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Three-dimensional imaging as a pre-operative tool in decision making for furcation surgery

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Abstract

Aim: To investigate the use of cone beam computed tomography (CBCT) in assessing furcation involvement (FI) and concomitant treatment decisions in maxillary molars.

Material and Methods: Twelve patients with generalized chronic periodontitis were consecutively recruited and CBCT was performed in maxillary molars ($n = 22$) with clinical FI and increased probing pocket depths. CBCT images were analysed and FI, root length supported by bone and anatomical features were evaluated. FI and treatment recommendations based on clinical examinations and periapical radiographs were compared with data derived from CBCT images.

Results: The estimated degree of FI based on clinical findings was confirmed in 27% of the sites, while 29% were overestimated and 44% revealed an underestimation according to CBCT analyses. Among degree I FI, 25% were underestimated, among degree II and II–III, the underestimation was as high as 75%, while all sites with degree III FI were confirmed in the CBCT. Discrepancies between clinically and CBCT-based therapeutic treatment approaches were found in 59–82% of the teeth, depending on whether the less invasive or the most invasive treatment recommendation was selected for comparison.

Conclusions: CBCT images of maxillary molars may provide detailed information of FI and a reliable basis for treatment decision.

Key words: 3D imaging furcation involvement; cone beam computed tomography; decision making; diagnosis; furcation surgery

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Maxillary molars with inter-radicular loss of periodontal tissue have an increased risk of additional attachment loss with an impaired long-term prognosis. Multiple factors influence the prognosis of furcation-involved teeth, including (i) tooth-related factors such as furcation involvement (FI) degree III, and bone loss at the initiation of periodontal therapy; (ii) factors related to the dentition such as the number of molars left (Dannewitz et al. 2006) and (iii) patient-related factors such as smoking habits, and the applied treatment modality (Hirschfeld & Wasserman 1978, Al-Shammari et al. 2001). Multi-rooted teeth respond less favourably to non-surgical periodontal treatment than single-rooted teeth (Nordland et al. 1987, Loos et al. 1989). In a clinical study with 11 years of supportive periodontal treatment (SPT), it has been demonstrated that probing pocket depth (PPD) of $\geqslant 6$ mm require further therapy in order to prevent ongoing loss of periodontal attachment (Matuliene et al. 2008). Surgical treatment aims for the (i) elimination of residual inflammation and, particularly in molars, in (ii) establishing the feasibility of daily oral hygiene measures in the long term. Both objectives are achieved by a pocket elimination approach combined with enduring accessibility in the furcation of the (remaining) molar roots. In a clinical intervention study, it was demonstrated that tooth maintenance of furcation-involved teeth is feasible in the long term, provided that an adequate treatment including periodontal surgery and subsequent SPT has been applied (Carnevale et al. 1998). Based on ''primum nihil nocere'', the surgical treatment should, however, aim in keeping as much tooth structure and periodontal attachment as possible. Several surgical techniques, including apically re-positioned flaps with or without tunnel preparation, root amputation, hemi-/trisection or root separation, have been described for the treatment of furcation involved maxillary molars. Classifying these

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procedures according to their invasiveness, that is, the amount of resected tooth structure and periodontal attachment, is reasonable. For example, surgical treatment of the first maxillary molar using an apically re-positioned flap (ARF) with tunnel preparation is less invasive compared with the resection of the mesiobuccal and the palatal root with the corresponding part of the clinical crown. Endodontic therapy is needed in the process of resective treatments and is preferably performed before periodontal surgery.

In order to select the appropriate treatment option, a thorough diagnosis is required, which comprises the estimation of the degree of horizontal and vertical FI, the assessment of the residual inter- and periradicular bone, and the evaluation of the root morphology with the length of the root trunk and the degree of root separation. Diagnosis is generally based on PPD, probing attachment level (PAL), probing of the furcation entrance and periapical radiographs (Kalkwarf & Reinhardt 1988). Accurate analysis of FI is, however, not feasible in many instances due to limited access, morphological variations and measurement errors. An ultimate diagnostic tool in verifying clinical and radiographic assessments is an explorative open flap procedure (Åkesson et al. 1992), for example, to assess the amount of the buccal attachment of the palatal root of a maxillary molar, which is otherwise difficult or even impossible to determine. This open flap procedure, however, necessitates pre-surgical endodontic treatment, an immediate treatment decision whether or not to maintain the tooth or the respective root, and further re-constructive rehabilitations in some cases.

