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Estimation of the remaining periodontal ligament from attachment-level measurements

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Abstract

Aim: Accurate assessment of the remaining area of periodontal attachment assists in determining the prognosis of a tooth. The aim of this study was to determine formulae to estimate the remaining area of periodontal attachment from attachment-level measures.

Materials and Methods: Roots of 30 extracted teeth of each tooth type were coated with vinyl acetate solution and α-cyanoacrylate monomer to produce a membrane. The membrane was removed after guidelines were drawn to simulate various attachment levels. The root surface area on the apical side of each simulated attachment level was measured using image analysis software. The net or percent root surface area and corresponding attachment level data were fitted to a linear, quadratic, cubic, and exponential functions and a growth curve.

Results: The linear function provided the most appropriate fit for the data. For net root surface area, a steeper slope was evident for tooth types with a larger mean total root surface area. For percent root surface area, a steeper slope was evident for tooth types with a shorter root length.

Conclusions: A linear function provides the most appropriate formula for estimation of the remaining area of periodontal attachment based on the attachment-level measurement.

Key words: attachment level; extracted tooth; root surface area; periodontal attachment; periodontal disease

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The amount of remaining periodontal attachment influences tooth prognosis and thus treatment planning. The limitations of probing attachment-level measurement in estimating periodontal attachment are well recognized. It provides a one-dimensional measure, does not take into account root shape, and tends to underestimate the remaining periodontal attachment (Klock et al. 1993).

The relationship between attachment level and remaining area of periodontal attachment has been studied using specific tooth types (Dunlap & Gher 1985, Gher & Dunlap 1985, Matsuura et al. 1989, Mowry et al. 2002), or a representative of each tooth type (Despeignes 1979). A recent study reported formulae for estimating the surface area of the dentogingival epithelium (i.e. the sulcular and junctional epithelium of healthy or pocket epithelium) for each tooth type (Hujoel et al. 2001). Formulae that accurately permit estimation of the remaining area of periodontal attachment from a clinical measurement provide useful information on tooth prognosis, for example in the case of abutment teeth for a prosthesis.

The aim of the present study was to derive formulae to estimate the remaining root surface area attached to the periodontal ligament for each tooth type at various clinical attachment levels, using a computer-aided membrane technique.

Materials and Methods

Four hundred and twenty extracted teeth (30 of each tooth type from the central incisor to the second molar on the right side of both arches) were used from a collection of extracted teeth at the Department of Oral Health, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences. Teeth with fused roots or obliterated cemento-enamel junctions because of caries or restorations were excluded from the study.

Root length was measured three times using a digital caliper (Mitsutoyo, Tokyo, Japan) and a dissecting microscope (SMZ-1B, Nikon Co., Kawasaki, Japan).

The surface area of the root, representing that remaining attached to periodontal ligament, was measured using the modified membrane technique (Jepsen 1963, Matsuura et al. 1989). Briefly, all soft-tissue and root accretions were carefully debrided with a scaler. The root was coated with petrolatum, and then with vinyl acetate solution (San-esu Giken Co., Tokyo, Japan) on three occasions at intervals of 30 min. between coatings. The same coating procedure was repeated using α-cyanoacrylate monomer (Toagosei Co., Tokyo, Japan), resulting in the formation of a ''membrane''. Parallel lines were drawn on the membrane 0, 2, 4, 6, 8, and 10 mm from the cemento-enamel junction with a superfine-pointed marking pen (YMSCR1-BK, Zebra Co., Tokyo, Japan) (Fig. 1) to simulate various attachment levels, and the membrane was subsequently stripped from the root surface using a disposable blade. For single-rooted teeth, vertical incisions were made on the centre of the buccal and lingual side of the root before membrane removal, while for multi-rooted teeth, incisions were made in the furcation area and on the buccal or palatal/lingual side of each root. The removed membranes were flattened on a grid paper (minimum scale; 1 mm, Kokuyo Co., Osaka, Japan) after sufficient cuts were made to permit it to be placed without folds (Fig. 2). An image of each pattern was obtained using a video camera and then converted to a digital computer image (Digital visual imaging system Wave Pict, Yoshida Co., Tokyo, Japan). The image was enlarged on a computer screen, and the root surface area attached to periodontal ligament with a simulated 0, 2, 4, 6, 8, and 10 mm attachment level was measured with a computer-assisted image analysis system (NIH image 1.61, National Institute of Health, Bethesda, MD, USA). The grid paper was used to calibrate the area measurement, and the mean of three measurements was calculated.

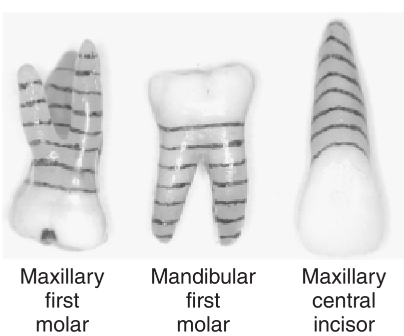

Fig. 1. Photograph showing parallel lines on the membrane-coated root surface to simulate various attachment levels.

