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ORIGINAL ARTICLE

Digital method for quantification of circumferential periodontal bone level using cone beam CT

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Abstract
Objectives The objective of this study is to develop a new approach for radiographically measuring circumferential periodontal bone level using cone beam CT (CBCT) data. Accuracy and precision were assessed using direct probe measurements on a human skull as a reference.
Materials and methods Digital quantification of circumferential periodontal bone levels was conducted considering bone level measurements, infrabony crater, and furcation detection. For this purpose, a human bony cadaver skull with a restoration free dentition was used, showing periodontal bony defects of teeth 15-17,25-27,35-37,45-47 (FDI classification). Image datasets were acquired using a Promax 3D CBCT device (Planmeca Oy, Helsinki, Finland) at 80 kV and 8 mA, 160 μm voxel size. Circumferential radiographic measurements between cemento-enamel junction and the alveolar crest for the mesial, central, and distal bone levels on the oral and vestibular sides of the examined teeth were carried out based on a prototype of specifically developed software. The measurements were performed by an expert panel of three independent, calibrated, and blinded observers. Manual probe measurements of the periodontal bone loss served as reference standard.
Results The adopted software allowed the quantification of periodontal bone loss at all examined teeth. Overall deviation between radiographic and manual measurements of the observers ranged between 0.36 and 0.69 mm; hereby, 83 % of all results were <0.5 mm. Comparing overall accuracy between the ten turns of radiological measurements, accuracy for all observers ranged from 0.29 to 0.46 mm. The present study design showed a 100 % detection of furcation involvement for radiographic evaluation.
Conclusions The adoption of a special measurement procedure in terms of a 3D coordinate system, which is placed through and perpendicular to the long axis of the tooth, allows consistent measurement positions of the mesial, central, and distal bone levels both for the oral and vestibular sides of the alveolar crest. In this way, reliable and reproducible quantification of circumferential periodontal bone loss using CBCT data with standardized resolution of 160 μm can be performed in all three dimensions.
Clinical relevance This new approach of radiographically assessing circumferential periodontal bone level using CBCT data shows a first promising attempt of accurate detection of periodontal bony defects. Yet, possible negative impact of further clinical parameters in terms of artifact occurrence will have to be furthermore carefully investigated.

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Keywords Periodontal diagnostics · Cone beam CT · Measurement accuracy · Circumferential bone level

Introduction

Radiographic examination has been, at all times, an adjuvant aid in the diagnosis of periodontal disease, determination of the prognosis, and evaluation of the outcome of treatment [1–3]. Today, a number of intraoral and extraoral imaging modalities are available to assist in the examination of the periodontal patient. Commonly used 2-D modalities include bitewing, periapical, and panoramic radiography. All of these modalities can provide important diagnostic information indeed, but none of them without limitations [3].

Hereby, the selection of the appropriate imaging technique cannot overcome the fundamental limitations of two-dimensional dental radiographic imaging, even if the images are of high quality as the 3D nature of an object is mapped to a 2D plane radiographically. With regard to the inconveniences related to 2-D technology, cone beam CT (CBCT) [12] may be useful in selected cases of infrabony defects and furcation lesions, if clinical and conventional radiographic examinations do not provide the information needed for therapy [4, 5, 8]. Where CBCT images include the teeth, care should be taken to check also for periodontal bone levels when performing a clinical evaluation [25]. This study is therefore aiming to evaluate a new method for precise and reproducible quantification of circumferential periodontal bone loss using CBCT data. Accuracy and reliability of radiographic evaluation is assessed using direct manual measures on a human skull as a reference standard.

Materials and methods

Subject matter of study

Accuracy assessment of the periodontal measurement procedure was conducted, comprising the detection of the circumferential bone level, infrabony crater, and furcation involvement. For this purpose, a preclinical study using a dry human cadaver skull with a restoration free dentition in both upper and lower jaws containing multiple periodontal osseous lesions was conducted.

