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Accuracy of three-dimensional imaging in assessing maxillary molar furcation involvement

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Abstract

Aim: To assess the accuracy of cone beam computed tomography (CBCT) in detecting furcation involvement (FI) in maxillary molars.

Material and Methods: Fourteen patients with generalized advanced chronic periodontitis were consecutively recruited and treated non-surgically. In maxillary molars considered for furcation surgery due to increased FI and/or increased probing pocket depths during re-evaluation, CBCT was performed and the degree of FI was evaluated from the CBCT images. Furcation surgery was performed in 25 maxillary molars. Intra-surgical FI assessments were compared with data derived from CBCT images.

Results: Overall, 84% of the CBCT data were confirmed by the intra-surgical findings (weighted $\kappa = 0.926$, 95% confidence interval: 0.681–1.0). While 14.7% (11 sites) were underestimated (CBCT less than intra-surgical value), in only 1.3% (one site) did the CBCT data lead to an overestimation compared with the intra-surgical analysis. The agreement between both assessments was the highest in distopalatal furcation entrances, followed by buccal and mesiopalatal.

Conclusions: CBCT images demonstrate a high accuracy in assessing the loss of periodontal tissue and classifying the degree of FI in maxillary molars.

Key words: cone beam computed tomography; 3D imaging; furcation involvement; maxillary furcation surgery

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Conventional clinical diagnoses of the furcation involvement (FI) of maxillary molars using a curved periodontal probe and two-dimensional (2D) radiographic imaging do not, in many instances, provide sufficient information about the molars' periodontal tissue support and the inter-radicular bone (Hempton & Leone 1997, Müller & Eger 1999, Al-Shammari et al. 2001). Detailed information about the furcation morphology is, however, required for molar teeth before they are subjected to periodontal surgery. Any discrepancies between pre- and intra-surgical findings may lead to an alteration of the surgical treatment plan (Müller & Eger 1999).

Three-dimensional diagnostic approaches, including cone beam computed tomography (CBCT) with reduced radiation exposure, have been introduced recently in periodontology (Misch et al. 2006, Mol & Balasundaram 2008, Barriviera et al. 2009, Grimard et al. 2009, Liang et al. 2009). CBCT has been applied in vivo for the assessment of furcation invasion and treatment planning in maxillary molars (Walter et al. 2009). Almost half of the assessments based on clinical measures and periapical radiographs revealed an underestimation of the FI when compared with the CBCT analysis. Several additional radiographic findings, such as fusion or proximity of roots, have also been found to be relevant for the decision-making process about whether to surgically treat a suspected maxillary molar. Discrepancies between conventional and CBCT-based treatment approaches were found in the majority of the teeth (Walter et al. 2009). Given the potential of 3D imaging for the diagnosis and treatment planning of FI maxillary molars, these radiographic data should be validated with intra-surgical findings.

The aim of this study was to compare the intra-surgical assessment of FI of maxillary molars with data generated by CBCT.

Conflict of interest and source of funding statement

The authors declare that they have no conflict of interests.
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Material and Methods

The study group comprised 14 patients, five women and nine men, with a mean age of 57.0 years (range 42–81 years) and a diagnosis of generalized chronic periodontitis. A total of 14 first and 11 second maxillary molars with 75 furcation entrances were included (Table 1). Patients were consecutively recruited during September 2006 and October 2009 from the pool of patients at the Department of Periodontology, Endodontology and Cariology, University of Basel, Switzerland. The study was approved by the Ethics Research Committee of the University of Basel, Switzerland (EK: 279/09). Patients were thoroughly informed about the rationale for the study and the methods applied and gave their informed consent.