As conventional two-dimensional (2D) radiographic imaging does not provide detailed information about the molars' periodontal tissue support and the inter-radicular bone, it might be useful to analyse particularly maxillary molar teeth with a three-dimensional (3D) diagnostic approach. Recently, dental cone beam computed tomography (CBCT) has been introduced to periodontology, and diagnostic accuracy has been verified in the detection and the quantification of periodontal defects in in vitro settings (Misch et al. 2006, Kasaj & Willershausen 2007, Vandenberghe et al. 2007, Mol & Balasundaram 2008). The radiographic tool provides good imaging quality with less radiation exposure than conventional CT devices (Mozzo et al. 1998, Schulze et al. 2004). The potential of this novel approach has not, until now, been evaluated clinically for decision making in the periodontal treatment of furcation-involved molars.

The aim of this study was to investigate the use and potential benefit of dental CBCT in assessing FI and concomitant treatment decisions in maxillary molars. This new approach is compared with diagnoses and treatment recommendations based on clinical and conventional radiographic examination.

Material and Methods

The study group comprised 12 patients (3 women and 9 men) with an average age of 57.5 years (range 41–80 years) and a diagnosis of generalized chronic periodontitis. Six patients had never smoked, two patients had formerly been heavy smokers (>20 cigarettes per day), one was a light smoker (five cigarettes per day) and three were currently heavy smokers. A total of 11 first and 11 second maxillary molars with 66 furcation entrances were included (Table 1). Patients were consecutively recruited during September 2006 and May 2008 from the pool of patients at the Department of Periodontology, Endodontology and Cariology, University of Basel, Switzerland. Complete clinical and radiographic examinations were performed and instructions for supragingival plaque control were given. Tooth extractions, provisional restorations, splinting of teeth, endodontic treatment and instruction for tobacco use cessation were conducted if indicated. Non-surgical periodontal treatment, that is, scaling and root planning with hand instruments and ultrasonic devices, was performed at least 6 months before inclusion in the study at all teeth with periodontal probing depths $\geqslant 4$ mm. Local anaesthesia was applied if required. All patients were included in a SPT program at 3–4 month intervals. The regularly performed re-evaluations of the periodontal conditions revealed ''closed periodontal pockets'' (Wennström et al. 2005), with PPD $\leqslant 4$ mm and no bleeding on probing (BoP) of most of the periodontia involved. Periodontal surgery was considered for sites with PPD $\geqslant 6$ mm. Individuals subjected to periodontal surgery in the maxillary molar area were further evaluated. Patients with at least one maxillary molar with persisting increased PPD ($\geqslant 6$ mm) and/or advanced FI, defined as horizontal inter-radicular loss of periodontal tissues of degree II or III, were considered for possible inclusion in the current investigation and gave their informed consent.

Clinical and radiographic examination

The following clinical evaluations of the included maxillary molar teeth were performed by two trained periodontists (C. W. or N. U. Z.), whose measurements were calibrated before the start of the study. The inter-observer agreement produced a Cohen's Kappa of 0.619.

PPD and PAL were measured to the nearest millimetre at six sites (mesiobuccal, buccal, distobuccal, distopalatal, palatal and mesiopalatal) of the selected maxillary molars using a periodontal probe graded in millimetres (PCPUNC-15; HU-Friedy, Chicago, IL, USA). The cemento-enamel junction or a stable reference point, such as the restoration margin, was used as the reference for the PAL measurements.

FI was measured at three sites (buccal, mesiopalatal and distopalatal) of the suspected maxillary molars using a curved scaled Nabers probe marked at 3 mm intervals (PQ2N; HU-Friedy) without elevation of a soft tissue flap.

The defect was characterized according to Hamp et al. (1975) using a modification of the furcation classification degree II, which was divided into degrees II and II–III.

