Cone-beam computed tomography performance in measuring periodontal bone loss

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Abstract: The present study aimed to evaluate the performance of cone-beam computed tomography (CBCT) in assessing periodontal bone loss. If effective, CBCT could potentially be a more comfortable and accurate way to evaluate this disease. One hundred and eighty tooth sites from 13 patients were included. Clinical attachment level (CAL) was measured, then CBCT images were acquired prior to periodontal surgery. Three periodontists measured the distance between the cemento-enamel junction and alveolar bone crest at the mesio-buccal, mid-buccal, disto-buccal, mesio-lingual/palatal, mid-lingual/palatal, and disto-lingual/palatal sites. Comparisons of measurements were made among three methods. Inter-observer and intra-observer variances were also analyzed. Statistically significant differences were found between CBCT and CAL + 2.04 mm (P = 0.000), as well as intra-surgical evaluation (P = 0.001). All sites showed differences in CBCT versus intra-surgical measurement and versus CAL + 2.04 comparisons, except the buccal sites (P = 0.187 and 0.147, respectively). This study indicates that the results of CBCT do not agree with results of intra-surgical measurement. As a result, CBCT should be used with caution and only when necessary, to avoid radiation hazards.

Keywords: alveolar bone level; clinical attachment level; cone-beam CT; periodontitis.

Introduction

Measurement of the residual alveolar bone before periodontal treatment can provide insights about the hard-tissue index, influence the administration and formulation of treatment plans, and predict prognosis of periodontitis. The most commonly used clinical measurements for periodontitis are the clinical attachment level (CAL) and pocket probing depth (PPD) (1). As CAL utilizes a fixed reference point rather than gingival margins that change with inflammatory alterations, the CAL measurement generally indicates the degree of periodontal bone resorption and provides a basic idea about the evaluation of periodontal disease. Full-mouth assessment that involves periodontal probing at six sites per tooth in the mouth (mid-buccal, disto-buccal, mesio-buccal, mesio-lingual/palatal, mid-lingual/palatal, and disto-lingual/palatal) (2) provides the optimal examination of periodontal conditions (3). However, manual periodontal probing can sometimes cause discomfort to patients (4), especially those who have not yet received treatment (5). A painful experience during this baseline examination procedure has always been a matter of concern but has rarely been addressed. Although there are some clinical approaches to reducing this pain, such as topical injection of anesthesia or topic superficial anesthesia, all have their own limitations (6).

Therefore, there has been an increasing amount of research to find a more comfortable and easier way to help or promote measurement of bone loss. Cone-beam
computed tomography (CBCT) appears to be a valuable noninvasive tool that is superior to the CAL method in periodontal evaluation and in accurate evaluation of alveolar bone loss. CBCT produces three-dimensional images as well as relatively high-quality images of hard tissue, overcoming the inherent drawbacks of two-dimensional periapical and panoramic radiographs that have been widely applied in dentistry, including periodontics (8). Previous studies have demonstrated that CBCT assessments are acceptable for the measurement of alveolar bone loss (2,9-15), while others reported a lower reliability of CBCT in the diagnosis of bone defects compared to direct measurements on the skull (16). Additionally, some studies were performed in vitro under more controlled and almost idealized conditions with no soft tissue simulation or radio-opaque markers (gutta-percha fragments or metallic balls) to facilitate identification of the cemento-enamel junction (CEJ) (9,15). Therefore, the aim of the present study was to evaluate the accuracy of CBCT and explore the differences between CBCT measurements and other methods of periodontal examinations.