In order to reduce additional external negative impact (e.g., additional artifact occurrence), this study was designed without soft tissue equivalents and high-density materials such as amalgam gold or titanium. For overcoming these limitations and approaching study conditions even closer to clinical everyday life, further studies are presently ongoing.

CBCT examination

For CBCT scanning, a Promax 3D® CBCT device (Planmeca Oy, Helsinki, Finland) was used. The occlusal plane of the jaws was positioned horizontally to the scan plane, and mid-sagittal plane was centered. The beam height at the surface of the image receptor (CMOS flat panel) was adjusted and set to visualize the entire jaws comprising a field of view (FOV) of 80-mm width and 80-mm height. Image matrix consisted out of 501×501 isotropic pixels. A total number of 501 slices of 0.16 mm isotropic voxel edge length was obtained. For image acquisition, the dose protocol was 80 kV and 12 mA using pulsed scanning time of 12 and 22 s.

Observers

A total of three observers with different levels of experience (beginner, advanced, expert) in both 3D imaging and CBCT usage (observers with 1, 3, and 6 years of working experience with CBCT devices) as well as clinical periodontology (all observers with several years of clinical experience) participated in the study. For radiographic interpretation, these experts were trained and calibrated to cope with the software and perform measurements of the defects using CBCT scan images. In this context, each observer was trained approximately 2 h with the software (this included the detailed learning of the software (1 h) and the time to practice own skills with the same set of five different adult periodontal image cases (1 h)). Subsequently, observers were asked to repeat radiographic measurements under same circumstances for a total of ten times within a 4-week interval. In order to analyze how "daily" performance could influence the observers, only one turn of measurements was allowed per day.

The gold standard was assessed by the same observers with manual probe measurements performed between the reference landmarks CEJ and AC at each tooth. Therefore, all observers were calibrated with the periodontal millimeter probe (CP-15, Hu-Friedy, Chicago, USA) and furcation probe (PQ-2 N, Hu-Friedy, Chicago, USA) using an acrylic glass ex vivo test model with defined millimeter scatter before doing the physical six-point measurements on the mesial, central, and distal bone levels on the oral and vestibular sides of the alveolar crest (AC).

Measurements

For measurement and validation purposes, both single- and multirooted teeth were considered. In order to represent different cortical and cancellous bone structures, both upper and lower jaws of the human skull model were examined (teeth 15-17,25-27,35-37,45-47 according to FDI classification). For radiological assessment and detection of periodontal bone loss, the dataset was exported as multistack file in DICOM format out of the manufacturer's software into a specific software implementation (Institut Straumann AG, Basel, Switzerland). The three-dimensional position of the tooth in *x*-, *y*-, and *z*-coordinate within the dental arch was determined by fixation of the central point of the examined tooth.

For accurate positioning, the cemento-enamel junction (CEJ) was referred to in both sagittal and coronal planes. Within a reconstructed 3D coordinate system, three transversal planes through and perpendicular to the long axis of the tooth allowed six bone level measurement positions of the mesial, central, and distal bone levels both for the oral and vestibular sides of the alveolar crest (Fig. 1a–d). In these transversal sections calculated and displayed, the cemento-enamel junction and the alveolar crest were referred to as landmarks and measurement points (Fig. 2).

As a consequence, every measurement point placed in the dataset could be referenced due to its defined *x*-/*y*- and *z*-coordinate values, and in this way, vertical linear distances between CEJ and AC automatically generated along the *z*-coordinate. As a result, radiological distances were obtained for the mesial, central, and distal bone levels and bone crater depths on the oral and vestibular sides of the alveolar crest. With regard to clinical periodontal six-point measurement scale systems, the circumferential bone level was represented in a similar way.

In addition, in the case of multirooted teeth, the potentially existing radiological furcation involvement was examined by identifying the furcation upper boundary (FUB) and furcation lower boundary (FLB) using a 360 ° rotational procedure (Fig. 3). Both radiological and clinical measurements were carried out by the same observers on two separate occasions within a 6-week interval.