- Degree 0: furcation not accessible with a periodontal probe
- Degree I: horizontal loss of periodontal tissue support up to 3 mm
- Degree II: horizontal loss of support exceeding 3 mm, but no more than 6 mm
- Degree II–III: horizontal loss of support exceeding 6 mm, but no detectable ''through and through'' destruction
- Degree III: horizontal ''through and through'' destruction of the periodontal tissue in the furcation

Tooth mobility was measured moving the tooth between two rigid instruments and classified according to the Miller's index (Miller 1938):

- Degree 0: no movement distinguishable
- Degree 1: first distinguishable signs of mobility

Table 1. Clinical findings, treatment recommendation and data obtained from CBCT analysis

Subject no.	Tooth region	FI (b/mp/dp)	PPD (mb-mp)	PAL (mb-mp)	Mobility	Pulp sensibility	Treatment recommendation*	CBCT FI (b/mp/dp)	CBCT Supported–unsupported tooth length ratio (mb/db/p)	CBCT Additional data†	CBCT Treatment recommendation*
1	27	III/III/III	3/4/6/5/2/7	5/8/6/6/5/9	1	+	1b/4b‡	III/III/III	3:16/3:16/4:15	B1	1b
2	26	II/III/III	3/3/3/8/5/6	4/5/5/8/7/9	1	–	1b/3a‡	III/III/III	-/3:11/-	C2, D1, D3, E	5
	16	II/II–III/II–III	2/3/4/6/6/6	4/6/7/8/9/7	0	+	1b	III/III/III	5:12/2:14/4:13	-	1b
	17	II–III/II–III/II–III	5/4/5/6/2/7	7/4/5/6/2/9	0	+	0/5	III/III/III	4:11/4:11/4:12	B1	1b
3	27	I/II/II–III	4/5/8/8/2/7	5/6/10/10/6/10	0	+	1b/4b‡	III/III/III	5:15/5:15/7:13	A1	1b
4	16	III/I/II–III	3/2/3/5/2/2	5/6/8/10/5/4	2	–	3b‡/4a‡/5	III/III/III	3:15/-/-	A3, D2, D3, E	5
5	26	II–III/I/II–III	2/3/9/8/2/3	4/7/12/9/4/4	0	+	3a‡	III/0/III	7:13/2:15/5:13	-	3a‡
	27	I/I/I	6/2/4/8/4/5	9/4/7/10/4/5	0	+	1a	0/I/II	8:15/3:14/7:15	B1	3a‡
6	26	I/I/II	4/3/5/6/2/3	4/8/8/7/4/3	0	+	1a/4b‡	I/0/I	§	B1	1a
	27	I/I/II	5/3/6/6/3/5	6/5/5/5/3/7	0	+	1a/4b‡	0/0/0	§	B1	1a
7	27	III/III/III	2/2/3/3/2/3	6/6/6/3/5/7	0	+	1b/3a‡/4a‡/4b‡	III/III/III	6:14/6:14/6:14	B1	1b
8	26	I/I/I	3/2/9/11/3/2	4/3/10/15/9/5	0	+	1a/3a‡	I/0/I	6:9/-/2:18	A3	1a
	27	I/II–III/II–III	7/2/9/10/6/7	11/4/11/10/6/7	0	+	1a/5	III/III/III	4:16/6:13/7:12	B1	1b
9	26	I/II–III/II–III	3/2/6/5/2;8	3/4/8/8/11/10	0	+	1b/3b‡	0/III/III	7:13/7:13/6:15	A1	3b‡
	27	I/III/III	5/2/8/8/3/5	8/4/9/9/4/7	0	+	1b/3b‡	0/III/III	8:14/8:14/8:13	A1	3b‡
	16	I/I/II–III	2/2/7/8/2/3	2/5/8/8/6/3	0	+	1b/3b‡/4b‡	0/0/II	8:12/8:12/7:13	B1	1a
	17	I/II/II–III	3/2/4/4/2/4	3/5/3/3/4/4	0	+	1b/5	0/0/0	12:10/12:10/9:11	B1	0
10	16	III/III/III	4/5/9/7/6/5	9/9/13/10/11/11	1	+	1b/4b‡	III/III/III	-/3:15/-	D1, D3	5
	17	II/II/II–III	7/3/6/8/3;9	10/5/8/9/4/11	0	+	3b‡/5	III/III/III	5:12/3:12/3:14	C1, C3	1b‡
11	16	II–III/I/II–III	3/3/5/6/5/8	6/6/8/9/7/9	1	+	1b/4b‡	III/III/III	6:13/4:16/7:15	D3	1b‡
12	26	II/II/II	4/6/9/5/9/8	7/9/12/10/15/12	1	–	1b/3a‡/4a‡	III/III/III	5:13/-/-	D2, D3	5
	27	II–III/II/II	3/2/4/7/6/3	5/4/6/12/11/7	3	+	1b/5	I/I/I	3:19/5:18/2:19	B1	1a

*Treatment recommendations (categorized in 0–5), see 'Material and Methods'.
†Additional data (classified in A–E), see 'Material and Methods'.
‡Root canal treatment (RCT) required.
§Supported–unsupported tooth length-ratio was not calculated due to lack of radiographic bone loss along the roots.
CBCT, cone beam computed tomography; FI, furcation involvement; PPD, probing pocket depth.