**Materials and Methods**

**Participants**

Thirteen patients (seven males, six females; mean age, 32.5 years; range 22-49) diagnosed with generalized chronic periodontitis were recruited from February 2014 to October 2015 at West China Hospital of Stomatology, Sichuan University. Prior to the investigation, all participants received initial therapy, including scaling and root planning, as well as oral hygiene instructions. Surgical periodontal procedures were completed according to treatment plans. Patients with restorations in the CBCT irradiation area and pregnant or lactating women were excluded from the study. A total of 18 single-rooted and 12 multi-rooted teeth were included. Both maxillary and mandibular teeth were included to reduce the errors from different cortical and cancellous bone structures. All the patients were informed about the study methods and written informed consent was provided. This study was approved by the Ethics Committee of West China School of Stomatology, Sichuan University (Registration No. WCHS-IRB-S-007-A05-V001.01).

**Imaging evaluation**

The periodontal bone levels and CBCT images were analyzed by three periodontists: periodontist 1 had 20 years of professional experience, and periodontists 2 and 3 were Ph.D. candidates. To eliminate inter-examiner bias, the three periodontists were trained and calibrated. In the pilot experiment, the CBCT data were measured 3 times with 5-day intervals to test intra-observer errors. The images were analyzed at different times; thereby, resulting in a blind study of the results.

**Pre-surgical clinical measurements**

The following clinical evaluations of CAL were performed before periodontal surgery by the three periodontists. To ensure effective and accurate measurement of periodontal bone loss during CBCT, periodontal surgery, and CAL, the same reference point was controlled. Distance between the CEJ and alveolar bone crest (AC) was measured using a six-site measuring method. The selected six sites were the mesio-buccal (MB), mid-buccal (B), disto-buccal (DB), mesio-lingual/palatal (ML), mid-lingual/palatal (L), and disto-lingual/palatal (DL). B and L points were chosen as the mid-buccal/lingual site in the surface. Points on proximal surfaces were located on the corner of each tooth (Fig. 1). A periodontal millimeter probe PCPUNC 15 (Hu-Friedy, Chicago, IL, USA) was used and clinically measured by the observers. Measurements falling between two marks on the periodontal probe were rounded up to the bigger millimeter. Recorded alveolar bone loss before periodontal surgery was the sum of CAL and the mean biological width (the junctional epithelium 0.97 mm; connective tissue attachment 1.07 mm) (17). The three periodontists were blinded to the CBCT data.
**CBCT examination**

A 3D Accuitomo CBCT device (J. Morita, Kyoto, Japan) was used for CBCT examination. The occlusal plane of the jaw was positioned horizontal to the scan plane, and the mid-sagittal plane was centered on the scan plane (18). The beam height on the surface of the image receptor was modulated and set to visualize the entire jaw (field of view, 100-mm wide and 100-mm high). For image acquisition, the dose protocol was 85.0 kV and 4 mA with a pulse scanning time of 17.5 s and a voxel size of 0.125 × 0.125 × 0.125 mm.

Three transverse planes passed through or were perpendicular to the long axis of the tooth. The measuring positions of bone level were the same as the positions measured in the pre-surgical clinical measurements and the following surgical measurements from the anatomical landmarks CEJ to AC. For evaluation of the central point of both sides, the linear distances were measured in sagittal planes both on vestibular and lingual (palatal) sides as three transversal planes perpendicular to and through the long axis of the tooth (19) (Fig. 2). Images were viewed by three trained dentists on a monitor set at a screen resolution of 1,280 × 1,024 pixels. The three doctors were all blinded to the clinical recordings. The final clinical dataset was the mean of measurements by the three observers.

**Intra-surgical clinical measurements**

Local anesthesia was administered to patients, and alveolar bone loss was evaluated by the three periodontists blinded to the previously obtained pre-surgical clinical parameters and CBCT data. The gold standard for the measurement of alveolar bone loss is the distance between the reference landmarks CEJ and AC during periodontal surgery. During surgical interventions in this study, the distance was measured by a periodontal probe placed at the same point as before periodontal surgery and in CBCT measurements (Fig. 3).