Statistical analysis

To evaluate the reliability of the repeated radiological and clinical measurements, mean and within-tooth standard deviation were first calculated for each observer and measurement site per tooth. In the second step, the coefficient of variation as normalized measure of dispersion was calculated for each tooth and observer. Finally, the mean coefficient of variation and mean standard deviation were calculated by averaging over all measured teeth for each observer separately to evaluate the agreement between the two methods of evaluation, in that case, the radiological evaluation and clinical measurement of the corresponding distances.

Pearson product–moment correlation coefficient was obtained to measure the strength of linear association between radiographic measurement differences and measurement distances. One-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences within the results of the different observers.

Paired *t* test was used to assess whether the means of the two groups of clinical and radiological measurements are statistically different from each other. For further interrater reliability analysis, SPSS reliability procedure (IBM SPSS v19, Chicago, USA) was performed.

For evaluation of furcation involvement both Pearson's chi-square test and Fisher's exact test were used to assess the statistical significance of deviation concerning the independence between both measurement procedures. All statistical calculations were carried out using IBM SPSS v19.

Results

Radiological evaluation

Radiographic assessment of all examined teeth could be accomplished by all observers. In this context, neither bias nor systematic overall variance could be found within in the radiographic or clinical measurements. Comparing overall accuracy between the repeated turns of radiological measurements, accuracy ranged from 0.29 to 0.46 mm (Table 1). After comparing all ten turns of measurements for all observers, highest mean differences between radiographic measurements were detected for oro-mesial (OM) sites

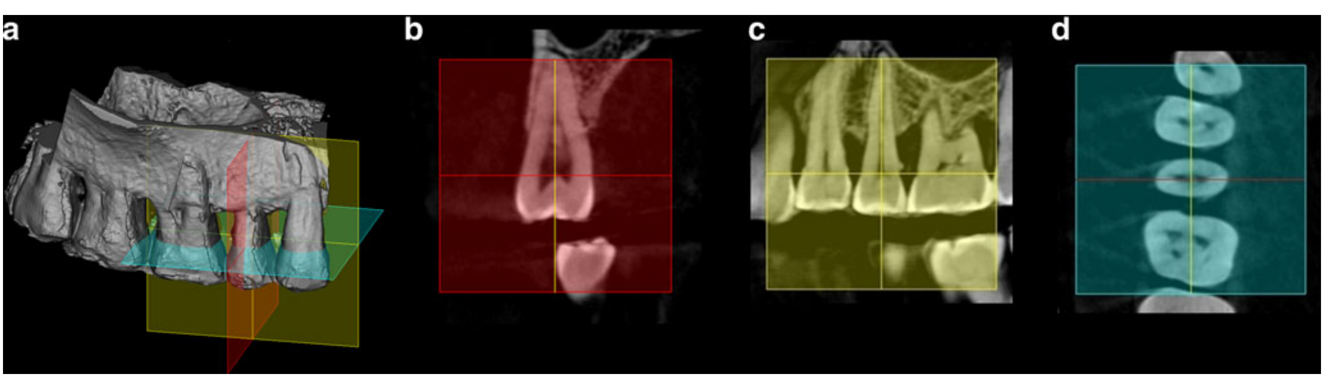


Fig. 1 Exact positioning of the digital coordinate system. **a** 3D reconstruction view in *x*-, *y*-, and *z*-coordinate for the selected tooth. **b**–**d** 2D view orientation: coronal, sagittal and axial view of tooth 15 (FDI; Institut Straumann AG, Basel, Switzerland)

