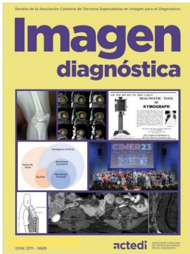

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Diagnostic Accuracy of Cone-Beam Computed Tomography for Furcation Defect Assessment in Chronic Periodontitis

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Abstract: The two dimensional radiograph and clinical probing underestimate furcation defects due to complex root trunk anatomy, soft-tissue thickness and superimposition of adjacent structures. A prospective diagnostic accuracy study was done to evaluate the performance of Cone Beam Computed Tomography (CBCT) in the identification and grading of furcation defects in chronic periodontitis with intra-surgical findings as a reference standard. A total of 72 molar teeth from 40 patients with stage II-IV periodontitis and suspected furcation involvement were assessed using the clinical assessment with a Nabers probe, intraoral periapical radiography and limited-field computed tomography (CBCT). The involvement of the furca was quantified as absent, Grade I, Grade II or Grade III. Accuracy indices, kappa and linear measurement errors were computed. Intra-surgical evaluation showed the presence of furcation defects in 54 of 72 molars (75.0%). CBCT provided superior sensitivity compared to periapical radiography in detecting furcation defects (94.4% vs. 68.5%, respectively) and equal specificity (88.9% vs. 77.8%). The overall accuracy rates were 93.1% for CBCT and 70.8% for periapical radiography. The agreement with the surgical grading was excellent for CBCT (weighted kappa = 0.82) and good for clinical probing (weighted kappa = 0.58). Mean absolute horizontal measurement error was lower for CBCT (0.36 ± 0.28 mm) than clinical probing (0.91 ± 0.64 mm, $p<0.001$). CBCT was effective in 3D diagnosis and furcation classification in selected chronic periodontitis patients and could be warranted when the diagnosis is inconclusive or when treatment planning involves regenerative or resective therapies.

Key Words: Cone-Beam Computed Tomography, Furcation Involvement, Chronic Periodontitis, Diagnostic Accuracy, Periodontal Defects, Intra-Surgical Measurement

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INTRODUCTION

Furcation involvement is one of the most significant factors of local complexity in chronic periodontitis as it is associated with the inability to diagnose or respond to treatment due to the retention of plaque, divergence of root surfaces, enamel projections and limited access [1]. Furcation involvement was added to the staging in the 2017 World Workshop classification as this is a factor that impacts the treatment complexity, prognosis and tooth retention [2,3]. Appropriate evaluation is necessary prior to any non-surgical treatment, regenerative surgery, odontoplasty, tunneling, root resection or extraction.

Traditional diagnostic method involves the use of periodontal probing and intraoral radiography. While probing is a good source of tactile information, it can overestimate or underestimate furcation extension if the opening is small, the gingival margin is thick and the probe angulation is limited or if calculus and inflammatory tissue is present [4,5]. Although conventional radiographs are valuable for knowledge of interproximal bone loss, the superimposition of the buccal and lingual cortical plates and the root make it difficult to see furcation morphology, especially in molars of the maxilla [6].

Multiplanar three dimensional visualization of PDB defects is possible with Cone-Beam Computed Tomography (CBCT) and can visualize horizontal and vertical component of furcation involvement without superimposition of anatomy [7]. Enhanced accuracy of CBCT for maxillary molar furcation involvement and for measurements of the periodontal bone defects were previously reported when compared to conventional imaging [8-11]. Although CBCT exposes the patient to extra radiation dose and cost, in the context of periodontology, it should be used in a case-specific manner based on the diagnostic benefit for the situation instead of being used routinely for screening [12].

Clinical data from other populations is still useful as the standards of furcation detection vary based upon tooth type, defect grade, examiner experience, voxel size and reference standard. The purpose of the present study was to evaluate the diagnostic performance of a limited field CBCT for detecting and grading the furcation defects in patients with chronic periodontitis, against intra-surgical assessment. The secondary aims were: to compare CBCT to clinical probing and intraoral periapical (IOPA) radiography and to assess the agreement for horizontal linear measurements of furcation.