**Statistical analysis**

Statistical analysis was performed separately for the CBCT, CAL + 2.04, and intra-surgical measurement (gold standard) groups. Normality of data were analyzed for each group using Kolmogorov-Smirnov ($P < 0.05$). Data were found to be non-normally distributed, and Kruskal-Wallis test was applied to analyze possible differences between the groups using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). Comparison between CBCT and direct surgical measurements, as well as CAL + 2.04 was performed with Wilcoxon signed rank test. $P < 0.05$ was considered statistically significant. Inter-rater and inter-rater agreement values of all measurement methods were examined by intra-class correlation coefficient (ICC).

**Results**

Table 1 shows the frequency of differences among CBCT, CAL + 2.04, and the intra-surgical measurement. There were no differences between CBCT measurement and intra-surgical measurement (gold standard) in 56% of sites, while 37% differed by at most 1 mm, 31% by at most 2 mm, 18% by at most 3 mm, 6% by at most 4 mm, and 7% by more than 4 mm. Alternatively, the agreement of the CBCT measurement with CAL + 2.04 occurred in only 56% of the sites, and differences of up to 1 mm, 2 mm, 3 mm, 4 mm, and over 4 mm were observed in 26%, 35%, 22%, 11% and 6% of all sites, respectively.

The comparisons among values of the CBCT measure-
ment, CAL + 2.04, and intra-surgical measurement by probing are shown in Table 2. No difference was observed between CAL + 2.04 and intra-surgical measurement, but there were statistically significant differences between CBCT and CAL + 2.04, as well as intra-surgical measurement. The value of CBCT assessment was lower than the probing measurement from CEJ to AC and closer to the intra-surgical measurement (gold standard).

Table 3 demonstrates differences among the values of measurements obtained by CBCT, clinical probing, and periodontal surgery in 180 sites. All measurements showed differences in CBCT versus intra-surgical measurement and versus CAL + 2.04 comparisons, except the buccal sites ($P = 0.187$ and 0.147, respectively).

**Discussion**

The level of alveolar bone is one of the important indicators for the degree of periodontal tissue destruction. This important variable guides the diagnosis and treatment process. Therefore, the accuracy of alveolar bone measurement is of great importance. Present study demonstrates differences among CAL + biological width (2.04 mm), CBCT assessments, and intra-surgical measurements. CAL is a diagnostic standard for measuring periodontitis (20). It measures the distance from the CEJ to the bottom of the periodontal pocket, while the CBCT image focuses on the distance between the CEJ and the AC. Therefore, the biological width consisting of junction epithelium (0.97 mm) and connective tissue attachment (1.07 mm)

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**Table 1** Frequency of differences between CAL and intra-surgical measurement compared to CBCT

<table>
<thead>
<tr>
<th>differences in millimeters</th>
<th>CBCT - surgery $n$ (%)</th>
<th>CBCT - (CAL + 2.04) $n$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1 (0.56%)</td>
<td>1 (0.56%)</td>
</tr>
<tr>
<td>0-1</td>
<td>67 (37.22%)</td>
<td>47 (26.11%)</td>
</tr>
<tr>
<td>1-2</td>
<td>56 (31.11%)</td>
<td>63 (35.00%)</td>
</tr>
<tr>
<td>2-3</td>
<td>33 (18.33%)</td>
<td>39 (21.60%)</td>
</tr>
<tr>
<td>3-4</td>
<td>11 (6.11%)</td>
<td>19 (10.56%)</td>
</tr>
<tr>
<td>&gt;4</td>
<td>12 (6.67%)</td>
<td>11 (6.11%)</td>
</tr>
</tbody>
</table>

CAL: clinical attachment level; CBCT: cone-beam computed tomography.

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**Table 2** Descriptions and correlations between CBCT, CAL, and intra-surgical measurements

<table>
<thead>
<tr>
<th></th>
<th>CBCT (A)</th>
<th>CAL + 2.04 (B)</th>
<th>intra-surgical measurement (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean (SD)</td>
<td>6.66 (2.38)</td>
<td>7.84 (2.39)</td>
<td>7.62 (2.40)</td>
</tr>
<tr>
<td>median (IQR)</td>
<td>6.37 (2.65)</td>
<td>8.04 (3.00)</td>
<td>7.80 (3.60)</td>
</tr>
</tbody>
</table>

**Kruskal-Wallis test**

- $A \times B$: $P = 0.000^*$
- $A \times C$: $P = 0.001^*$
- $B \times C$: $P = 0.126$

* $P < 0.05$

CAL: clinical attachment level; CBCT: cone-beam computed tomography; SD: standard deviation; IQR: interquartile range.

