Referring crown-to-root ratio and root surface area to assess periodontitis severity and prognosis

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Abstract

Background: Whether the linear crown-to-root ratio (CRR) decided by 3D and 2D clinical attachment loss (CAL) can be applied to evaluate the periodontitis severity and tooth prognosis was rarely examined.

Materials: Sixty-six mandibular and maxillary single-rooted human premolars were surveyed by micro-computed tomography. CRRs at the levels of defined mild, moderate and severe periodontitis severity were analyzed. Statistical significance was confirmed by t -testes.

Results: Along with the definitions, both the findings of coronal 25% root surface area (RSA) with CRR=1:1 corresponded to ≤3.0 mm linear radiographic bone loss (L-RBL) and 20% RSA with CRR=4:5 at L-RBL=1.6–1.9 mm signified ≤15% L-RBL were categorized as mild periodontitis. Similarly, the results of coronal RSA≤52% with CRR≤3:2 at L-RBL≤5.0 mm and RSA=40% with CRR=5:4 at 4.0 mm L-RBL denoted 30% L-RBL were characterized moderate periodontitis. Additionally, relying on whether a 1.0mm connective tissue attachment (CTA) was included, CRR=1:1 at 25% L-RBL or CRR=4:3 at 35% L-RBL corresponded to a 25% clinical attachment loss (CAL), which could be used to distinguish a fair prognosis from a good prognosis. Either the level with 50% L-RBL at CRR=2:1, or the level with 50% CAL and 60% L-RBL at CRR=5:2 could be applied to differentiate a poor prognosis from a questionable prognosis.

Conclusions: The periodontitis severity and tooth prognosis defined by 2015 academic classification could be evaluated according to a range of corresponding RSAs and CRRs. The length and morphology of the tapered roots and decreasing CTA enclosure partially explained the findings.

Background

The measurement of linear radiographic bone loss (L-RBL) was adopted to evaluate the severity of periodontitis. One study decided the severity of periodontal disease based on the location of the alveolar crest categorized as within 1/3 of the total root length (RL), between 1/3 and 2/3 or more than 2/3 of the total RL[1]. According to the guidelines of American Academy of Periodontology (AAP) for determining severity of periodontitis, bone loss of up to 15% of the RL or ≥2.0 mm and ≤3.0 mm RBL is characterized as mild periodontitis, 16% to 30% of RL or >3.0mm and ≤5.0mm RBL is classified as moderate periodontitis, and 30% of RL or >5.0mm RBL indicates severe periodontitis[2]. Despite the limitations of conventional radiographic techniques and the evidence provided[3], most studies have offered valuable information on periodontal RBL based on two-dimensional (2D) calculation[4–6]. The application of three-dimensional (3D) radiographic examinations in the dental clinic for routine periodontal assessment was previously impractical, but recently 3D radiographic examinations have become feasible and popular for dental treatment[7]. The amount of root surface area (RSA) of permanent dentition has been appraised from both 2D and 3D perspectives[8, 9]. A dental laser scanner examination suggested that the amount of RBL in single-rooted human premolars was under-assessed from the 2D view point[10].

Crown-to-root ratio (CRR) has been extensively applied to assess the linear ratio of the tooth root retained in alveolar bone to estimate the severity of periodontitis and to assign tooth prognosis[11, 12]. Currently, periodontists have used a CRR value of 1:1 to differentiate a periodontitis tooth with a favorable prognosis from one with an unfavorable prognosis[13]. One CRR value is not only discordant with appraising the teeth for mild, moderate or severe periodontitis but is also inadequate for distinguishing the prognosis of periodontitis teeth as good, fair, poor, questionable or hopeless[14, 15]. Dental fields have utilized micro-computed tomography (micro-CT) to explore the micro structure of alveolar bone, dental pulp and RSA[9, 12, 16–20]. After tooth scanning, the restored 3D data of the test edit ems can be translated into 2D output by the use of an associated software program for RSA calculation. The RSA and CRR information at the evaluated levels can be analyzed thereafter.

We hypothesized that based on the definition from the guidelines of AAP; the values of the L-RBL percentages at the evaluated levels would be consistent with the measured values from the linear L-RBL millimeter aspect. The aims of this study were to employ a micro-CT to survey extracted human single-rooted premolars and measure the RSAs at the evaluated L-RBL levels. Whether the amount of RSA and L-RBL percentages were comparable to each other at the assessed CRR levels was also determined. Corresponding to linear RL millimeter measurements, the concept of clinical attachment loss (CAL) was also applied to estimate the effects of CAL on CRR determination. Finally, we discuss the CRR values of periodontal prognostic appraisals according to the RSA and L-RBL ratios.

Methods

Materials

Thirty-one intact maxillary and 35 intact mandibular premolars were collected from patients who underwent orthodontic or periodontal treatment in the dental department. All patients provided written informed consent before extraction. This clinical study followed the Declaration of Helsinki and was approved by the Medical Ethics Committee. All methods were performed in accordance with the Taiwan Dental Association guidelines and regulations.