The detailed clinical and radiographic periodontal examinations are described in Walter et al. (2009). In brief, complete clinical and radiographic examinations were performed by two trained periodontists (N. U. Z. and C. W.), whose measurements were calibrated (Cohen's $\kappa = 0.619$). Instructions for supragingival plaque control were given and, if necessary, for stopping tobacco use. Tooth extractions, provisional restorations, splinting of teeth and endodontic (re-) treatment were conducted if indicated. Non-surgical periodontal treatment, i.e. scaling and root planing with hand instruments and ultrasonic devices, was performed at least 6 months before inclusion in the study on all teeth with periodontal probing depths of $\geqslant 4$ mm. Local anaesthesia was administered if indicated. All patients were included in a supportive periodontal treatment programme at 3–4-month intervals. Re-evaluations of the periodontal conditions were regularly performed and revealed "closed periodontal pockets" (Wennström et al. 2005), i.e. with probing pocket depths (PPD) of $\leqslant 4$ mm and no bleeding on probing of most of the periodontia involved. Periodontal surgery was considered for sites with PPD $\geqslant 6$ mm or increased FI. Individuals subjected to periodontal surgery in the maxillary molar area were further evaluated using CBCT. A comparison of the data from CBCT analysis and non-surgical FI assessments in part of the current study population was published in Walter et al. (2009). Patients with at least one maxillary molar with persisting increased PPD ($\geqslant 6$ mm) and advanced FI, defined as horizontal inter-radicular loss of periodontal tissues of degree 2 or 3 (Hamp et al. 1975), were considered for possible inclusion in the current investigation.

Table 1. Data about furcation involvement (FI) obtained from CBCT analyses, performed treatments and FI obtained from intra-surgical findings

Subject no.	Tooth region	PPD (mb-mp)	FI CBCT (b, mp, dp)	Periodontal surgery	
				Treatment*	FI (b, mp, dp)
1	26	3/3/3/8/5/6	III/III/III	5	III/III/III
	16	2/3/4/6/6/6	III/III/III	1b	III/III/III
	17	5/4/5/6/2/7	III/III/III	1b	III/III/III
2	27	4/5/8/8/2/7	III/III/III	1b	III/III/III
3	16	3/2/3/5/2/2	III/III/III	5	III/III/III
4	26	2/3/9/8/2/3	III/0/III	3a	III/0/III
	27	6/2/4/8/4/5	0/I/II	1a	0/I/II
5	26	4/3/5/6/2/3	I/0/I	1a	I/I/I
	27	5/3/6/6/3/5	0/0/0	1a	I/I/I
6	27	2/2/3/3/2/3	III/III/III	1b	III/III/III
7	26	3/2/6/5/2/8	0/III/III	3b	I/III/III
	27	5/2/8/8/3/5	0/III/III	3b	I/III/III
	16	2/2/7/8/2/3	0/0/II	1a	I/I/II
	17	3/2/4/4/2/4	0/0/0	1a	I/I/I
8	16	4/5/9/7/6/5	III/III/III	5	III/III/III
	17	7/3/6/8/3/9	III/III/III	1b	III/III/III
9	16	3/3/5/6/5/8	III/III/III	1b	III/III/III
10	26	4/6/9/5/9/8	III/III/III	5	III/III/III
	27	3/2/4/7/6/3	I/I/I	1a	I/I/I
11	26	3/2/9/9/2/3	0/I/II	3a	0/I/II
12	16	3/2/2/3/3/4	III/III/III	3a	III/III/III
13	26	3/2/3/4/3/9	III/III/III	1b	III/III/III
	27	4/5/4/6/3/3	III/III/III	1b	III/I/III
14	16	3/2/3/3/8/4	I/II/I	3b	I/II/I
	17	3/2/3/8/7/3	0/0/II	1a	0/0/II

*Treatment according to invasiveness: 1. open flap debridement with apically repositioned flap (ARF), without (a)/with tunnelling (b); 2. root separation; 3. (a–c) amputation/trisection of the distobuccal, palatal or mesiobuccal root (with or without root separation or tunnel preparation); 4. (a–c) trisection and removal of two roots (palatal and the distobuccal, distobuccal and the mesiobuccal, mesiobuccal and the palatal root); 5. extraction of the entire tooth. CBCT, cone beam computed tomography; PPD, probing pocket depth.