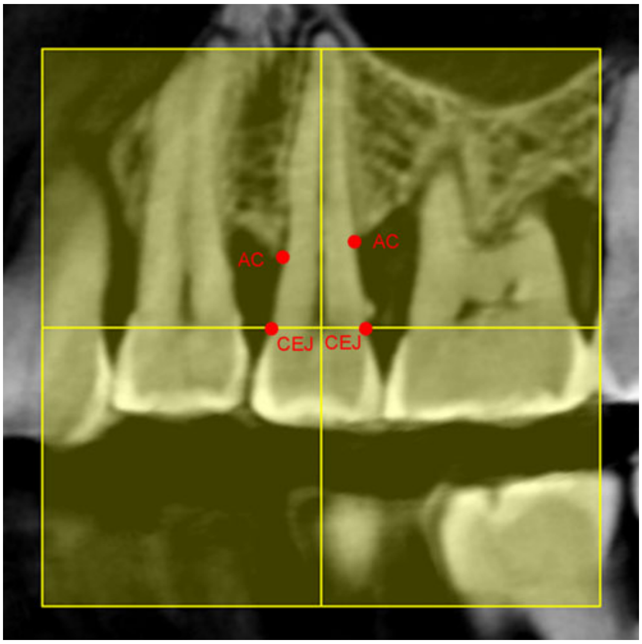


Fig. 2 Selection of anatomical landmarks for further automated radiological measurement purposes: *CEJ* cemento-enamel junction, *AC* apical crest, in sagittal view

0.46 mm (SD 0.48), followed by oro-distal (OD) 0.33 mm (SD 0.24) and oral (O) sites 0.32 mm (SD 0.21), whereas vestibular (V) sites generally showed better results. Smallest discrepancies were shown for the vestibulo-distal sites, 0.29 mm (SD 0.10) (Fig. 6).

As one objective was to compare the accuracy of the measurements with regard to the observers' performance, due to tooth anatomy, the accuracy within the group of single-rooted teeth (Table 1) was ranging between 0.26 mm (SD 0.03) to 0.34 mm (SD 0.11). For multirooted

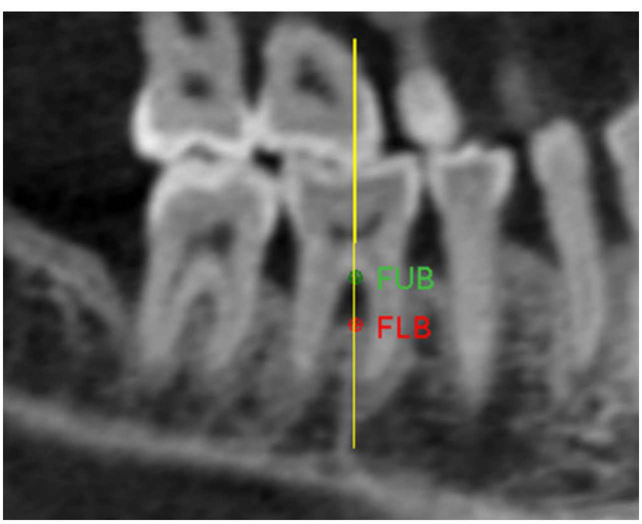


Fig. 3 Selection of anatomical landmarks for further automated radiological measurement purposes: *FUB* furcation upper boundary, *FLB* furcation lower boundary in sagittal view

Table 1 Mean differences for a total of ten turns of radiological measurements carried out by all observers analyzed per measurement site and tooth (in mm)

	Mean	Standard deviation	Standard error
Measurement site			
Vestibular	0.29	0.34	0.05
Vestibular-mesial	0.31	0.19	0.03
Vestibular-distal	0.28	0.10	0.01
Oral	0.32	0.20	0.03
Oral-mesial	0.46	0.47	0.07
Oral-distal	0.33	0.23	0.03
Tooth according to FDI classification			
15	0.26	0.05	0.02
16	0.30	0.08	0.04
17	0.30	0.12	0.07
25	0.30	0.18	0.10
26	0.26	0.01	0.01
27	0.30	0.02	0.01
35	0.34	0.11	0.06
36	0.33	0.07	0.04
37	0.45	0.20	0.11
45	0.26	0.04	0.02
46	0.31	0.07	0.04
47	0.55	0.28	0.16

teeth, results ranged between 0.27 mm (SD 0.02) to 0.55 mm (SD 0.29). One-way ANOVA showed statistically highly significant measurement differences (p=0.05) between the groups of single- and multirooted teeth (F(1,358)=26.65, p=0.00). Overall accuracy for single-rooted teeth was on average 0.29 mm (SD 0.10) versus 0.36 mm (SD 0.15) for multirooted teeth (Fig. 4).