Tooth samples were examined from the crown cusp to the root apex with micro-CT (SkyScan 1076, Bruker, Kontich, Belgium) using a cone beam method under the following settings: tube voltage, 100 kV; tube current, 100 μA; pixel matrix, 2,000 × 2,000; slice thickness, 18 μm. The apex of each premolar was stabilized vertically on a fixture parallel to the long axis of the tooth. Generally, the micro-CT instrument took 10 minutes to scan a tooth. Subsequently, the instrument exported the digital imaging data to files, each 5 GB file containing 1,300–1,500 sliced images obtained from a single tooth. These exported data were subsequently analyzed and edited using the DataViewer, CTVol, and CTVox software (Bruker), and 3D images were reconstructed from the 2D images using this software. The 3D geometry files were generated for each mask and saved as stereolithography (STL) files. An STL format model with approximately 1,500,000–2,000,000 fine triangle surfaces describing a 3D premolar structure was developed. The RSAs of premolars were calculated as the sum of specific fine triangle areas using the Pro/Engineer software (PTC, Needham, MA, USA).

The 2D RL of a scanned premolar was determined by measuring the distance from the apex to an average cementoenamel junction (CEJ) point (g–h in Figures 1 C and H). The CEJ point was defined as the midpoint of the two midpoints of the interproximal and buccolingual lines (f and e, respectively, in Figure 1). The measurement of the L–RBL in millimeters and percentages at coronal 3.0 mm, 5.0 mm, 15%, 25%, 30% and 50% L–RBLs of teeth were considered and evaluated. The amount and percentage of RSAs and L–RBLs at the evaluated CRRs of 4:5, 1:1, 5:4, 4:3, 3:2, 2:1 and 5:2 were analyzed. The collected teeth were assigned to the maxillary and mandibular groups. A dental laser scanner examination was employed to confirm the macro-structure findings of the teeth scanned by micro-CT.

Statistical analyses

Both maxillary and mandibular premolars were analyzed after rationalizing the amounts of L–RBL and RSA at planned levels to the total amounts of RL and RSA for every individual tooth before intra- or inter-group analyses to avoid tooth size and root morphology bias. The independent *t*-tests were conducted to evaluate the significant differences of general anatomic measurement between the maxillary and mandibular premolars; and between micro-CT and dental laser scanner. Independent *t*-tests were also performed to study the variations in the L–RBL or RSA amount between the maxillary and mandibular premolars at the corresponding CRRs ($p < 0.05$). Paired *t*-tests explored the significance between inter– and/or intra–groups of the L–RBL measurements in millimeters, L–RBL percentages and RSA at the evaluated CRRs and L–RBLs coronoapically ($p < 0.05$).

A one-sample *t*-test was performed to assess whether the measured amount and ratio were consistent with those proposed at the evaluated CRRs, RSAs, and L-RBLs, and the test supported the null hypotheses. The null hypotheses (H0) were as follows:

1st H0: The variation between the measured and proposed ratios of bone support at L-RBLs of 3.0 mm and 5.0 mm (or L-RBLs of 15%, and 30%) were ≤2% (|mean—3.0 mm and 5.0 mm (or 15% and 30%)| ≤ 2%); and 1st H1 were >2%.

2nd H0: The variation between the measured and proposed amount of bone support at CRRs of 4:5, 1:1, 5:4, 4:3, 3:2, 2:1 and 5:2 based on the RSA or L-RBL measurements were ≤2% (|mean—15% (or 20%, 25%, 30%, 35%, 40%, 45%, 50%, 60% and 70%)| ≤ 2%); and 2nd H1 were >2%.

Results

A total of 66 maxillary and mandibular premolars were cleaned and scanned. The attained raw data of the tooth structures were obtained as 2D images, which were assembled and converted into 3D reconstructions (Figure 1). When the 3D RSAs at the evaluated L–RBLs and CRRs levels were analyzed, the examined parameters, including RSA, L–RBL, and CRR, demonstrated an extensive distribution pattern for both maxillary and mandibular premolars. However, only the total RSA parameter exhibited a significant variation between the maxillary and mandibular premolars (Table 1, p = 0.002).

To differentiate mild from moderate periodontitis, a coronal L–RBL value of 23.91 ± 0.36% for maxillary premolars and 22.90 ± 0.46% for mandibular premolar reflected a level of 3.0 mm L–RBL (Table 1). However, a value of 1.89 ± 0.03 mm L–RBL for maxillary premolars and 1.99 ± 0.04 mm L–RBL for mandibular premolars corresponded to a 15% L–RBL (Table 2). To distinguish moderate from severe periodontitis, a value of 39.86 ± 0.60% coronal L–RBL for maxillary premolars and 38.17 ± 0.77% coronal L–RBL for mandibular premolars corresponded to a value of 5.0 mm L–RBL (Table 1). Nevertheless, a value of 3.79 ± 0.06 mm L–RBL for maxillary premolars and 3.98 ± 0.08 mm L–RBL for mandibular premolars matched with a 30% L–RBL (Table 2).