Analyses of dental CBCT

CBCT were performed in the posterior maxillary area using the high-resolution imaging system 3D Accuitomo 60, XYZ Slice View Tomograph (J. Morita, Kyoto, Japan). Cylindrical volumes of 4×4–6×6 cm, settings in the range of 74–90 kV, 5–8 mA and voxel sizes in the range of 0.08–0.25 mm (2 lp/mm) were used depending on the region of interest. CBCT was performed 3–6 months before surgery. The CBCT images of each tooth included were analysed in the horizontal, sagittal and transversal sections by two of the authors (C. W. and N. U. Z.). All images were analysed on the same monitor (48 cm, 19°, Viewmedic 19C, Totoku, Japan) under standard conditions. The software i-Dixel-3DX (J. Morita), with a linear measurement tool and a digital magnification lens, was used. It facilitates a continuous motion with the cursor in the 3D area visualized in the three planes on the computer screen (Fig. 1).

FI was calculated in the horizontal plane by measuring the distance between the outer root surface and the inter-radicular bone to the nearest millimetre. The degree of FI was graded according to Hamp et al.'s (1975) classification system.

Degree 0: no horizontal loss of periodontal tissue support, i.e. no radiolucency in the furcation area.
Degree I: horizontal loss of periodontal tissue support up to 3 mm.
Degree II: horizontal loss of support exceeding 3 mm, but no "through and through" destruction.
Degree III: horizontal "through and through" – destruction of the periodontal tissue in the furcation.

Intra-surgical examination of FI

When resective therapy was planned and/or periapical lesions were present

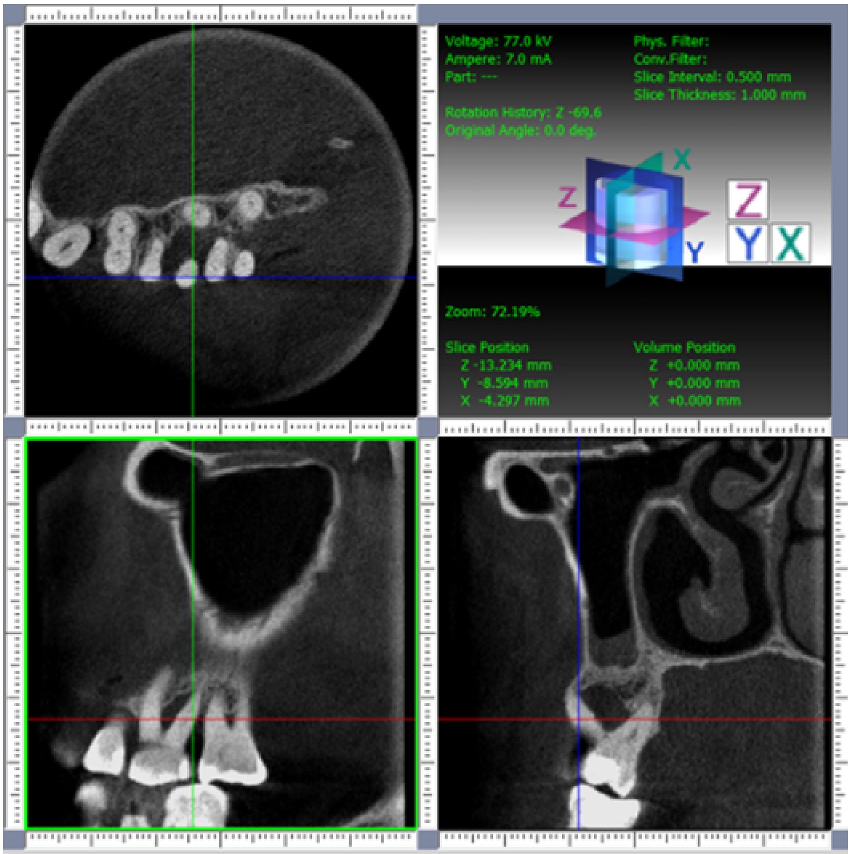

Fig. 1. Cone beam computed tomography with horizontal, sagittal and transversal sections of the first and the second left maxillary molars (subject no. 4).