METHODS

The study was prospective diagnostic accuracy study which was done in the Department of Periodontology of a tertiary dental teaching institution following Institutional Ethics Committee approval and written informed consent. The study was conducted in a paired design, where every eligible molar was clinically, periapically radiographically, CBCT and intra-surgically evaluated. The reference standard was intra-surgical measurement directly after the reflection and debridement of the flaps.

Patients of age between 30-65 years who had generalized chronic periodontitis/stage II-IV periodontitis, one or more molar teeth in the maxilla or mandible with suspect furcation involvement, probing pocket depth ≥5 mm and radiographic bone loss were included. Exclusion criteria included: pregnancy, uncontrolled systemic disease, previous periodontal surgery at the selected site within 12 months, extensive restorations covering the furcation, endodontic-periodontal lesions, root fracture, third molars, acute periodontal abscess and the inability to obtain CBCT images.

Forty patients (72 molars) were included. The sample size was determined to achieve 80% power and 5% alpha error when detecting a difference of at least 20% in sensitivity between CBCT and periapical radiography with a surgical prevalence of furcation defects of about 70%. Molar was the analytical unit and clustering by patient was described. UNC-15 periodontal probe and Nabers furcation probe were used for clinical examination. The degree of horizontal involvement was graded as absent, Grade I (<3 mm horizontal penetration), Grade II (≥3 mm but not through and through) or Grade III (through and through defect).

Intraoral periapical radiographs were taken in a standardized manner with the use of an individualized bite block and paralleling technique. The limited field of view included the molar region involved, the voxel size was 0.2 mm, the tube voltage (kVp) was 90 and the current (mA) was 8, with exposure times determined based on the manufacturer's guidelines. The three dimensional images were reconstructed with axial, coronal and sagittal planes. Periapical radiographs and CBCT scans were independently evaluated by two calibrated examiners, who were blinded to intra-surgical findings. All decisions were made with consensus. All 15 molars not included in the study were calibrated and intra-examiner reliability was tested after two weeks.

A structured reading checklist was used to interpret CBCT data. The furcation entrance was first located within the axial sections and then cross sectional and sagittal reconstruction were scrolled to locate the furcation entry with the greatest horizontal extent of the bone loss. Adjustments were made to the contrast and level of the windows but all examiners used the same zoom and orientation. Maxillary buccal, mesial and distal furcations as well as mandibular buccal and lingual furcations were processed in the same manner. The readers noted the presence or absence of the furcation, rated the defect with a grade and measured the furcation defect depth from root surface to the deepest horizontal margin of interradicular bone visible in the furcation area.

If indicated in periodontal treatment, open flap debridement was performed. Following flap elevation and granulation tissue removal, the Horizontal Furcation Depth (HFD) was measured using a Nabers probe to the nearest 0.5 mm and furcation depths were determined by probing and direct visualization. The main result was diagnostic accuracy for the detection of any furcation defect with CBCT. Sensitivity, specificity, positive predictive value, negative predictive value, grade-wise agreement, weighted kappa and absolute measurement error were the secondary outcomes. Means with Standard Deviations (SD) were used for continuous variables and numbers and percentages for categorical variables. Paired proportions compared using McNemar test. Kappa values interpreted for agreement and paired t-test for measurement errors. The p-value <0.05 was taken as significant.

Analysis was conducted at two levels for the diagnostic validity: A binary model was first used to test for the presence or not of any furcation defect. Secondly, an ordinal model was evaluated for the correct classification of Grade I, Grade II and Grade III defects. False-positive CBCT was defined as furcation defects identified on the radiograph but not surgically and false-negative CBCT was defined as furcation defects that were surgically identified but not on the radiograph. The binary outcome was used descriptively in the ROC framework and the area under the curve was computed from the consensus radiographic interpretation. No missing data were imputed as all selected teeth completed all diagnostic procedures and surgical confirmation.