From the perspective of the CRR, the 12.68 ± 1.07% L-RBL level for maxillary premolars and 13.58 ± 1.11% L-RBL level for mandibular premolars at a CRR of 4:5; and the 2.72 ± 0.14 mm L-RBL level for maxillary premolars and 3.02 ± 0.18 mm L-RBL level for mandibular premolars at a CRR of 1:1 corresponded closely to the differentiating levels used to distinguish mild and moderate periodontitis(15% and 3.0mm L-RBL, Table 3, Figures 1:D and I). Furthermore, the 30.15 ± 0.86% L-RBL level for maxillary premolars and 30.86 ± 0.89% L-RBL level for mandibular premolars at a CRR of 5:4; or the 4.71 ± 0.14 mm L-RBL level for maxillary premolars and 5.07 ± 0.19 mm L-RBL level for mandibular premolars at a CRR of 3:2 corresponded well to the levels used for 15% and 3.0 mm L-RBL moderate and severe periodontitis(30% and 5.0 mm L-RBL, Table 3, Figures 1: D and I). No significant deviation was perceived in comparing maxillary and mandibular premolars (Table 1—3).

The macro-structure analyses of the tested teeth according to the dental laser scanner were similar to those findings examined by micro-CT (Table 4).

Discussion

In this micro-CT survey, mandibular premolars presented with a smaller amount of RSA. A more complicated root morphology, wider buccolingual dimension and remarkable interproximal concavity of the maxillary premolars might partially explain the findings[21]. Therefore, mandibular and maxillary teeth were considered separately. Additionally, the RSAs and CRRs were analyzed by percentages and ratios after calibrating the data of individual teeth to reduce the bias of tooth size, root length and root morphology. Despite the limitations of traditional and current radiographic techniques, the biologically significant information acquired from linear radiographic parameters is critical in deciding severity of periodontitis, proposing a treatment plan and estimating disease prognosis[7, 22].

Connective tissue attachment (CTA) and L-RBL

A vertical bitewing survey reported a range of 0 to 2.0 mm in physiological distance between the CEJ and the alveolar crest in adolescents with clinically healthy gingiva[23]. Another bitewing study presented similar results in 13–14-year-old adolescents with no clinical attachment loss at the first molars[24].

However, a wide prevalence range in the sites with a distance more than 2.0 mm from the CEJ to the alveolar crest was reported in young adult[25]. Furthermore, the consensus concept of biological width, including 1.07 mm of connective tissue (CT) plus 0.97 mm of the epithelium[26], has been extensively cited and is essential in differentiating the inconsistency among CAL and L-RBL. The importance of the epithelium on periodontal attachment is significant, but its protecting role seems superior to that of periodontal support. Thus, the considerations of epithelium on CTA were excluded in this prognosis discussion. Generally, most studies applied a 2D radiographic approach to inspect severity of periodontitis and assign prognosis. Only a limited number of studies have related severity of periodontitis to tooth prognosis from a 3D CTA perspective, which was used to characterize the RSA in this study[9, 10]. This study correlated the percentage and length of L-RBL with severity of periodontitis from the aspects of the CRR and RSA measurements. In this discussion, the roles of RSA(3D CTA) on L-RBL were excluded to avoid distracting the analysis of L-RBL parameters in determining severity of periodontitis. However, the characteristics of RSA were taken into account and emphasized during the discussion of periodontal prognosis.

CRRs at evaluated L–RBL levels (Table3 and Figure 1: D and I)

The coronal 1.6–1.9 mm L–RBL at a CRR of 4:5 corresponded to a 15% L–RBL, and a 21%–22% L–RBL at a CRR of 1:1 were comparable to 3.0 mm L–RBL for premolars, a value used to differentiate mild periodontitis from moderate periodontitis. However, the evaluated parameters at 15% L–RBL and 3.0 mm L–RBL were inconsistent. Similarly, 4.0 mm L–RBL at a CRR of 5:4 corresponded to a 30% L–RBL for premolars, a value used to indicate moderate periodontitis. Furthermore, a 40% L–RBL at a CRR of 3:2 was comparable to a 5.0 mm L–RBL, which indicates a diagnosis of severe periodontitis. Although the millimeter data at 30% L–RBL was not in accordance with a 5.0 mm L–RBL of severe periodontitis, the levels of >5.0 mm L-RBL, >40% L-RBL and >50% RSA at a CRR>3:2 levels could be used to differentiate severe periodontitis for premolars. Mandibular and maxillary premolars demonstrated a non-significant comparison at the evaluated L-RBL levels. However, the RSA values were significantly higher than the hypothesized amount at the equivalent 15% and 30%L-RBL levels for both premolar groups. Root length derived from the guidelines of AAP should be 16.7 mm–20.0 mm (these numbers were speculated from the definition that a 3.0mm root length indicated a 15% radiographic bone loss, and a 5mm root length indicated a 30% radiographic bone loss)[2]. However, the average root length in this premolar study was 12.6 mm–13.3 mm. A previous study revealed that various tooth types remain dissimilar in supporting tissues at the same clinical attachment level. For example, when an 8.0 mm CAL was detected for maxillary canines, it retained approximately 43% of supporting tissues. Nevertheless, a secondary maxillary premolar might only reserve 27% of supporting tissues at the same attachment level[27]. Theoretically, only a cylinder root without a tapering angle can meet the consistence of 2D and 3D measurements. A dental laser scan study also provided similar results to support the concept that a more tapered shaped root presents more RSA distribution at the coronal levels and more discrepancy between the 2D and 3D measurement[10]. The complexity of the root shape can also affect the inconsistency of the two measurements. The amount of RSA at the examined L-RBL and CRR levels were included in this study, although collection of 3D information from the daily dental clinic is not popular. Furthermore, a consistent agreement on the concept of applying RSA to relate disease severity and treatment prognosis is still required.