Degree 2: crown deviates within 1 mm of its normal position
Degree 3: mobility is easily noticeable and the tooth moves more than 1 mm in any direction or can be rotated in its socket

Pulp sensibility was tested using CO_2. Periapical radiographs were made from maxillary molars using intra-oral dental films (IP 22 Insight Doppel SP size 2; Kodak GmbH, Stuttgart, Germany), a film-holder with 90° angulation (Rinn; Dentsply Rinn, Elgin, IL, USA) for the parallel technique, and standardized exposure time and X-ray tube voltage (Dental EZ HDX, 65 kV, 7 mA; Dental EZ, Hertfordshire, UK) (Fig. 1).

The CBCTs were performed in the distal maxillary area using the high resolution imaging system 3D Accuitomo 60, XYZ Slice View Tomograph (J. Morita, Kyoto, Japan) with a cylindrical volume of 4 cm × 4 cm to 6 cm × 6 cm, and settings in the range of 74–90 kV and 5–8 mA.

Analyses of dental CBCTs

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.). The software i-Dixel-3DX (J. Morita) with a linear measurement tool and a digital magnification lens was applied, which facilitates a continuous motion with the cursor in the 3D area visualized in the three planes on the computer screen (Fig. 2).

FI was calculated in the horizontal plane measuring the distance between the outer root surface and the interradicular bone to the nearest millimetre. The degree of FI was graded as follows:

Degree 0: no horizontal loss of periodontal tissue support, that is, 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

The degree II–III as used for clinical estimations was not applied in the CBCT analysis due to the difference in

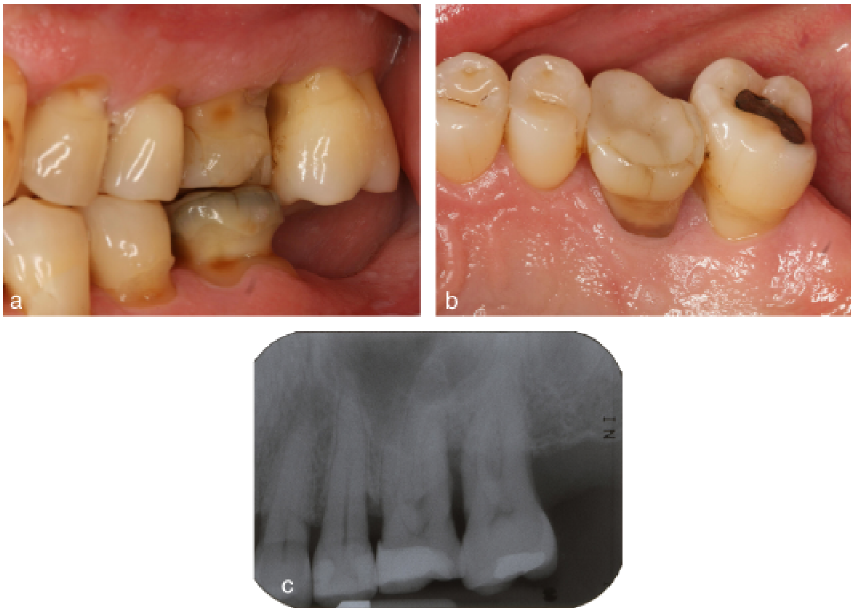

Fig. 1. Intra-oral clinical photographs of left maxillary molars (a, b) and periapical radiograph (c) of subject no. 8.