in the respective maxillary molar, root canal treatment was performed before the surgical intervention. The CBCT-generated data were available to the surgeon before the periodontal surgery. During surgery, patients first rinsed with chlorhexidine (0.2%), and then local anaesthesia was administered labially and palatally, and paramarginal or sulcular incisions were performed, depending on the amount of keratinized tissue present. The surgical area affected all teeth with PPD ⩾ 6 mm of a maxillary quadrant. A distal wedge was prepared if indicated. Vertical releasing incisions were made palatally and labially. After thorough debridement using hand instruments and ultrasonics, the furcation defects were visualized and evaluated by a trained periodontist (C. W. or N. U. Z.) and the assisting dentist, who was blind to the CBCT data. FI was classified at three sites (buccal, mesiopalatal and distopalatal) of the suspected maxillary molars according to measurements with a curved scaled Nabers probe (PQ2N, HU-Friedy, Chicago, IL, USA), marked at 3 mm intervals (Hamp et al. 1975).

Furcation surgery was performed according to a recently introduced classification of invasiveness (Table 1 and Fig. 2; Walter et al. 2009):

1. open flap debridement with an apically repositioned flap (ARF), without (a)/with tunnelling (b);
2. root separation;
3. (a–c) amputation/trisection of the distobuccal, palatal or mesiobuccal root (with or without root separation or tunnel preparation);
4. (a–c) trisection and removal of two roots (palatal and the distobuccal, distobuccal and the mesiobuccal, mesiobuccal and the palatal root);
5. extraction of the entire tooth.

The wound was sutured using 5 × 0 or 6 × 0 monofil polyethylene sutures (Prolene, Ethicon, Johnson and Johnson, Somerville, NJ, USA). Patients were advised to rinse twice a day with chlorhexidine (0.2%). Sutures were removed 6 or 7 days post-surgery. Patients were shown how to apply fluorid and chlorhexidine gel in the furcation area and/or between the (remaining) roots, and scheduled for supportive periodontal treatment at 3–4-month intervals. The treated molars were restored with fixed dental prosthesis, if indicated.

Comparison of intra-surgical and CBCT-based assessments

The degree of FI recorded during periodontal surgery was compared with the degree estimated previously from CBCT imaging. The CBCT diagnosis was either confirmed or a radiographic over- or underestimation was revealed according to the intra-surgical data.

Statistical analysis

The null hypothesis was that no difference exists between the CBCT-based estimation and the following intra-surgical assessment. The rate of agreement was analysed using Cohen's κ and weighted κ with 95% confidence intervals (CI) and an approximate standard error (Cohen 1960, Fleiss et al. 1969). Weighted κ were used in order to assign different weights to subjects where the assessments differed by categories (FI), which meant that the amount of disagreement could be taken into account. For explorative statistics, cross tables and mosaic plots were created. All calculations were performed using the statistical package R (the R Foundation for Statistical Computing Version 2.9.2, Vienna, Austria).

Results

The measurements of PPD obtained during re-evaluation are presented in Table 1, as are the FIs from the CBCT analyses and FI recorded during surgery. The analysis from CBCT revealed an FI in 59 out of 75 furcation entrances. While an FI degree I was assessed in nine and degree II in five entrances, the majority of sites (45) revealed a through and through involvement (degree III). The furcation surgery comprised an open flap debridement with ARF in 15 molars (seven without, eight with tunnelling). Root amputation was performed on six teeth (three times distobuccal and three times palatal root resection), and four teeth were extracted after intra-surgical analyses. These intra-surgical measurements showed that the furcation was not involved (degree 0) in five entrances, FI degree I was found in 21, FI degree II in five and FI degree III in 44 entrances. All molars had an FI degree I–III in at least two of the three entrances, in both the CBCT and the intra-surgical analysis.

Comparison of FI in CBCT and intra-surgical assessment

Overall, 84% of the CBCT data were confirmed by the intra-surgical findings, with a weighted $\kappa = 0.926$ (95% CI: 0.681–1.0). This indicates a high degree of accuracy and verifies the null hypothesis (Fig. 3a). According to the six-level nomenclature (Landis & Koch 1977), κ values between 0.81 and 0.92 are considered as an almost perfect agreement. Among the sites that did not reveal an FI in the CBCT, five were verified as FI degree 0 following debridement, while 11 showed indeed an FI degree I intra-surgically. All entrances with FI degree I or II in CBCT were verified intra-surgically. Among the sites with FI degree III, all except one were indeed through and through furcations. Thus, while 14.7% (11 sites) were underestimated (CBCT less than intra-surgical value), only 1.3% (one site) revealed an overestimation in the CBCT as compared with the intra-surgical analysis.