Applying RSA and CRR to periodontal prognosis (Figure 1: E and J)

The teeth with approximately 25% clinical and radiographic periodontal attachment loss have been categorized into fair prognosis. The percentage of RSA was difficult to measure clinically. Therefore, percentages of L-RBL and linear CAL were applied to confer tooth prognosis. The measurement of a CRR of 1:1, 3.0 mm L-RBL, and >25% RSA at coronal 25% L-RBL levels for premolars corresponded to the fair prognosisby the McGuire definitions[14]. However, when linear CAL was applied to define tooth prognosis, at least 1.0mm CTA should be taken into account. A measurement of 1.0 mm linear RL bone support was comparable to 10% RSA for the coronal half of the RL in this study (Table 3). Values of 35% L-RBL, >4mm L-RBL and 45% RSA at a CRR of 4:3 correlated with a fair prognosis level. Furthermore, values of 50% L-RBL, >6.0 mm L-RBL, and 60% RSA at a CRR of 2:1 for premolars without a 1.0 mm CT inclusion could be applied to differentiate poor prognosis from questionable prognosis. However, when the location of 50% linear CAL was used to distinguish poor from questionable prognosis, the differentiated level moved apically to a position of 60% L-RBL, ≥7.0 mm L-RBL, and 70% RSA at a CRR of 5:2.

Coordinate periodontal and prosthetic prognosis with CRR

Based on prosthodontic research, the survival rate of the abutment teeth for removable partial denture with CRRs of 5:4–3:2 is reduced significantly in 7 years[28]. A value of 30%—40% L-RBL at a CRR of 5:4—3:2 was in accordance with that which is defined by the AAP as severe periodontitis. Therefore, it is reasonable to assign severe periodontitis diagnosis to the prosthetic abutment teeth that experienced 30%–40% L-RBL or 40%–50% RSA bone detachment at a CRR of 5:4–3:2. Additionally, the teeth with 30%—40% L-RBL at a CRR of 5:4—3:2 were characterized as fair–poor periodontal prognosis by McGuire[14]. Accordingly, it is reasonable to assign a fair–poor periodontal prognosis to the prosthetic abutment teeth in severe periodontitis and a reduced survival prognosis. In addition to CRR, many other parameters, including occlusal force, preparation conditions of abutment tooth, pier abutment tooth, and endodontic treatment and other factors, should be considered before assigning a prognosis to teeth with compromised periodontal attachment.

Differences between our observations and those of others may be partially explained by inconsistent definitions used to categorize periodontitis severity and prognosis, as well as various other factors, including the tapering effect of the root shape, root concavities, root morphology, crown length and root length[27]. Other types of teeth, such as incisors, canine, and molars, may demonstrate various CRR characters and thus warrant additional studies.

This study is limited to single rooted maxillary and mandibular premolars. The teeth having multiple roots or teeth having different single-root tooth morphology than premolar teeth will be studied in the future.

Conclusions

In summary, despite the limitations of the present study, a value of 20%–30% coronal RSA and a L-RBL of 2.0–3.0 mm at a CRR of 1:1–4:5 corresponded to a ≤15% L-RBL, a value that indicates mild periodontitis. Similarly, a 40–50% coronal RSA and a L-RBL of 4.0–5.0 mm at a CRR of 5:4–3:2 corresponded to a ≤30% L-RBL that indicates moderate periodontitis. Additionally, >50% coronal RSA, >5.0 mm L-RBL and >3:2 CRR corresponded to a >30% L-RBL that indicates severe periodontitis. Depending on whether the 1.0 mm connective tissue attachment is included, values of 25%–35% L-RBL at a CRR of 1:1–4:3 corresponded to a 25% CAL, which could be applied to distinguish a fair prognosis from a good prognosis, and values of 50% to 60% L-RBL at a CRR of 2:1–5:2 corresponded to a 50% CAL, which is used to differentiate a poor prognosis from a questionable prognosis.

Abbreviations

L-RBL: linear radiographic bone loss; RL: root length; AAP: American Academy of Periodontology; 2D: two-dimensional; RSA: root surface area; CRR: Crown-to-root ratio; micro-CT: micro-computed tomography; CAL: clinical attachment loss; STL: stereolithography; CEJ: cementoenamel junction; CTA: connective tissue attachment; CT: connective tissue.