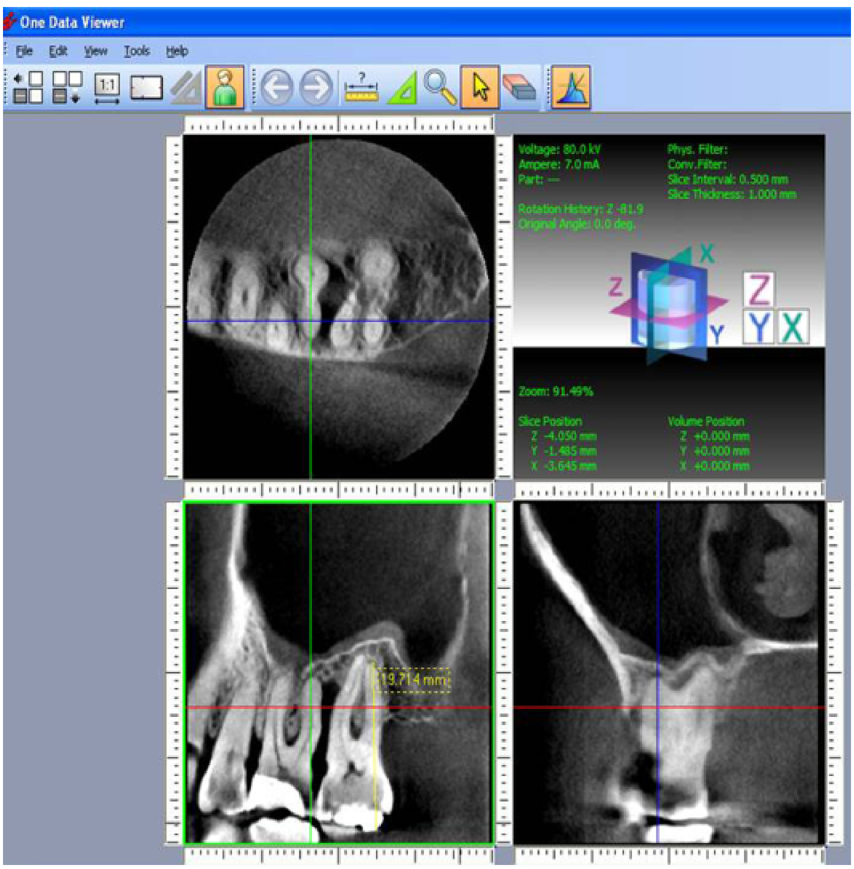

Fig. 2. Cone beam computed tomography (CBCT) with horizontal, sagittal and transversal sections of first and second left maxillary molars (subject no. 8).

the horizontal measures, thus assessing a straight line in the horizontal plane of the CBCT, while clinically a curved probe was used (Fig. 2).

The surrounding bony support of each maxillary molar root was assessed in the appropriate sagittal or transversal plane in the long axis of the root. In addition, the residual tooth lengths including the root compartment not surrounded by alveolar bone and the clinical crown were measured and presented as ratios between supported and unsupported tooth lengths.

Additional radiographic findings obtained from CBCT imaging were categorized as follows:

A: fusion of the whole or part of two adjacent roots indicated by the lack of a separating periodontal ligament

A1: fusion of mesiobuccal and distobuccal root
A2: fusion of mesiobuccal and palatal root
A3: fusion of distobuccal and palatal root

B: root proximity indicated by two separating periodontal ligaments

B1: root proximity at buccal roots
B2: root proximity at mesiobuccal and palatal root
B3: root proximity at distobuccal and palatal root

C: periapical lesion – localized radiolucency surrounding the apical region

C1: periapical lesion at the mesiobuccal root
C2: periapical lesion at the distobuccal root
C3: periapical lesion at the palatal root

D: combined periodontal-endodontic lesion – radiolucency around the apex communicating with the periodontal defect

D1: periodontal-endodontic lesion at the mesiobuccal root
D2: periodontal-endodontic lesion at the distobuccal root
D3: periodontal-endodontic lesion at the palatal root

E: other findings, such as root perforation, fenestration defects, missing buccal/palatal bone plate or overfill of the root canal

Treatment recommendations

Clinical and radiographic findings with intra-oral photographs were presented to a periodontist not involved in the clinical therapy (C. W. or N. U. Z.) without viewing the corresponding CBCT images. The periodontists then made recommendations for further periodontal treatment.

Treatment options were graduated from a less invasive, that is, keeping as much periodontal attachment as possible, to a more invasive approach. In this classification, the mesiobuccal root with an average root surface area of 118 mm^2 was considered a more valuable root than the palatal (115 mm^2) or the distobuccal root (91 mm^2) (Bower 1979, Gher & Dunlap 1985, Al-Shammari et al. 2001):

0: no surgical treatment, SPT

1: ARF

1a: ARF without tunnel preparation
1b: ARF with tunnel preparation

2: root separation

3: amputation/trisection of a root (with or without root separation or tunnel preparation)

3a: amputation/trisection of the distobuccal root
3b: amputation/trisection of the palatal root
3c: amputation/trisection of the mesiobuccal root

4: trisection and removal of two roots

4a: trisection of the palatal and the distobuccal root
4b: trisection of the distobuccal and the mesiobuccal root
4c: trisection of the mesiobuccal and the palatal root

5: extraction of the entire tooth

If the clinical and radiographic findings did not clearly indicate a distinct periodontal therapy, several treatment options were considered (Table 1).