With regard to the relation between measurement differences and measurement distance, Pearson product–moment correlation showed no significant results for vestibulo-mesial (VM) sites (r(36)=0.01, p=0.99). Weak positive correlation was found for O sites (r(36)=0.17, p=0.33), OM sites (r(36)=0.19, p=0.28), and OD sites (r(36)=0.15, p=0.36). Medium correlation was found for vestibulo-distal (VD) sites (r(36)=0.39, p=0.02). Strong positive correlation was found for V sites (r(36)=0.56, p=0.00). As determined by one-way ANOVA, the influence of individual observer activity on measurement error over all measurement sites was not statistically significant (F(2,11)=0.13, p=0.87).

Comparison of clinical and radiological measurement accuracy

Overall deviation between radiographic and clinical measurements carried out by the observers ranged between 0.36

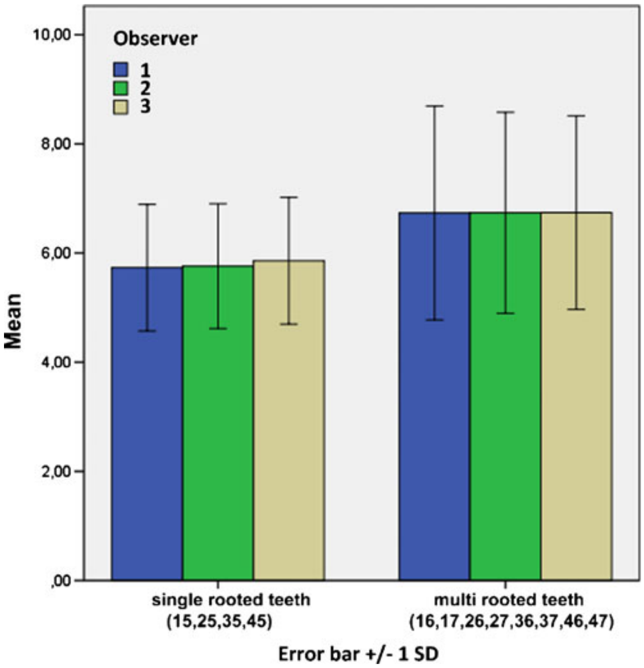


Fig. 4 Overall mean radiographic measurement results (SD) for single-/multirooted teeth. Deviation related to each observer (in mm)

and 0.69 mm; hereby, 83 % of all results were <0.5 mm. In this context, a tendency towards slight better results of vestibular measurement sites (VM, V, VD) compared to oral sites (OM, O, OD) could be observed. Highest measuring deviations between radiographic and clinical measurements were detected for OM sites (0.69 mm), and smallest discrepancies were shown for VD sites (0.37 mm) (Fig. 5a, b).

Paired t test showed that the influence of individual observer activity on measurement error over all measurement sites was not significant (p=0.05) for oral ($t(359)$=0.97, p=0.34) and vestibulo-mesial ($t(359)$=0.35, p=0.73) sites, but for oro-mesial ($t(359)$=3.67, p=0.00), oro-distal ($t(359)$=3.81, p=0.00), vestibular ($t(359)$=2.41, p=0.02) and vestibulo-distal ($t(359)$=3.12, p=0.00) sites.