RESULTS

Forty patients and 72 molars were evaluated. The mean age was 46.8±8.9 years and 23 patients (57.5%) were

Table 1: Baseline Patient and Molar Characteristics

Variable	Value
Patients assessed	40
Molars assessed	72
Age (years)	46.8±8.9
Male/Female	23/17
Mandibular molars	43 (59.7%)
Maxillary molars	29 (40.3%)
Stage II/III/IV periodontitis	10/23/7
Mean probing pocket depth (mm)	6.4±1.1
Mean clinical attachment loss (mm)	6.8±1.3

Values are Mean±SD or number (%)

Table 2: Diagnostic Accuracy for Detecting any Furcation Defect

Diagnostic method	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Clinical probing	88.9	66.7	88.9	66.7	83.3
Periapical radiography	68.5	77.8	90.2	45.2	70.8
CBCT	94.4	88.9	96.2	84.2	93.1

Reference standard was intra-surgical diagnosis, PPV: Positive predictive value, NPV: Negative predictive value, CBCT: Cone-beam computed tomography

Table 3: Agreement and Measurement Performance Against Intra-Surgical Assessment

Parameter	Clinical probing	Periapical radiography	CBCT	p-value
Weighted kappa for grading	0.58	0.46	0.82	-
Correct Grade I classification	9/15 (60.0%)	6/15 (40.0%)	12/15 (80.0%)	0.018
Correct Grade II classification	16/25 (64.0%)	14/25 (56.0%)	22/25 (88.0%)	0.006
Correct Grade III classification	12/14 (85.7%)	9/14 (64.3%)	13/14 (92.9%)	0.041
Mean absolute measurement error (mm)	0.91±0.64	1.26±0.72	0.36±0.28	<0.001
Inter-examiner kappa	0.71	0.63	0.86	-

p-values compare CBCT with periapical radiography for grade-wise classification and CBCT with clinical probing for measurement error

male. Mandibular molars constituted 43 sites (59.7%) and maxillary molars 29 sites (40.3%). Intra-surgical assessment confirmed furcation involvement in 54 of 72 molars (75.0%). Grade I, Grade II and Grade III furcation defects were found in 15, 25 and 14 molars, respectively.

CBCT correctly identified 51 of 54 surgically confirmed furcation defects and 16 of 18 molars without furcation involvement. Sensitivity, specificity, positive predictive value, negative predictive value and overall accuracy were 94.4, 88.9, 96.2, 84.2 and 93.1%, respectively. In comparison, periapical radiography showed sensitivity of 68.5%, specificity of 77.8% and overall accuracy of 70.8%. The sensitivity difference between CBCT and periapical radiography was significant ($p<0.001$). Clinical probing showed high sensitivity but lower specificity than CBCT.

The area under the curve for CBCT-based detection was 0.92, compared with 0.73 for periapical radiography. CBCT false-negative findings were limited to three shallow Grade I lesions, two in maxillary molars and one in a mandibular molar. Two CBCT false-positive findings occurred in molars with concave root trunk morphology and early interradicular cortical thinning that did not meet the surgical threshold for Grade I involvement. Periapical radiography missed a larger proportion of Grade I and Grade II lesions, especially in maxillary molars.

Agreement with intra-surgical grading was highest for CBCT. Weighted kappa was 0.82 for CBCT, 0.58 for clinical probing and 0.46 for periapical radiography. CBCT performed particularly well for Grade II and Grade III defects, while early Grade I defects contributed most false-negative CBCT findings. The mean absolute horizontal measurement error was significantly lower for CBCT than for clinical probing and periapical radiography-derived estimation. Inter-examiner agreement for CBCT grading was excellent (kappa = 0.86) (Table 1-3).

DISCUSSION

This study showed that the diagnosis and grading of furcation defects assessed by the limited-field CBCT has high diagnostic accuracy in chronic periodontitis involving molars. The sensitivity, specificity and overall accuracy of CBCT were 94.4, 88.9 and 93.1%, respectively, against intra-surgical findings. These were better than periapical radiography and had higher grade-wise agreement than clinical probing. The findings reveal that CBCT is helpful when precise furcation morphology is required for the more complex periodontal treatment planning.