In a second step, CBCT data were presented, and the periodontist treating the patient (C. W. or N. U. Z.) and a blinded periodontist (C. W. or N. U. Z.) discussed possible treatment options for the affected tooth. Based on clinical data, periapical radiographs and CBCT findings, a consensus was finally reached for the most adequate treatment approach.

Comparison of conventionally based and CBCT-based assessments

The degree of FI obtained by periodontal probing was compared with the degree estimated from CBCT imaging. The clinical diagnosis was either confirmed, or a clinical over- or underestimation was revealed according to the CBCT data. Treatment recommendations based on clinical evaluation and periapical radiographs alone were compared with decision making following supplemental CBCT imaging.

Statistical analysis

The Wilcoxon signed rank-test ($p < 0.05$) was used for the analysis of differences between the degree of FI as well as between the selected treatment options. The less invasive approach or, in a separate comparison, the most invasive therapeutic approach was selected if more than one option was taken into consideration clinically. The null hypothesis was that no differences exist between the CBCT-based estimations and treatment recommendations and the clinical assessments.

Results

The clinical findings and data from the CBCT analyses are presented in Table 1.

FI in the CBCT *versus* conventional analysis

FI was clinically observed in all 66 furcation entrances, while a FI degree I–III was found in 52 sites according to the CBCT (Table 1). Overall, only 27% of the clinical findings were confirmed in the CBCT (Table 2), while 29% were overestimated (CBCT < clinical value) and 44% revealed an underestimation (CBCT > clinical value, $p = 0.076$). Among the degree I FI, 25% were underestimated, whereas among the degrees II and II–III, the underestimation was as high as 75%. Hence, almost two thirds (62%) of the clinical degree II furcations and the majority of the sites with clinical degree II–III (84%) were indeed degree III furcations. Obviously, all clinically assessed degree III furcations were verified in the CBCT as a through and through lesion. An overestimation was observed in more than 50% of the clinical degree I furcations, which showed no radiolucency in the furcation area (degree 0 in CBCT).

The CBCT analyses revealed several additional findings such as root fusion (five times) or root proximity (10 times), which were not clearly discernible from the periapical radiographs. Combined periodontal-endodontic lesions were

Table 2. Degree of furcation involvement (FI, $n = 66$) obtained by periodontal probing compared with the degree obtained by CBCT imaging

Clinical diagnosis of FI	I				II				II–III				III				All FI	II and II–III*			
Location of FI	b	mp	dp	Total I	b	mp	dp	Total II	b	mp	dp	Total II–III	b	mp	dp	Total III		B	mp	dp	Total II and II–III
CBCT = clinical value	2	1	1	4 20%	–	–	–	–	–	–	–	–	4	5	5	14 100%	18 27%	–	–	–	–
CBCT < clinical value	6	5	–	11 55%	–	2	3	5 38%	–	–	3	3 16%	–	–	–	–	19 29%	–	2	6	8 25%
CBCT > clinical value	2	2	1	5 25%	4	3	1	8 62%	3	4	9	16 84%	–	–	–	–	29 44%	7	7	10	24 75%
N	10	8	2	20	4	5	4	13	3	4	12	19	4	5	5	14	66	7	9	16	32

The clinical diagnosis was confirmed (CBCT = clinical value) or classified as over- (CBCT < clinical value) or underestimated (CBCT > clinical value) after evaluation of CBCT images (*n* and %).

*Frequencies of clinically diagnosed furcation involvement II and II–III combined. The clinical classifications furcation involvement II and II–III corresponds to furcation involvement II in the CBCT.

CBCT, cone beam computed tomography.