Furcation involvement

Both Pearson's chi-square test and Fisher's exact test statistically showed a highly significant association between both measurement methods for the detection of furcation involvement (Chi-square (1)=36, p=0.00). A 100 % detection of furcation involvement for both radiographic and clinical evaluation could be assessed. Regarding all examined teeth, the representing 75 % of the total showed a true positive result meaning which is neither clinical nor radiological furcation involvement, whereas 25 % of the total showed a true negative result. Sensitivity and specificity for radiological detection of clinical furcation involvement was 100 %, indicating that all clinical furcation involvements in the examined teeth could be radiologically detected and confirmed by all observers irrespective from the extent of the furcation.

Discussion

For the first time, reproducible and accurate quantification of periodontal bone defects based on CBCT datasets were achieved using the presently described measurement software prototype. In this context, one has to consider that one of the major drawbacks of conventional radiography is the two-dimensional representation of three-dimensional structures. Important morphologic or pathologic aspects of the alveolar bone may remain undetected as a result of overlaying

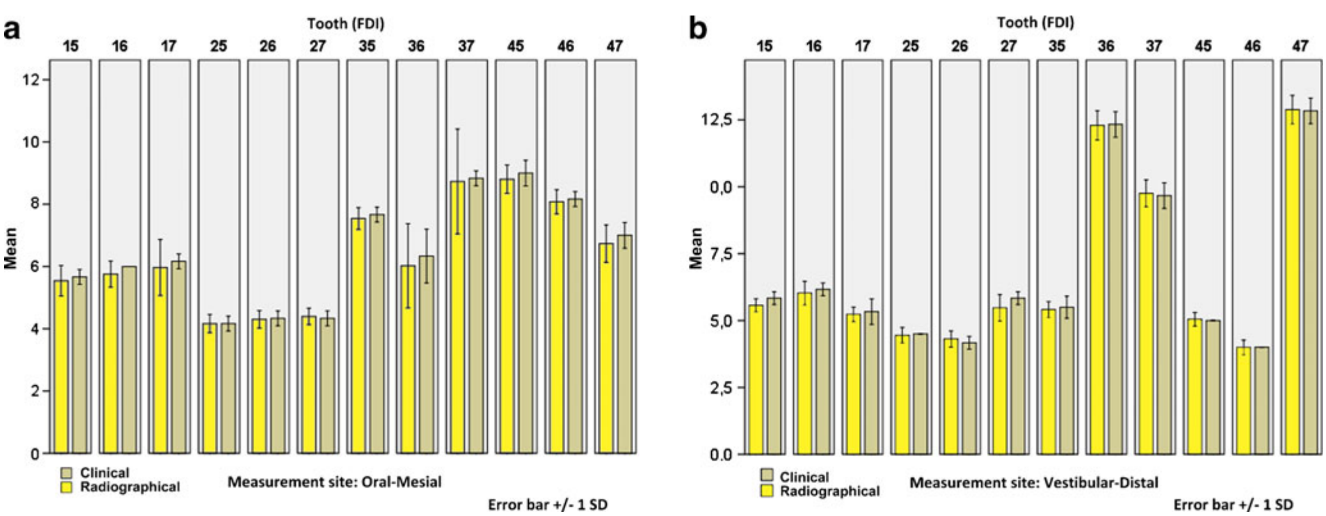


Fig. 5 Separate comparison of clinical and radiographic measurements of every evaluated tooth for all observers (in mm). Results of **a** oral-mesial measurement site and **b** vestibular-distal measurement site

structures of teeth and other anatomic structures. Only the interdental alveolar bone levels can be assessed with some level of certainty. However, detection and quantitative assessment of two- and three-wall defects still remain challenging even in these areas. These limitations not only decrease the sensitivity of conventional 2-D radiographs but also result in underestimating the actual bone loss even if high quality images are produced [7, 10].

