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# Measurement of root surface area of permanent teeth in a Chinese population

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ABSTRACT

*Objectives:* The aim of this study was to investigate the relation between the remaining area of periodontal attachment and the attachment levels for each type of permanent teeth in a Chinese population by using micro-computed tomography (micro-CT) scans.

*Design:* A total of 440 extracted permanent teeth (including each tooth type except for the third molars) were collected from a Chinese population and scanned using a micro-CT. The CT data were input into Mimics 15.01 to generate 3D tooth models. To simulate various attachment levels, the roots were virtually cut at 0, 2, 4, 6, 8, and 10 mm from the cemonto-enamel junction (CEJ). The net and percent remaining root surface area (RSA) were measured and calculated, and the data corresponding to attachment level were fitted to a linear function.

*Results:* A Linear function can perfectly fit in relating the simulated attachment level to the net and percent remaining RSA ($R^2 > 0.99$, and $p < 0.001$ for each tooth type). For net remaining RSA, the slope of the linear function was steepest for maxillary first molars ($b_1 = -39.32$) and least steep for mandibular central incisor ($b_1 = -13.08$); whereas for the percentage of remaining RSA, the slopes ($b_1$) were relatively within a narrow range, from −7.40 (maxillary canine) to −9.64 (maxillary first molars).

*Conclusion:* Micro-CT offers simple and precise technique for quantitative analysis of the RSA. The total amount and vertical distribution of the RSA varied by tooth type. Linear formulas can perfectly describe the relation between the attachment level and the net and percent remaining RSA.

## 1. Introduction

Accurate assessment of the total root surface area (RSA) and the amount of remaining attachment surface area assists in formulating the tooth prognosis and treatment plan (Hujoel, Bollen, & Schork, 1989; Yamamoto et al., 2006). However, previous methods, such as membrane technique (Yamamoto et al., 2006), weighting conversion (Klock, Gjerdet, & Haugejorden, 1993), or division planimetry (Dulap & Gher, 1985; Hermann, Gher, Dunlap, & Pelleu, 1983; Levy & Wright, 1978), either show the disadvantage of lacking accuracy, or are complicated to operate (Hujoel, 1994; Klock et al., 1993). Periodontal probing and/or measurement of the bone height along the root surface on the radiographs are more practical means for clinicians to evaluate the amount of attachment loss, whereas the measured values are 1-dimensional, and may cause errors in estimating the exact RSA of a 3-dimensional root (Chen, Chen, & Jeng, 2002). Recently, we utilized the micro-computed tomography (micro-CT) technique to analyze the relationship between root variations and the corresponding RSA (Gu, Tang, Zhu, & Feng, 2016; Gu et al., 2012). We proved that a micro-CT combined with Mimics software allows for accurate analysis of the RSA due to its high precision and powerful function of virtual simulation, and that anatomic root variations may affect the total amount and vertical distribution of the RSA. However, one limitation of our study was that we had only analyzed four tooth types (maxillary and mandibular first premolars, and mandibular first and second molars) and eight root variation forms, and so the study had not included each tooth type.The relationship between attachment level and remaining RSA has been studied previously by many scholars (Dulap & Gher, 1985; Gu et al., 2016; Mowry et al., 2002; Yamamoto et al., 2006). Yamamoto et al. (2006) and Wu and Yin (2010) had reported that linear functions could provide appropriate formula for estimation of the remaining RSA from the attachment level, whereas there were other scholars who reported that at least for maxillary or mandibular first molars, the % RSA did not taper evenly from the CEJ to

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the apex; there was a ballooning of the % RSA in the furcation area (Dulap & Gher, 1985; Hermann et al., 1983; Gher & Dunlap, 1985). Hujoel et al. (1989) further pointed out that linear measurements were less accurate in roots with complex anatomy and tended to underestimate the true amount of the remaining periodontal attachment because the curvature of the roots was ignored. Moreover, the mean values of the total RSA for certain tooth types were variable in different studies (Gu et al., 2016; Yamamoto et al., 2006). The discrepancy may be due to differences in methodology, sample size, and the ethnic background of the subjects.

The purpose of this study is to analyze the relationship between the remaining RSA and attachment level for each tooth type in a Chinese population by using micro-CT scans.

## 2. Materials and methods

A total of 440 permanent teeth (from the central incisor to the second molar) were collected in the Department of Dentistry, The First People's Hospital of Wujiang District, Suzhou, China, from January 2006 to December 2015. All subjects were native Chinese, and the teeth were extracted because of nonrestorable caries, trauma, periodontal disease, or orthodontic or prosthodontic reasons. The tooth type of the specimen was accurately identified by the operator according to its external anatomy, position in the dental arch, tooth sockets in the jaw bone, and dental history. Teeth with open apices or obliterated cemento-enamel junctions (CEJ) because of caries or restorations were excluded from the study. Teeth with extra root(s) or fused roots were also excluded from the investigation.

Each specimen was scanned along the tooth axis with voxel size of 15 or 21 μm by using a micro-CT scanner (Inveon; Siemens Medical Solutions, Knoxville, TN). The data sets were transferred to the Mimics 15.01 (Materialise, Leuven, Belgium) software in DICOM format, and reconstructed into 3D images.