Table 3. Treatment recommendations according to clinical findings and periapical radiographs compared with treatment recommendations made following CBCT analysis: (a) the less invasive treatment approach was used for comparison in cases were several options were considered; (b) the most invasive treatment approach was used for comparison in cases were several options were considered

Clinical recommendation	0	1a	1b	2	3a	3b	3c	4a	4b	4c	5	Total (*n*)	Total (%)
(a)													
CBCT = clinical recommendation	–	3	5	–	1	–	–	–	–	–	–	9	41
CBCT > clinical recommendation*	1	2	5	–	–	1	–	–	–	–	–	9	41
CBCT < clinical recommendation†	–	–	3	–	–	1	–	–	–	–	–	4	18
N	1	5	13		1	2	–	–	–	–	–	22	100
(b)													
CBCT = clinical recommendation	–	–	1	–	1	2	–	–	–	–	–	4	18
CBCT > clinical recommendation*	–	1	–	–	1	–	–	1	1	–	–	4	18
CBCT < clinical recommendation†	–	–	–	–	1	–	–	–	7	–	6	14	64
N	–	1	1	–	3	2	–	1	8	–	6	22	100

*CBCT-based treatment recommendation is more invasive than clinical.
†CBCT-based treatment recommendation is less invasive than clinical.
CBCT, cone beam computed tomography.

found in nine roots affecting five teeth (Table 1). Further, in one tooth (tooth 26 in patient 2), a palatal root perforation in the area of the post and a missing buccal bone wall at the mesiobuccal root were observed. The first maxillary molar in patient 4 exposed 2 mm overfill on the palatal root, while the filling material in the distobuccal root was 2 mm short of the apex and a periapical lesion was visible.

Treatment recommendations with CBCT *versus* conventional approach

While the analysis of clinical data and periapical radiographs indicated more than one treatment option in most maxillary molars, the additional CBCT analysis facilitated a clear decision for further periodontal treatment in all teeth investigated.

Selecting the less invasive treatment recommendation among those considered according to clinical findings and periapical radiographs, an agreement was observed in 41% of the teeth, while in another 41% the CBCT-based treatment decision was more invasive than the clinical one (Table 3a). Discrepancies between the CBCT-based and the clinical therapeutic approaches amounted to 59% with the less invasive treatment ($p = 0.084$), rising to as much as 82% when the most invasive treatment recommendation was selected ($p = 0.004$, Tables 3a and 3b). Hence, the CBCT-based therapeutic approach differed significantly from the less and the most invasive clinical treatment recommendation. Additional CBCT findings, such as root perforation (patient 2) or combined periodontal-endodontic lesions (patients 4, 10 and 12), led to the decision to extract the tooth in question. Amputation of the distobuccal (3a) or palatal root (3b) was planned in 10 molars, but was not feasible in two maxillary molars (patients 4 and 8) due to the fusion of the distobuccal and palatal root. In one molar (tooth 17 in patient 9), the CBCT analysis revealed an overestimation of FI. Hence, the surgical intervention, which had been planned based on the clinical findings and periapical radiographs, was not indicated according to the CBCT findings.

Discussion

The present study has demonstrated that findings from a 3D CBCT add substantial information about the root form and proximity, FI and the presence of mineralized connective tissue at maxillary molar teeth. It was further observed that these additional data led to a discrepancy in treatment recommendations for the majority of molars with the treatment decisions based on clinical data and periapical radiographs.

Several authors have reported difficulties in correctly estimating the FI of maxillary molar teeth from clinical measurements and periapical radiographs (Zappa et al. 1993, Eickholz 1995). Using intra-surgical horizontal probing and silicone impressions, Zappa et al. (1993) found that 27% of true degree III furcations had been clinically underestimated, while overestimation was found in 18–21% of the degree I and 21% of the degree II furcations. The differences between the clinical and surgical assessments measured up to 9 mm, demonstrating a limited value of the clinical measures, which probably assigned inadequate treatment modalities (Zappa et al. 1993). Eickholz (1995), however, did not find significant differences between the pre-surgical and intra-surgical furcation classes. In this study, clinically estimated degree III furcations were excluded, and 14% of the clinical degree II involved furcations exposed a degree III intra-surgically (Eickholz 1995). In the current study, the established Hamp classification (1975) was modified by a sub-classification of FI degree II. The additional FI II–III allows for a discrimination of horizontal loss of periodontal tissue exceeding 6 mm without detectable ''through and through'' destruction. However, the majority of FI degrees II and II–III were indeed horizontal through and through defects according to the CBCT. Morphological factors such as long root trunks, root concavities, bifurcation ridges and small furcation entrances contribute considerably to the difficulties in accurately assessing the FI clinically (Al-Shammari et al. 2001). Because of these limited options to properly estimate the horizontal attachment loss of maxillary molars, intra-operative alteration of a treatment plan is frequently required.