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**Table 3** Differences in CBCT measurement, intra-surgical assessment, and CAL measurement

<table>
<thead>
<tr>
<th></th>
<th>CBCT</th>
<th>CAL + 2.04</th>
<th>intra-surgical</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>5.98 (2.19)</td>
<td>7.71 (2.19)</td>
<td>6.87 (2.13)</td>
</tr>
<tr>
<td>median (IQR)</td>
<td>5.91 (1.83)</td>
<td>8.04 (2.25)</td>
<td>7.00 (3.00)</td>
</tr>
<tr>
<td>$P$ value</td>
<td>0.000$^*$</td>
<td>0.008$^*$</td>
<td>0.008$^*$</td>
</tr>
<tr>
<td>B</td>
<td>6.51 (2.68)</td>
<td>6.91 (2.18)</td>
<td>7.00 (2.33)</td>
</tr>
<tr>
<td>median (IQR)</td>
<td>6.23 (3.00)</td>
<td>7.04 (3.00)</td>
<td>7.00 (4.00)</td>
</tr>
<tr>
<td>$P$ value</td>
<td>0.147</td>
<td>0.187</td>
<td></td>
</tr>
<tr>
<td>DB</td>
<td>6.83 (2.53)</td>
<td>8.37 (2.17)</td>
<td>7.77 (2.74)</td>
</tr>
<tr>
<td>median (IQR)</td>
<td>6.74 (2.69)</td>
<td>8.54 (3.00)</td>
<td>8.00 (5.00)</td>
</tr>
<tr>
<td>$P$ value</td>
<td>0.000$^*$</td>
<td>0.013$^*$</td>
<td>0.001$^*$</td>
</tr>
<tr>
<td>ML</td>
<td>6.77 (1.92)</td>
<td>8.44 (2.27)</td>
<td>7.93 (1.96)</td>
</tr>
<tr>
<td>median (IQR)</td>
<td>6.26 (2.95)</td>
<td>8.04 (3.00)</td>
<td>8.00 (3.00)</td>
</tr>
<tr>
<td>$P$ value</td>
<td>0.000$^*$</td>
<td>0.001$^*$</td>
<td>0.001$^*$</td>
</tr>
<tr>
<td>L</td>
<td>6.68 (2.36)</td>
<td>7.44 (2.82)</td>
<td>7.60 (2.30)</td>
</tr>
<tr>
<td>median (IQR)</td>
<td>6.61 (2.69)</td>
<td>7.54 (4.00)</td>
<td>7.50 (3.25)</td>
</tr>
<tr>
<td>$P$ value</td>
<td>0.005$^*$</td>
<td>0.009$^*$</td>
<td></td>
</tr>
<tr>
<td>DL</td>
<td>7.17 (2.56)</td>
<td>8.17 (2.43)</td>
<td>8.57 (2.62)</td>
</tr>
<tr>
<td>median (IQR)</td>
<td>7.00 (2.87)</td>
<td>8.04 (2.25)</td>
<td>9.00 (3.00)</td>
</tr>
<tr>
<td>$P$ value</td>
<td>0.015$^*$</td>
<td>0.000$^*$</td>
<td></td>
</tr>
</tbody>
</table>

* $P < 0.05$

(17) is supposed to be the difference between CBCT and CAL. Although the biological width may involve variations among subjects, the variations are small (21,22).