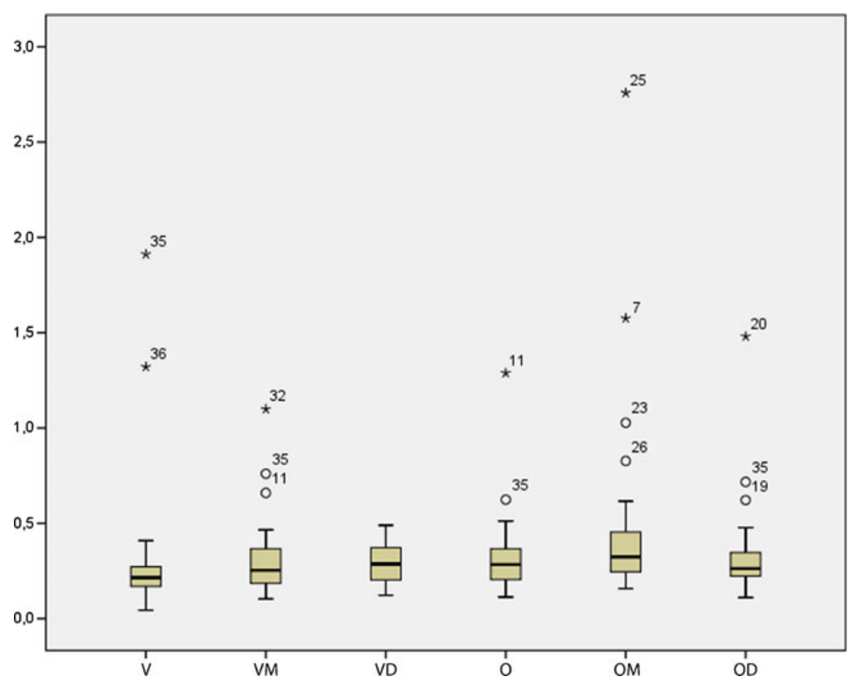
In the present study, we were able to confirm our hypothesis that CBCT would allow an accurate assessment of bone levels and accurate description of infrabony defects. This study could underline the fact that CBCT allows a very precise assessment of bone craters and furcation involvements. With overall mean deviation for radiographic measurements of 0.34 mm (SD 0.14), the present results are situated with the range as described in the literature and can be regarded as an accurate assessment of periodontal bone levels based on CBCT cross-sectional slices (mean underestimation of 0.29 mm), compared to intraoral CCD images (mean error of 0.56 mm) [6, 8, 9, 13]. Vandenberghe et al. [6] and Misch et al. [9] showed that craters and furcation involvement were all detectable (100 %) on CBCT data, while only 67–71 % of the crater defects and 56 % of the furcation involvements were identified on the intraoral CCD images [6]. The results of the present study could endorse these results by successful detection of 100 % of all existing craters and furcations in the presented skull model.

One significant problem, which can affect the image quality and diagnostic accuracy of CBCT images, is the appearance of artifacts. Important types of artifacts such as scatter, streaking artifacts, and beam hardening were caused by high-density neighboring structures, such as enamel, metal posts, and restorations [14, 15]. This problem has to be investigated in future research projects explicitly, using datasets in combination with metalliferous restorations. As our study project intends to be a first step for successful ex vivo testing of detection of circumferential periodontal bone level, we explicitly tried to minimize any negative affection by possible artifact occurrence and therefore used a skull model without metal restorations.

For the same reasons and to reduce another form of image degradation for CBCT images, so-called “motion artifacts” which occur because of patient movement during the scanning process, we used the best fixation of the skull model in the CBCT device, using head-stabilizing devices as well as short-scanning times.