A separate analysis of the three furcation locations showed that there seemed to be the greatest degree of agreement between CBCT and intra-surgical measurements for the distal ($\kappa = 0.95$, 95% CI:0.603–1.0) and buccal ($\kappa = 0.94$, 95% CI:0.465–1.0) entrances, while the agreement for the mesial measurements amounted to $\kappa = 0.89$ (95% CI: 0.449–1.0) (Fig. 2b–d). The lower value for the mesial entrances was caused by the underestimation (CBCT less than intra-surgical) in four entrances, which were assessed as FI degree 0 in CBCT, and one overestimation as FI degree III in the CBCT, which was shown to be an FI degree I intra-surgically.

Discussion

The present study has demonstrated that estimates from a 3D CBCT of the FI of maxillary molars have a high degree of agreement with those from intra-surgical assessments.

While data derived from CBCT proved to be very accurate in maxillary molars with FI, discrepancies exist between the pre-surgical clinical assessments and the CBCT. The definitions of the terms ‘‘underestimation’’ and ‘‘overestimation’’ were based on the assumption that the method with higher accuracy serves as a reference (accuracy of FI diagnosis: clinical FI < CBCT FI < intra-surgical FI). Hence, for the comparison of clinical FI data with CBCT data in Walter et al. (2009), the estimation of FI in CBCT was supposed

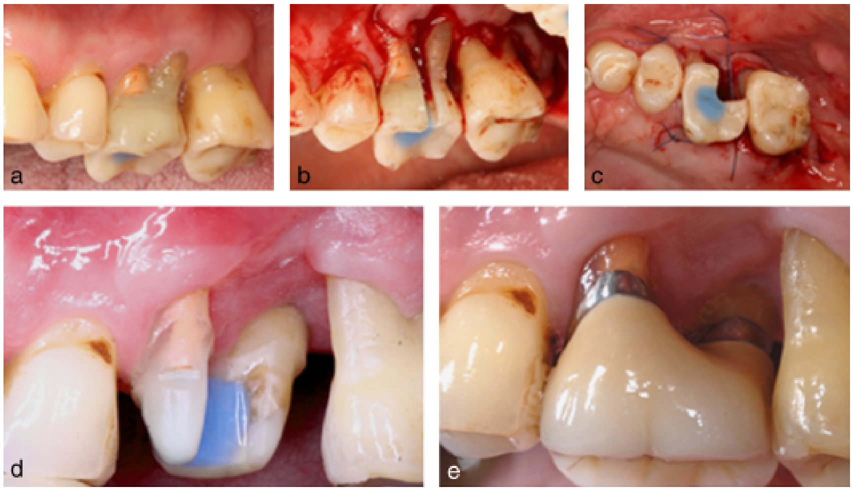

Fig. 2. Intra-surgical clinical photographs of the left maxillary molars of subject no. 4. (a) Pre-surgical view, (b) tri-section of the distobuccal root in the first maxillary molar, (c) the flap is fixed with monofil synthetic sutures 5 × 0, (d) 4 months p.o., the wound healing was uneventful, (e) a crown with an extended metal margin is placed and the patient is instructed in meticulous oral hygiene.