Misch et al. (2006) and Vandenberghe et al. (2007) analysed linear measurements of periodontal defects made with CBCT images or periapical radiographs of skulls. While radiographic detection was restricted to inter-proximal defects, the 3D capability of CBCT offered significant advantages in identifying and measuring buccal and lingual defects (Misch et al. 2006). CBCT was superior for assessing FIs and crater defect, but periapical radiographs scored better for contrast, bone quality and delineation of the lamina dura (Vandenberghe et al. 2007). Good accuracy in terms of linear and volumetric measurements of osseous defects was confirmed for CBCT in several in vitro studies (e.g. Misch et al. 2006, Pinsky et al. 2006). In the current material, the furcation area was analysed in the three sections of the CBCT, and several additional morphological variations like root proximity or root fusion were detected. It was found that in the majority of maxillary molar teeth, clinical data and periapical radiographs led to two or even more different treatment options, while using CBCT data provided a better basis for selecting a distinct treatment plan.

It is obvious that the accurate detection of the FI and the assessment of the root morphology affects the diagnosis and is consequently essential for the choice of treatment, the tooth prognosis and the maintenance procedures. The CBCT facilitates more detailed surgical treatment planning with a clear decision about resective interventions with a specification of the roots that are planned to be kept. Ideally, pre-operative endodontic treatment is then performed only in those roots intended to keep, while the coronal part of the root to be resected is obturated with composite resin. In addition, the CBCT enables the estimation of periapical lesions, or combined periodontal-endodontic lesions, the assessment of the existing root canal treatment, and the appraisal of the second mesiobuccal root canal, which was indeed observed in all specimens investigated in the current material. Avoiding unnecessary treatment interventions enables a marked reduction in patient discomfort, treatment time and costs, and enhances treatment effectiveness.

Ross & Thompson (1980) reported a high incidence of 90% furcation-involved maxillary molars in a population treated for generalized chronic periodontitis. FI was detected more frequently by conventional periapical radiographs than by clinical examination. While in 65% of FI teeth, there was an agreement in the clinical and radiographic findings about FI, 22% were found by radiographic examination only, and in 3% FI was detected by clinical examination alone (Ross & Thompson 1980). In the present study, the CBCTs facilitated an exact estimation of the FI, root proximities and root fusions. These measures enabled a more reliable diagnosis and prognosis of the root and a more adequate treatment planning. Selecting the appropriate therapy is of great importance, particularly when the tooth or remaining roots are in need of restorative treatment and/or are planned as abutments for a fixed dental prosthesis (FDP).

McGuire (1991) and McGuire & Nunn (1996) observed a tooth loss of 2% in periodontally treated patients during maintenance, with maxillary molars being the most frequently extracted teeth. Compared with the initial tooth prognosis given following the active phase of periodontal therapy, the 5- and 8-year estimations showed tremendous improvements particularly for teeth initially assigned to a good, fair or even poor prognosis. Deteriorations, however, occurred mainly in teeth initially assessed as questionable or hopeless, that is, presenting with severe attachment loss resulting in a poor crown-to-root ratio, inaccessible degree II or III furcation and/or increased tooth mobility. The group of hopeless teeth were defined as those having inadequate attachment for maintenance, where extraction was advised but not performed due to the patients' requests (McGuire 1991, McGuire & Nunn 1996). In the current material, the residual attachment of every single root was assessed in the CBCT and related to the tooth length not supported by alveolar bone (ratio supported:unsupported tooth length), which is deemed to be a more appropriate measure than the crown-to-root ratio itself. Although no strict data exist about the minimum amount of periodontal support ensuring the capability to serve as abutment for a single tooth restoration or an FDP, the current findings help to assess the residual attachment and indicate a possible need to adjust the occlusal surfaces.

The application of dental CBCT enables a distinct and more detailed assessment of FI in maxillary molars than with the conventional approach using clinical measurements and periapical radiographs. The additional CBCT analysis revealed discrepancies in treatment recommendations for the majority of molars from the decisions based on conventional data. Employing this radiographic tool for treatment planning in furcation-involved maxillary molars helps to verify the clinical diagnosis and avoid redundant surgical or endodontic interventions.

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Clinical Relevance

Scientific rationale for the study: Difficulty in clinical diagnosis of FI in maxillary molars and selecting the appropriate treatment modality.
Principal findings: The dental CBCT facilitates a more detailed assessment of FI and provides a more reliable and profound basis for treatment decisions than the conventional clinical measurements with periapical radiographs.
Practical implications: The 3D imaging has the potential for a more accurate diagnosis of FI and thus presents relevant data for pre-operative decision making.