The amount of total and remaining RSA at different attachment levels were measured as previously described (Gu et al., 2016). To obtain the RSA, the tooth model was "cut" into two parts along the CEJ on the proximal view. The surface area of the root portion, excluding the area of the cross-section, can be calculated by the software. To simulate various attachment levels, parallel V-shaped cutting lines were defined on the proximal root surface at 2, 4, 6, 8, and 10 mm from the CEJ. The remaining RSA corresponding to each attachment level was obtained as above for each tooth type (Fig. 1).

Root length was measured as the vertical distance between the highest level of the CEJ and the root tip along the long axis of the tooth. The volume of the root portion (including the volume of the root canal cavity) below the CEJ can be obtained directly by the Mimics software.

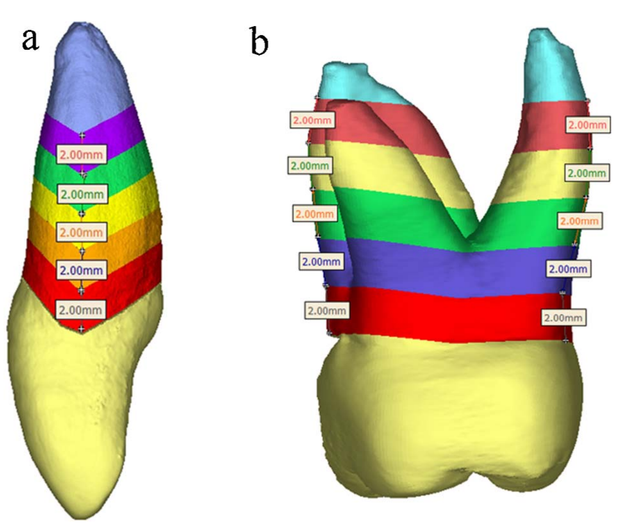


**Fig. 1.** Measurement of remaining root surface area at various attachment levels: (a) 0, 2, 4, 6, 8, and 10 mm from the CEJ of a maxillary central incisor, and (b) a maxillary first molar.

The relationship between the remaining net ($mm^2$)/percentage RSA and the simulated attachment level (mm) was modeled using a linear function for each tooth type. Linear regression was also used to estimate the relationship between the mean total RSA ($mm^2$) and the mean root volume ($mm^3$) for each tooth type. $p < 0.05$ was considered statistically significant.

## 3. Results

Tables 1 and 2 summarize the mean total and remaining RSA at different attachment levels for each tooth type. The mean total RSA, as well as the mean root volume, is highest for the maxillary first molars and lowest for the mandibular central incisors (RSA: 410 vs. 141 $mm^2$; root volume: 495.9 vs. 124.4 $mm^3$). The mandibular central incisors also have the shortest mean root length (12.1 mm), whereas the maxillary canines have the longest mean root length (17.6 mm).

Linear functions fitted perfectly in relating the simulated attachment level to the remaining net/percentage RSA ($R^2 > 0.99$, and $p < 0.001$ for each tooth type) (Table 3, Figs. 2 and 3). For the remaining net RSA, the slope of the linear function was highest for the maxillary 1st molars ($b_1 = -39.32$) and lowest for the mandibular central incisors ($b_1 = -13.08$). For the percentage of the remaining RSA, however, the 14 regression lines are close to each other, and the slope ($b_1$) varied in a small range from −7.40 (maxillary canine) to −9.64 (maxillary first molars).

Linear function also fitted perfectly in relating the mean root volume to the mean total RSA for 14 tooth types ($R^2 = 0.975$, and $p < 0.001$). The regression formula is as follows:

$$y\,(\text{root surface area}) = b_0 + b_1 {*} x\,(\text{root volume})\,(b_0 = 42.49,\ b_1 = 0.71)$$

## 4. Discussion

The total RSA, as well as its distribution pattern, is mainly determined by root size (root length and root girth) and the radicular topography (including root number or the presence of a furcation) (Mowry et al., 2002). Moreover, it is well-known that root shape can be influenced by ethnic factors (Scott & Turner, 1997), and the data derived from one ethnic group may be inapplicable to another during dental treatment. Until now, accurate RSA data on Chinese populations is still absent. This study was based on a large sample size (440 specimens), and all the teeth were collected from native Chinese people. Our pilot study has demonstrated that the high resolution micro-CT and 3D reconstructions of tooth models by Mimics software allowed more efficient and accurate measurement of the RSA, and the intra- and inter-observer errors could be controlled at a very low level (Gu et al., 2016). To accurately simulate various attachment levels of periodontal ligament, V-shaped cutting lines parallel to the CEJ were defined in the proximal root surface, which can better reflect the clinical situation than the division planimetry technique could do. The latter method cross-sectioned the root along a straight line perpendicular to the long axis of the tooth.

Tables 1 and 2 suggest, whether in maxillary, or in mandibular dentitions, on average, the 1st molars have the largest amount of total RSA, followed by the 2nd molars. The canines have more RSA than the premolars, and the 1st and 2nd premolars have a very similar amount of RSA. The incisors have the least amount of RSA in the dentition and the mean value was "least to greatest": mandibular central incisor < mandibular lateral incisor < maxillary lateral incisor < maxillary central incisor. A maxillary tooth usually has more RSA than its lower counterpart; the discrepancy is largest between the maxillary and mandibular central incisors (195.2 vs. 141.1 $mm^2$), and lowest between the maxillary and mandibular 2nd molars (383.0 vs. 372.5 $mm^2$). The