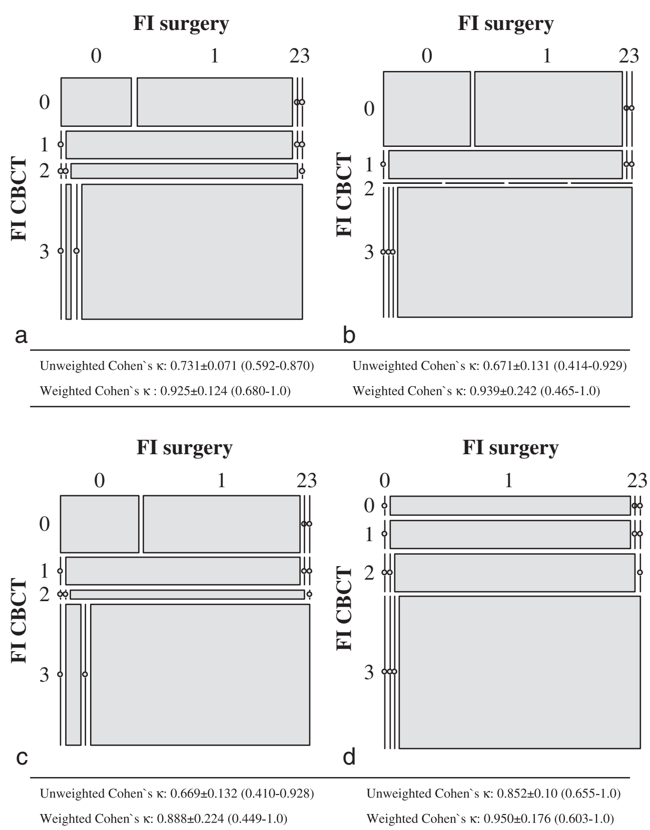

Fig. 3. Degree of furcation involvement (FI, $n = 75$) obtained by cone beam computed tomography imaging compared with intra-surgical findings. The level of agreement between both assessments was calculated by means of Cohen's unweighted and weighted κ statistic (approximate standard error, 95% CI) for: (a) all FI, (b) buccal FI, (c) mesiopalatal FI and (d) distopalatal FI.

to be more accurate. In contrast, in the present investigation analysing CBCT-generated data in comparison with intra-surgical assessments, the latter was supposed to be the ''gold standard'' and taken as a reference. The CBCT data were compared with this gold standard and were therefore either confirmed or rated as over- or underestimated.

According to Walter et al. (2009), the estimated degree of FI based on clinical findings was confirmed in the CBCT in only 27% of the sites, while 29% were overestimated and 44% revealed an underestimation according to CBCT analyses. The overall agreement was ''moderate,'' with a Cohen's weighted $\kappa = 0.518$ (95% CI:0.269–0.767). Among degree I FI, 25% were underestimated, among degree II and II–III (i.e. $\geqslant 6$ mm, but not ''through and through''), the underestimation was as high as 75%, while all sites with degree III FI were confirmed in the CBCT. The largest discrepancies were observed in distal furcation entrances ($\kappa = 0.319$, 95% CI: -0.059–0.697), while the agreement in buccal entrances was $\kappa = 0.584$ (95% CI:0.135–1.0) and $\kappa = 0.528$ (95% CI:0.085–0.971) in mesial sites. It was further demonstrated that CBCT can provide substantial additional information about the root morphology and the residual attachment of maxillary molar teeth (Walter et al. 2009).

Clinical and conventional radiographic measures have been shown to have limitations in several studies when compared with intra-surgical assessments as the ''gold standard''. In these in vitro and in vivo studies, underestimations of more severely defect morphologies, such as FI degree II and III, are common irrespective of the radiographic measure applied. Eickholz and Hausmann (2000) investigated the inter-proximal bone loss from pre-surgical periapical radiographs and found that the defects were on average 1.4 mm deeper intra-surgically. Topoll et al. (1988) compared the clinical and radiological findings of involved furcations with the morphological situation during surgical treatment. With periapical radiographs, the degree of FI was correctly identified and classified in 44% of all investigated molars, with panoramic radiographs in 40%, and with clinical probing alone in 54%. Thus, simple clinical probing appears to be more accurate in assessing the involved furcations than either of the conventional radiological imaging techniques.