In order to investigate the potential negative influence of artifact occurrence in CBCT data, in particular, for periodontal application, the authors would like to refer to corresponding study designs presently under investigation. Effective doses in dental CBCT modalities are generally coherent to the detector system [11] used and the exposition parameters applied during the examination. Devices using “image intensifiers” generally cause lower X-ray doses compared to flat panel devices. Furthermore, the effective doses of CBCT scanners vary [18–22], and as would be expected, the limited volume scanners, which are specifically designed to capture information from a small region of the maxilla or mandible, deliver a lower effective dose as less of the maxillofacial skeleton is being exposed to radiation. Ludlow et al. [17] reported dose reduction when using smaller FOV examinations. In the present study, we have

Fig. 6 Box plot of exact differences between radiographic bone level measurements of the three observers. The chart shows mean (*black line*), interquartile range (*boxes*), and extreme values for every measurement site. *V* vestibular, *O* oral, *M* mesial, *D* distal. After comparing all ten turns of measurements for all observers, highest mean differences (SD) between radiographic measurements were detected for oro-mesial sites, followed by oro-distal and oral sites, whereas vestibular sites generally showed slightly better results



applied a standardized dose protocol of the manufacturer for a lightweight patient in order to verify accuracy results with minimal doses approximately in the range of a film-based periapical survey of the entire dentition (13–100 μSv) [6, 16]. Nevertheless, the use of CBCT should still be carefully justified. More research with a larger sample size in the future will determine ideal exposure settings and optimized image quality without loss of accuracy.

When defining accuracy in terms of clinical measurement, a certain discrepancy in the range of 0.5–1 mm between actual bone level and estimated bone level on radiographs has to be considered as inevitable, but clinically acceptable [26]. Small or large errors in locating the CEJ and the alveolar crest can respectively lead to over- and underestimation of disease prevalence [6].

All linear measurements, in this study, were done using a standardized dry skull for in vitro pilot testing of the precision of the new method. Considering that a 0.5–1 mm discrepancy can be rated as clinically acceptable [6, 7, 26]. CBCT is accurate enough in 91.7 % of all our measurements. In case of a hypothetical 1 mm discrepancy [26], 100 % of our study results would be in the range of value (Fig. 6). With regard to literature, only limited studies have been reported on the advantages of CBCT for periodontal diagnosis. Stratemann et al. [23] showed that volumetric data rendered with CBCT systems provided highly accurate data compared with the gold standard of physical quantification. CBCT measurements were also shown to be consistent between scan sequences and therefore represent a valid tool for direct measurements between marked reference points [24].

Accordingly, it is important to note the reliability of the depicted measurement model achieved under the present study conditions, notably because of the fact that examiners, despite of their CBCT experience, had never worked with a similar software-based measurement design before participating in the study.

The described study prototype including the need for manual adjusting, both measurement coordinate system and measurement landmarks, showed a mean linear accuracy between 0.29 mm (SD 0.1) for single-rooted teeth and 0.36 mm (SD 0.15) for multirooted teeth. In relation to the chosen voxel size, the smallest identifiable unit of 0.16 mm on this CBCT unit over all measurements were within the range of three voxels or even smaller. It is expected that a similar range of accuracy has at least to be considered under clinical conditions because of other factors such as geometrical errors and artifact occurrence.

In any case, when defining accuracy in terms of clinical measurement, a certain discrepancy between actual bone level and estimated bone level on radiographs will always have to be considered as clinically acceptable, some lack of agreement between different methods of measurement is inevitable. Although a large potential towards new standards in periodontal radiographic diagnostics may result, it has to be emphasized again that this application has to be seen as an adjunct to the clinical examination, not a substitute for it. One may assume that where CBCT images include the teeth, care should be taken to check also for periodontal bone levels [6, 25]. The presented measuring procedure may therefore a very helpful tool. Given the limited number of publications on this subject, more research for periodontal bone level assessment using larger sample sizes as well as clinical studies with intraoperative checkup as a gold standard for the bone defects may be helpful.

Conclusion

For precise and accurate measuring of circumferential periodontal bone levels, the presented new measuring procedure appears to be a first promising step using CBCT data for periodontal issues. Considering advantages, limitations, risks, and machine-specific variations of CBCT, the present study showed the accuracy and potential applicability of a specific CBCT for radiological periodontal diagnosis. In future research, clinical trials should be carried out to verify this statement.

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Conflict of interest The authors declare that they have no conflict of interest.

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