Declarations

Ethics approval and consent to participate

This clinical study protocol was approved by the Ethics Committee at the Chang Gung Memorial Hospital, Taiwan (IRB104–9462B, 106–3752C) and it has been carried out in accordance with local legislation.

Consent for publication

All authors have consented to the publishing of this Manuscript.

Availability of data and material

The data that provide the basis for the presented results of this study is available by contact to the corresponding author, but restrictions apply to the availability of these data and to a certain time period, as the data were used under license for the current study, and so are not publicly available.

Competing interests

The authors declare that they have no competing interests.

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Authors’ contributions

HH, CC, and HL have made substantial contributions to conception and design of the study. CL, YP and HL have been involved in data collection and data analysis. HH, CL and HL have been involved in data interpretation, drafting the manuscript and revising it critically and have given final approval of the version to be published.

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References

1.Hugoson A, Jordan T: *Frequency distribution of individuals aged 20–70 years according to severity of periodontal disease. Community Dent Oral Epidemiol* 1982, *10(*4):187–192.

2.*American Academy of Periodontology Task Force Report on the Update to the 1999 Classification of Periodontal Diseases and Conditions. Journal of periodontology* 2015, *86(*7):835–838.

3.Armitage GC, Research S, Therapy Committee of the American Academy of P: *Diagnosis of periodontal diseases. J Periodontol* 2003, *74(*8):1237–1247.

4.Akesson L, Hakansson J, Rohlin M: *Comparison of panoramic and intraoral radiography and pocket probing for the measurement of the marginal bone level. Journal of clinical periodontology* 1992, *19(*5):326–332.

5.Albandar JM: *Validity and reliability of alveolar bone level measurements made on dry skulls. Journal of clinical periodontology* 1989, *16(*9):575–579.

6.Jeffcoat MK, Reddy MS: *Digital subtraction radiography for longitudinal assessment of peri-implant bone change: method and validation. Advances in dental research* 1993, *7(*2):196–201.

7.Mol A: *Imaging methods in periodontology. Periodontology 2000* 2004, *34:*34–48.

8.Hujoel PP: *A meta-analysis of normal ranges for root surface areas of the permanent dentition. Journal of clinical periodontology* 1994, *21(*4):225–229.

9.Gu Y, Tang Y, Zhu Q, Feng X: *Measurement of root surface area of permanent teeth with root variations in a Chinese population-A micro-CT analysis. Archives of oral biology* 2016, *63:*75–81.

10.Hong HH, Chang CC, Hong A, Liu HL, Wang YL, Chang SH, Yen TH: *Decreased Amount of Supporting Alveolar Bone at Single-Rooted Premolars Is Under Estimated by 2D Examinations. Sci Rep* 2017, *8:*45774.

11.Nunn ME, Fan J, Su X, Levine RA, Lee HJ, McGuire MK: *Development of prognostic indicators using classification and regression trees for survival. Periodontology 2000* 2012, *58(*1):134–142.

12.Penny RE, Kraal JH: *Crown-to-root ratio: its significance in restorative dentistry. The Journal of prosthetic dentistry* 1979, *42(*1):34–38.

13.Avila G, Galindo-Moreno P, Soehren S, Misch CE, Morelli T, Wang HL: *A novel decision-making process for tooth retention or extraction. Journal of periodontology* 2009, *80(*3):476–491.

14.McGuire MK, Nunn ME: *Prognosis versus actual outcome. II. The effectiveness of clinical parameters in developing an accurate prognosis. Journal of periodontology* 1996, *67(*7):658–665.

15.McGuire MK, Nunn ME: *Prognosis versus actual outcome. III. The effectiveness of clinical parameters in accurately predicting tooth survival. Journal of periodontology* 1996, *67(*7):666–674.

16.Kato A, Ohno N: *Construction of three-dimensional tooth model by micro-computed tomography and application for data sharing. Clinical oral investigations* 2009, *13(*1):43–46.

17.Parsa A, Ibrahim N, Hassan B, van der Stelt P, Wismeijer D: *Bone quality evaluation at dental implant site using multislice CT, micro-CT, and cone beam CT. Clinical oral implants research* 2015, *26(*1):e1–7.

18.Ferraz C, Freire AR, Mendonca JS, Fernandes CA, Cardona JC, Yamauti M: *Effectiveness of Different Mechanical Methods on Dentin Caries Removal: Micro-CT and Digital Image Evaluation. Operative dentistry* 2015, *40(*3):263–270.

19.Hong H-H, Liu H-L, Hong A, Chao P: *Inconsistency in the Crown-to-Root Ratios of Single-Rooted Premolars Measured by 2D and 3D Examinations. Scientific Reports* 2017, *7(*1):16484.

20.Hong HH, Hong A, Huang YF, Liu HL: *Incompatible amount of 3-D and 2-D periodontal attachments on micro-CT scanned premolars. PloS one* 2018, *13(*3):e0193894.