Little work has been carried out to assess the advantages of 3D computed tomographies for periodontal diagnosis. Vandenberghe et al. (2008) compared the detection of periapical radiographs and CBCT with the intra-oral situation following flap surgery in two human skulls containing multiple periodontal defects (FIs and intra-bony defects). On the periapical radiographs, the detection of FI failed in 44% of the cases, and only 20% of the FIs were correctly classified. In contrast, 100% detectability and correct classification were observed with CBCT. Misch et al. (2006) obtained similar results, with 100% detection of the artificially created intra-bony defects with CBCT and only 67% on periapicals. Fuhrmann et al. (1997) found that only 21% of the artificial FIs were identified on periapicals and 100% through high-resolution CT. Mengel et al. (2005) compared the periapical radiographs, panoramics, CT and CBCT measurements of different experimental periodontal defects (furcations, dehiscences, fenestrations) with their corresponding histologic specimens. Intra-oral radiography was limited by visibility in the buccolingual direction, while image quality (such as contrast, brightness, distortion and clarity of bone structures) was superior using CBCT. In the present in vivo investigation, the assessment from CBCT was correct in 84% of all maxillary furcations. An underestimation was observed in 14%, all of which were actually FI degree I, while no involvement was found in the CBCT. These discrepancies may be explained by the surgical protocol probably leading to a minor loss of periodontal tissues during instrumentation involving Gracey curettes and ultrasonic devices. For clarification, FI degree I is defined as ''furcation entrance – just detectable with horizontal loss of periodontal tissues up to 3 mm''. An overestimation in the CBCT was a rare finding in this sample. In one of the second maxillary molars, an expected ''through and through'' – destruction of the periodontal tissue in the furcation was not confirmed intra-surgically. The discrepancies between both measurements were most likely related to an overestimation of the degree of demineralization in the furcation area in the radiographic image.

The drawback of all radiological techniques is the exposure to radiation of high-risk organs in the skull, such as the eye lens and thyroid gland. One of the advantages of the CBCT is that it requires less radiation exposure with a smaller volume that can be restricted to examine only the area of interest. However, the fundamental principle for diagnostic radiology abbreviated ALARA (as low as reasonably achievable) has to be followed, and additional CBCT procedures should be reserved for special cases (Farmann 2005). No matter how low the dose, it is excessive if it is unlikely to improve the outcomes of the treatment provided. The study described in this paper shows that the FI in maxillary molars can be classified with CBCT to a high degree of accuracy. According to Walter et al. (2009), CBCT facilitates a more detailed surgical treatment planning with a clear decision about resective interventions in the maxillary molar region. In contrast, clinical data and periapical radiographs led to two or even more different treatment options. Ideally, complete preoperative endodontic treatment is performed only in those roots that are intended to be retained. Avoiding unnecessary treatment interventions generally enables a reduction in patient discomfort, treatment time and costs, and thus probably leads to greater treatment effectiveness. Based on the findings of this study, CBCT imaging in the posterior maxillary area has some clear benefits. However, neither long-term data on CBCT-''guided'' maxillary molar surgery nor data from a cost–benefit analysis are available for this new application.

Thus, the indication for additional CBCT imaging should be based not just on the clinical situation, e.g. a suspected trifurcation, which is hard to detect and interpret, but also on selection criteria derived from the overall periodontal and reconstructive treatment plan. Such criteria could be the need for retention of posterior abutment tooth with good prognosis, and patient's dental and/or medical history and compliance. Moreover patient's desires and requests are also relevant, e.g. if they favour tooth retention and want to avoid implant placement with maxillary sinus surgery. The technical and financial effort involved and the additional radiation risk of the CBCT examination can be justified in patients for whom clinical measures and conventional radiographs cannot provide sufficient information. CBCT could also be used for more complex periodontal treatment planning, such as resective furcation surgery, which also involves prior endodontic and consecutive restorative treatment.

Conclusions

In the present study, CBCT and intra-surgical assessments of maxillary molar FI were found to be in substantial agreement. CBCT enables an exact estimation and classification of the FI, as well as a visualization of the root morphologies with root proximities or root fusions. These measures are essential for a reliable diagnosis and prognosis of the maxillary molar and for adequate treatment planning, particularly when the tooth or remaining roots are in need of restorative treatment.

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Clinical Relevance

Scientific rationale for study: Difficulty exists in clinically diagnosing FI in maxillary molars and selecting the appropriate treatment modality.

Principal findings: Assessments of the FI of maxillary molars with dental CBCT were found to agree well with the intra-surgical findings.

Practical implications: Using 3D imaging provides relevant data for pre-operative decision making. In selected cases, CBCT should be used as an additional diagnostic tool in the maxillary posterior region.