2015⁴</i>
Domain 1: Patient Selection	Was a consecutive or random sample of patients enrolled?	Y	Y	Y	Y	Y	Y	Y
	Was a case-control design avoided?	Y	Y	Y	Y	Y	Y	Y
	Did the study avoid inappropriate exclusions?	Y	Y	Y	Y	Y	Y	Y
	Could the selection of patients have introduced bias?	L	L	L	L	L	L	L
	Concerns regarding applicability: Is there concern that the included patients do not match the review question?	L	L	L	L	L	L	L
Domain 2: Index Test	Were the index test results interpreted without knowledge of the results of the reference standard?	U	U	U	N	U	U	U
	If a threshold was used, was it pre-specified?	U	U	U	U	U	U	U
	Could the conduct or interpretation of the index test have introduced bias?	L	L	L	L	L	L	L
	Concerns regarding applicability: Is there concern that the index test, its conduct, or interpretation differ from the review question?	L	L	L	L	L	L	L
Domain 3: Reference Standard	Is the reference standard likely to correctly classify the target condition?	Y	Y	Y	Y	Y	Y	Y
	Were the reference standard results interpreted without knowledge of the results of the index test?	Y	Y	Y	Y	Y	Y	Y
	Could the reference standard, its conduct, or its interpretation have introduced bias?	L	L	L	L	L	L	L
	Concerns regarding applicability: Is there concern that the target condition as defined by the reference standard does not match the review question?	L	L	L	L	L	L	L
Domain 4: Flow and Timing	Was there an appropriate interval between index test(s) and reference standard?	U	U	U	Y	Y	U	U
	Did all patients receive a reference standard?	Y	Y	Y	Y	Y	Y	Y
	Did patients receive the same reference standard?	Y	Y	Y	Y	Y	Y	Y
	Were all patients included in the analysis?	Y	Y	Y	Y	Y	Y	Y
	Could the patient flow have introduced bias?	L	L	L	L	L	L	L

	<i>Item</i>	<i>Leung et al, 2010⁴⁸</i>	<i>Misch, Yi and Sarment, 2006⁴⁹</i>	<i>Mol and Balasundaram, 2008⁵⁰</i>	<i>Qiao et al, 2014³⁶</i>	<i>Raichur et al, 2012⁴¹</i>	<i>Takeshita et al, 2015⁵⁰</i>	<i>Vandenberghe, Jacobs and Yang, 2007⁵²</i>	<i>Vandenberghe, Jacobs and Yang, 2008⁴⁵</i>	<i>Walter, Weiger and Zitzmann, 2010⁴⁵</i>
Domain 1: Patient Selection	Was a consecutive or random sample of patients enrolled?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Was a case-control design avoided?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Did the study avoid inappropriate Y exclusions?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Could the selection of patients have introduced bias?	L	L	L	L	L	L	L	L	L
	Concerns regarding applicability: L Is there concern that the included patients do not match the review question?	L	L	L	L	L	L	L	L	L

	<i>Item</i>	<i>Leung et al, 2010⁴⁹</i>	<i>Misch, Yi and Sarment, 2006¹⁹</i>	<i>Mol and Balasundaram, 2008⁸⁰</i>	<i>Qiao et al, 2014³⁶</i>	<i>Raichur et al, 2012⁴¹</i>	<i>Takeshita et al, 2015⁵⁰</i>	<i>Vandenberghe, Jacobs and Yang, 2007³²</i>	<i>Vandenberghe, Jacobs and Yang, 2008⁴⁸</i>	<i>Walter, Weiger and Zitzmann, 2010⁴³</i>
Domain 2: Index Test	Were the index test results interpreted without knowledge of the results of the reference standard?	U	Y	U	Y	U	U	U	Y	U
	If a threshold was used, was it pre-specified?	U	U	U	U	U	U	U	U	U
	Could the conduct or interpretation of the index test have introduced bias?	L	L	L	L	L	L	L	L	L
	Concerns regarding applicability: Is there concern that the index test, its conduct, or interpretation differ from the review question?	L	L	L	L	L	L	L	L	L
Domain 3: Reference Standard	Is the reference standard likely to correctly classify the target condition?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Were the reference standard results interpreted without knowledge of the results of the index test?	U	Y	Y	Y	Y	Y	Y	Y	Y
	Could the reference standard, its conduct, or its interpretation have introduced bias?	L	L	L	L	L	L	L	L	L
	Concerns regarding applicability: Is there concern that the target condition as defined by the reference standard does not match the review question?	L	L	L	L	L	L	L	L	L
Domain 4: Flow and Timing	Was there an appropriate interval between index test(s) and reference standard?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Did all patients receive a reference standard?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Did patients receive the same reference standard?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Were all patients included in the analysis?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Could the patient flow have introduced bias?	L	L	L	L	L	L	L	L	L

Yes (Y), no (N), unclear (U). Risk: low (L)/high (H)/unclear (U).
 Yes (Y), no (N), unclear (U). Risk: low (L)/high (H)/unclear (U).