The frequency of differences between CBCT and CAL + 2.04, as well as intra-surgical measurements, have been analyzed. Results show that differences under 1 mm only occur in 26.67% and 37.78%, respectively. Precision to ± 1 mm with a periodontal probe is acceptable in clinical experience (23), and here, the CBCT measurements even improve the precision to ±0.01 mm. Usually, measurements between two marks of the periodontal probe are rounded up to the bigger millimeter. This may be why CBCT data are different than the other two methods of probing assessments.

There is also no significant difference between CAL + 2.04 and intra-surgical measurements (Table 2). To ensure accuracy and reliability of the results, the six site measurements are used for the clinical assessment of alveolar bone level (2). Factors such as force, angulation, and position (24) that influence the accuracy of probing are also taken into consideration. The inter-rater agreement of intra-surgical, CAL, and CBCT measurements are 0.94, 0.89, and 0.95, respectively. This implies a negligible inter-rater variation and a favorable diagnostic efficiency in this study.

On the other hand, CBCT shows statistically significant differences when compared to the intra-surgical measurement (gold standard) and CAL + 2.04 (Table 2). From a clinical perspective, this means that the CBCT measurement is not accurate enough to demonstrate periodontal bone loss. This finding is different than a previous study that compared the accuracy of CBCT and surgical measurements (2). Those studies only included the premolars and molars but not the anterior teeth. Additionally, a previous study by Mol et al. (11) demonstrated that the accuracy of CBCT in measuring the anterior aspect of the jaw is limited, which may result from the morphology of the periodontal bone and considerably thinner buccal and lingual plates in the anterior region. Also, Ising et al. (25) found that the lowest average error from CBCT was 0.33 mm for the incisors, while the highest average error was 0.74 mm for the premolars. It is possible that the accuracy of identifying periodontal defects may vary (26) with different CBCT equipment, depending on the resolution.

By measuring different sites of teeth with different locations, this study indicates see that radiography may underestimate bone loss as compared to clinical situations, a conclusion different from previous studies (2,10). One of the reasons may be that in clinical probing, when measurements fall between two marks on the periodontal probe, the larger value is selected; however, the exact values can be read in CBCT images. Additionally, alveolar bone height measurements from conventional clinical 0.4-mm voxel-size CBCT images may influence the accuracy of assessment (27). Compared with measurements from the 0.4-mm resolution images, the measurements from the 0.25-mm resolution images will be significantly more accurate (27). At times it is also difficult to find the same angles when measuring the distance from CEJ to AC in CBCT imaging compared with clinical measurement, as clinical probing usually favors a more accessible entry. At the contour point of the teeth, the periodontal probe should not be close to the tooth surface.

Table 3 shows the six-site differences of all teeth obtained by these three methods, and only buccal sites show no statistically significant difference among intra-surgical, CBCT, and CAL measurements. This result is consistent with Feijo et al. (28), stating a tendency toward better results in vestibular measurement sites compared to lingual or palatal sites, but in that study only maxillary molars are assessed. As the lingual side has poor accessibility and is difficult to measure by direct probing, differences may exist between CBCT and probing.

Thus, the present study investigates for the first time in vivo performance of CBCT in evaluating alveolar bone levels, including anterior teeth and posterior teeth, and compares it with the CAL method. The data shows that both clinical measurements and CBCT images have limitations in evaluating alveolar bone loss, and a complete representation of periodontal conditions can be obtained by combining clinical examinations and radiological methods.

However, the authors cannot ignore the higher radiation doses for CBCT in alveolar bone loss measurements compared with conventional panoramic and intra-oral imaging (29). When there is metal in the projection, such as metal crowns or amalgam fillings, artifacts will form and make it difficult to identify the edge of the alveolar bone. Therefore, it should be used only when necessary, to avoid radiation hazards.

In conclusion, the measurements of CBCT are significantly different from CAL + 2.04 and intra-surgical assessment. Both clinical measurements and CBCT have their inherent weaknesses. In clinical periodontal diagnosis, CBCT should be used with caution, only when necessary.

**Conflict of interest**
The authors declare no conflict of interest.
References