21.Novak KF, Takei HH: *Determination of prognosis.* In: *Carranza's clinical periodontology.* 11 edn. 3251 Riverport lane, St. Louis, Missouri 63043: Elsevier, Sauunders; 2014: 373–383.

22.Bragger U: *Radiographic parameters: biological significance and clinical use. Periodontology 2000* 2005, *39:*73–90.

23.Kallestal C, Matsson L: *Criteria for assessment of interproximal bone loss on bite-wing radiographs in adolescents. Journal of clinical periodontology* 1989, *16(*5):300–304.

24.Hausmann E, Allen K, Clerehugh V: *What alveolar crest level on a bite-wing radiograph represents bone loss? Journal of periodontology* 1991, *62(*9):570–572.

25.Jenkins WM, Papapanou PN: *Epidemiology of periodontal disease in children and adolescents. Periodontology 2000* 2001, *26:*16–32.

26.Gargiulo AW, Wentz FM, Orban B: *Dimension and relation of dentogingival junction in humans. J Periodontol* 1961, *32(*3):261–267.

27.Yamamoto T, Kinoshita Y, Tsuneishi M, Takizawa H, Umemura O, Watanabe T: *Estimation of the remaining periodontal ligament from attachment-level measurements. Journal of clinical periodontology* 2006, *33(*3):221–225.

28.Tada S, Allen PF, Ikebe K, Zheng H, Shintani A, Maeda Y: *The Impact of the Crown-Root Ratio on Survival of Abutment Teeth for Dentures. Journal of dental research* 2015, *94(*9 Suppl):220s–225s.

Tables

Table 1. The L−RBL percentages at evaluated L−RBL levels.

	Maxillary premolars (n=31)		Mandibular premolars (n=35)		Maxilla vs. Mandible
	Mean ± SE		Mean ± SE		*P* < 0.05
Total tooth length	19.81 ± 0.31 mm		20.53 ± 0.28 mm		*p* = 0.092
RSA at 0% L−RBL	226.16 ± 5.99 mm^2		202.43 ± 4.37 mm^2		*p* = 0.002**
Total RL	12.63 ± 0.19 mm		13.28 ± 0.27 mm		*p* = 0.056
CRR with 0% L−RBL	1:1.83 ± 0.08		1:1.88 ± 0.07		*p* = 0.626
L−RBL % at L−RBLs	Average ± SE	(*P* < 0.05& H0)	Average ± SE	(*P* < 0.05& H0)	*P* < 0.05
L−RBL % at 3rd mm L−RBL	23.91 ± 0.36%	vs. 15% L−RBL <0.001 (H1)	22.90 ± 0.46%	vs. 15% L−RBL <0.001 (H1)	*p* = 0.095
L−RBL % at 5th mm L−RBL	39.86 ± 0.60%	vs. 30% L−RBL <0.001 (H1)	38.17 ± 0.77%	vs. 30% L−RBL <0.001 (H1)	*p* = 0.095

L−RBL: Linear radiographic bone loss measured from CEJ to root apex at 2D perspective

RSA: Root surface area with periodontal attachment determined by a 3−D image.

RL: Radiographic root length measured from CEJ to apex at 2D viewpoint

Independent t test for maxilla vs. mandible**:** *: p < 0.05, **: p < 0.01, ***: p < 0.001

Paired *t* tests for the acquired percentages vs. defined percentages at examined L−RBL mm levels**:***: p < 0.05, **: p < 0.01, ***: p < 0.001

H1: Significance between the measured and defined percentages at evaluated levels by one sample *t* test

Table 2. The L–RBL millimeters at evaluated L–RBL planes.

	Maxillary premolars (n=31)		Mandibular premolars (n=35)		Maxilla vs. Mandible
L–RBL %	Average ± SE	(H 0/1& $P <$ 0.05)	Average ± SE	(H 0/1& $P <$ 0.05)	P<0.05
RL at 15% L–RBL	1.89 ± 0.03 mm	vs. 3.0 mm <0.001 (H1)	1.99 ± 0.04 mm	vs. 3.0 mm <0.001 (H1)	p = 0.056
RL at 30% L–RBL	3.79 ± 0.06 mm	vs. 5.0 mm <0.001 (H1)	3.98 ± 0.08 mm	vs. 5.0 mm <0.001 (H1)	p = 0.056
RL at 50% L–RBL	6.28 ± 0.09 mm	vs. 6.0 mm <0.001 (H1)	6.65 ± 0.13 mm	vs. 6.0 mm < 0.001 (H1)	p = 0.056

Independent *t* test for maxilla vs. mandible**:** *: p < 0.05, **: p < 0.01, ***: p < 0.001

Paired *t* tests for the acquired millimeters vs. defined millimeters at examined L–RBL % levels**:** *: p < 0.05, **: p < 0.01, ***: p < 0.001

H1: Significance between the measured and defined amount at evaluated percentages by one sample *t* test

Table3. The amount and percentages of RSA and L–RBL at evaluated CRRs.