CBCT has the diagnostic advantage that is biologically and anatomically plausible. Furcation defects are 3D lesions, which can be buccolingual, vertical and/or oblique. This anatomy is collapsed onto a two-dimensional image with conventional periapical radiographs and distorted by the projection geometry, superimposition of roots and masking by the cortical bone. This is the reason that periapical radiography had a high positive predictive value but a low negative predictive value in the present study. Periapical radiolucency was not predictive of furcation involvement, especially in maxillary molars.

Another clinical benefit of CBCT is the ability to show the relationship between the furcation entrance, root trunk length and residual interradicular bone and adjacent root concavities. These features can be challenging to incorporate in two dimensional x-rays. Clinically, the information might affect the choice of access flap debridement, regenerative therapy, furcationplasty, odontoplasty, tunnel preparation, root separation or extraction. Value of CBCT therefore is no longer just the number of accuracy; it's transforming the unclear morphology into a visual map for individual treatment planning.

Our results corroborate those of other studies that have reported a high CBCT accuracy for the diagnosis and analysis of furcation involvement of the maxillary molars and horizontal bone loss [13,14]. Qiao et al. reported the high accuracy of CBCT in the assessment of periodontal tissue loss as well as root morphology in the maxillary molars with generalized chronic periodontitis [8]. Similarly, Pajnigara et al. found that CBCT was also beneficial in identification and post-operative evaluation of furcation defects [10]. This study is a follow-up to these observations and compares the CBCT, clinical probing and periapical radiography in the same molars to a surgical standard.

There was significant CBCT agreement and moderate clinical probing agreement. Clinical probing will continue to be essential, as it is inexpensive, repeatable and used during the routine periodontal charting. Probing may not, however, be a complete indicator of the extent of the lesion if the furcation entrance is small or if the probe cannot follow the internal contour. Previous researchers, including Zappa *et al*. [5], have reported some of the weaknesses and disadvantages of clinical furcation diagnosis and systematic reviews are still ongoing, which are showing the variations in diagnostic methods [15]. CBCT should therefore be considered as an additional-not a replacement-for periodontal examination.

Early furcation involvement in Grade I was most difficult in this study. Small horizontal defects in the vicinity of the furcation opening were not always detected on CBCT or when consensus was reached. This could be related to voxel size, partial-volume averaging, residual calculus and/or early bone loss or limited contrast between bone loss and root surface. By contrast, CBCT proved to be very accurate for Grade II and Grade III defects, which are of clinical significance because they warrant different treatment choices; regeneration, resective and extraction-based.

The primary drawback to CBCT is exposure to radiation. Modern guidelines for periodontal imaging focus on justification, optimization and use of CBCT only when the diagnostic value will impact patient care [12,16]. Recent low-dose CBCT studies indicate that low-dose protocols might provide good measurements of furcation defect in experimental protocols but clinical studies are required prior to the generalisation of low-dose protocols [17]. The present study employed a small field of view to provide lower exposure without compromising diagnostic quality.

Previous radiographs, periodontal charting and the anticipated treatment consequences should also be taken into account when making the decision to prescribe CBCT. In a shallow, well treated molar, there may be little benefit to CBCT. However, if a molar has deep pockets, an uncertain furcation grade, regenerative potential, an endodontic history, root proximity or planned surgical therapy, then a limited volume scan may be warranted based on the diagnostic yield. This is also in line with ALARA and ALADA principles as it is a selective approach, with minimum radiation exposure and still being diagnostic.

Small sample size, single-center design, examiner dependence and analytical unit of molars instead of patients are limitations of this study. Surgical assessment is a good reference standard but can be affected by access, bleeding, residual granulation tissue and probe angulation. The low-dose CBCT protocols, automated segmentation and the role of CBCT in decision making on the long-term survival of the tooth and the patient's treatment outcomes should be explored in further multicenter studies using AI-assisted furcation detection [18].

CONCLUSIONS

The limited-field CBCT proved to be very sensitive, specific and to have good agreement with intra-surgical diagnosis for furcation defects in chronic periodontitis. CBCT was more accurate than periapical radiographs and better grading reliability than clinical probing particularly in Grade II and Grade III defects. CBCT may be used selectively if there is a lack of clarity in the standard radiographs and when more detailed, three dimensional information is likely to influence periodontal treatment planning.

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