	Maxillary premolars (n=31)	Mandibular premolars (n=35)	Maxilla vs. Mandible
	Mean ± SE	Mean ± SE	$P < 0.05$
RSA&L−RBL at CRR = 4:5			-
RSA% (vs.20% RSA)	18.17 ± 1.62% (H0)	19.98 ± 1.57% (H0)	$p = 0.427$
L−RBL mm& % (vs. 15%)	1.62 ± 0.15 mm&12.68 ± 1.07% (H0)	1.88 ± 0.17 mm&13.58 ± 1.11% (H0)	$p = 0.567$
RSA % vs. L−RBL %	$p < 0.001$	$p < 0.001$	-
RSA&L−RBL at CRR = 1:1			-
RSA% (vs. 25% RSA)	25.62 ± 1.22% (H0)	28.35 ± 1.23% (H0)	$p = 0.122$
L−RBL mm&% (vs. 20% & 25%)	2.72 ± 0.14 mm&21.41 ± 0.97% (H0)	3.02 ± 0.18 mm&22.22 ± 1.00% (H0)	$p = 0.567$
RSA % vs. L−RBL %	$p < 0.001$	$p < 0.001$	-
RSA&L−RBL at CRR = 5:4			-
RSA% (vs. 40% RSA)	40.88 ± 1.65% (H0)	42.35 ± 1.53% (H0)	$p = 0.516$
L−RBL mm&% (vs. 30%)	3.82 ± 0.14 mm&30.15 ± 0.86% (H0)	4.16 ± 0.18 mm&30.86 ± 0.89% (H0)	$p = 0.567$
Lost RSA % vs. L−RBL %	$p < 0.001$	$p < 0.001$	-
RSA&L−RBL at CRR = 4:3			
RSA% (vs. 45% RSA)	44.45 ± 1.55% (H0)	45.27 ± 1.56% (H0)	$p = 0.710$
L−RBL mm& % (vs. 35%)	4.14 ± 0.14 mm&32.64 ± 0.83% (H0)	4.48 ± 0.19 mm&33.33 ± 0.86% (H0)	$p = 0.567$
Lost RSA % vs. L−RBL %	$p < 0.001$	$p < 0.001$	
RSA&L−RBL at CRR = 3:2			
RSA% (vs. 50% RSA)	48.67 ± 1.34% (H0)	49.67 ± 1.32% (H0)	$p = 0.599$
L−RBL mm&% (vs. 40%)	4.71 ± 0.14 mm&37.13 ± 0.77% (H0)	5.07 ± 0.19 mm&37.77 ± 0.80% (H0)	$p = 0.567$
LostRSA % vs. L−RBL %	$p < 0.001$	$p < 0.001$	

RSA&L−RBL at CRR = 2:1			-
RSA% (vs. 60% RSA)	60.07 ± 1.06% (H0)	61.15 ± 1.31% (H0)	$p = 0.532$
L−RBL mm&% (vs. 50%)	6.03 ± 0.14 mm&47.61 ± 0.64% (H0)	6.44 ± 0.20 mm&48.15 ± 0.67% (H0)	$p = 0.567$
Lost RSA % vs. L−RBL %	$p < 0.001$	$p < 0.001$	-
RSA& L−RBL at CRR = 5:2			-
RSA% (vs. 70% RSA)	67.59 ± 1.16% (H0)	69.34 ± 1.24% (H0)	$p = 0.322$
L−RBL mm &% (vs. 60%)	6.97 ± 0.14 mm&55.09 ± 0.52% (H0)	7.74 ± 0.30 mm&58.01 ± 1.82% (H0)	$p = 0.567$
LostRSA % vs. L−RBL %	$p < 0.001$	$p < 0.001$	-

Independent *t* test for maxilla vs. mandible: *: p < 0.05, **: p < 0.01, ***: p < 0.001

Paired *t* tests for 2D L−RBL % vs. RSA %: *: p < 0.05, **: p < 0.01, ***: p < 0.001

2nd H0: no significance between the measured and proposed ratios by one sample *t* test

Table4. The evaluated amount of RSA and RL by laser scan and micro-CT.

	Maxillary premolars			Mandibular premolars		
	Laser Scan (n=36)	Micro-CT (n=31)	mean ± SE *P* < 0.05	Laser Scan (n=35)	Micro-CT (n=35)	mean ± SE *P* < 0.05
TTA (mm^2)	432.48 ± 8.22	449.17 ± 9.99	0.200	380.46 ± 6.53	394.08 ± 6.75	0.151
TTL (mm)	19.82 ± 0.31	19.81 ± 0.31	0.982	20.60 ± 0.28	20.53 ± 0.28	0.858
Total RSA (mm^2)	220.78 ± 5.52	226.16 ± 5.99	0.516	199.51 ± 4.45	202.43 ± 4.37	0.641
Total RL (mm)	12.60 ± 0.25	12.63 ± 0.19	0.925	13.45 ± 0.25	13.28 ± 0.27	0.651
RSA with 25% RL	150.64 ± 3.83	148.82 ± 4.56	0.761	134.37 ± 3.17	132.97 ± 2.96	0.747
RSA with 50% RL	90.80 ± 2.48	83.98 ± 3.22	0.094	78.13 ± 2.04	74.55 ± 1.93	0.208
RL with 25% RSA	9.93 ± 0.21	10.08 ± 0.18	0.595	10.72 ± 0.21	10.58 ± 0.27	0.518
RL with 50% RSA	7.47 ± 0.17	7.59 ± 0.15	0.594	8.07 ± 0.17	8.24 ± 0.19	0.502

Independent *t* test for laser scan vs. micro-CT.: *: $p < 0.05$

TTA: Total tooth area (mm^2)

TTL: Total tooth length (mm)

Figures

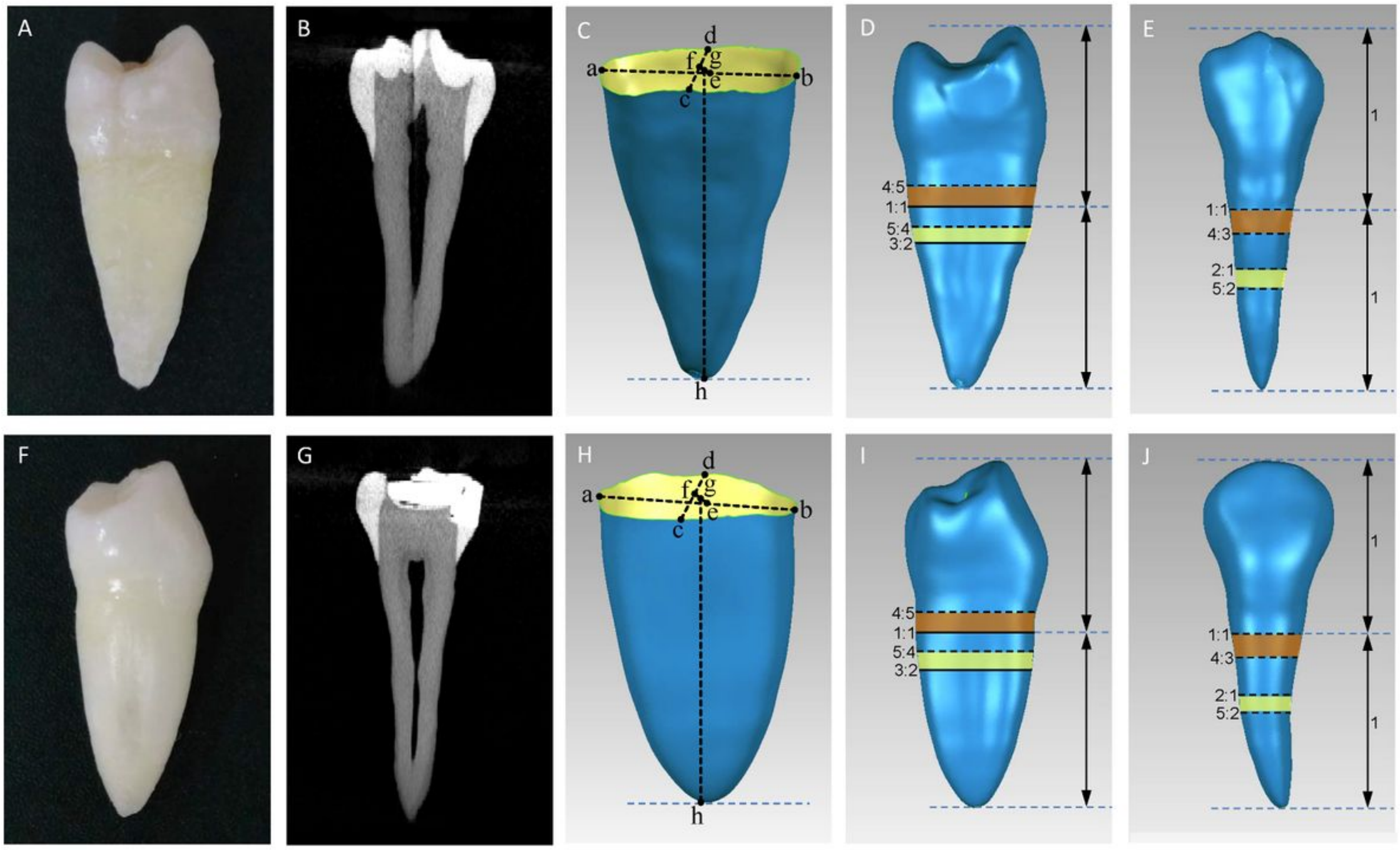

Figure 1

Views and estimated levels of a micro-CT scanned maxillary premolar (A–E) and mandibular premolar (F–J). Sagittal section of premolar (B and G). STL format model, a–b: line connecting the buccal and lingual CEJ, c–d: line connecting the mesial and distal CEJ, e: midpoint of a–b, f: midpoint of c–d, g: midpoint of e–f, representing the CEJ from a 2D perspective, and g–h: representing the 2D RL (C and H); Corresponding CRRs to periodontal severity (D and I); Corresponding CRRs to periodontal prognosis (E and J).