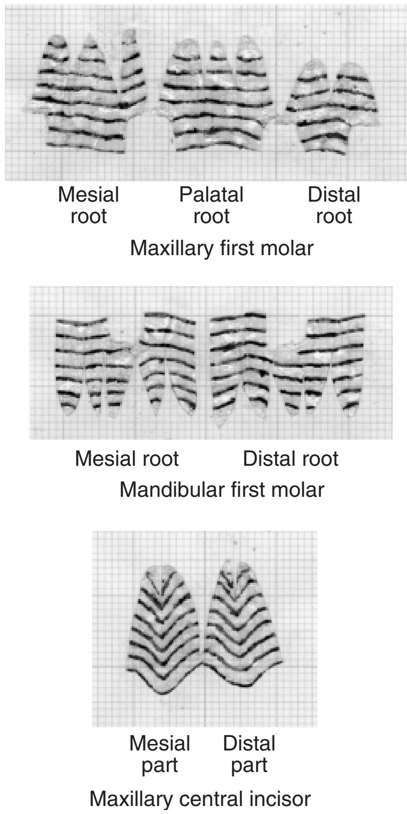

Fig. 2. Digital computer images of the patterns on grid paper.

To check the accuracy of the method, it was also applied to a cylindrical test body with a known surface area (255 mm^2). The discrepancy between 10 repeat measurements and the true value ranged from -1.7% to 1.5%.

To estimate the reproducibility of this method, 10 repeat measurements were performed on the central incisor, canine, first premolar, and first molar in the maxilla (three of each tooth type). The range of coefficients of variation was 0.039–0.050 for the central incisor, 0.034–0.044 for the canine, 0.037–0.057 for the first premolar, and 0.028–0.040 for the first molar.

The relationship between the net remaining root surface area (mm^2) attached to the periodontal ligament and the simulated attachment level (mm) was modelled using linear, quadratic, cubic, and exponential functions and a growth curve. These equations were fitted for each of the 14 tooth types.

For each extracted tooth, the remaining root surface area was calculated as a percent of the total root surface area, and the relationship between the percent remaining root surface area and the simulated attachment level was modelled as above for each tooth type. Statistical Package for the Social Science 11.0J for Windows (SPSS Japan, Tokyo, Japan) was used for the analysis.

Results

The mean root length and mean total root surface area for each tooth type are shown in Table 1. The mean root length was shortest for the central incisors and longest for canines in both arches. The mean total periodontal ligament area of the first molar was larger than for any other tooth type, and more than twice that of the central incisor in the same arch.

Linear, quadratic, and cubic functions fitted better than other functions in relating the simulated attachment level to the net remaining area of periodontal attachment (Table 2). The difference in the coefficient of determination among the three functions for each tooth type was less than 0.01 for all the tooth types. The b_1 value (slope) of the linear function for net root surface area was lowest for the first molars and highest for the central incisors in both arches (Table 2),

Table 1. Mean root length and total root surface area for each tooth type

	Root length (mm)	Total root surface area (mm^2)
Maxilla		
Central incisor	12.2 ± 1.4	200.7 ± 25.9
Lateral incisor	13.4 ± 1.4	202.9 ± 25.2
Canine	16.6 ± 1.9	291.9 ± 38.8
First premolar	12.9 ± 1.6	249.4 ± 37.3
Second premolar	13.9 ± 1.6	232.9 ± 32.0
First molar	13.5 ± 1.7	467.7 ± 61.6
Second molar	12.7 ± 1.4	368.4 ± 52.4
Mandible		
Central incisor	12.0 ± 1.0	159.5 ± 18.9
Lateral incisor	12.6 ± 1.2	180.0 ± 23.9
Canine	14.9 ± 1.6	265.2 ± 38.1
First premolar	14.7 ± 1.1	237.5 ± 28.9
Second premolar	14.0 ± 1.7	212.4 ± 27.7
First molar	12.6 ± 1.3	432.8 ± 61.2
Second molar	12.6 ± 1.2	368.4 ± 52.4

n, 30. Values are expressed as mean $\pm$ SD.

Table 2. Coefficient of determination of five functions fitted to relate simulated attachment level to net root surface area attached to the periodontal ligament

	Linear				Quadratic		Cubic		Exponential		Growth	
	R^2	b_0	b_1	p	R^2	p	R^2	p	R^2	p	R^2	p
Maxilla												
Central incisor	0.875	195.6	– 16.96	<0.001	0.879	<0.001	0.879	<0.001	0.759	<0.001	0.759	<0.001
Lateral incisor	0.870	198.3	– 17.54	<0.001	0.874	<0.001	0.874	<0.001	0.753	<0.001	0.753	<0.001
Canine	0.819	290.1	– 20.52	<0.001	0.819	<0.001	0.819	<0.001	0.771	<0.001	0.771	<0.001
First premolar	0.827	245.1	– 20.90	<0.001	0.829	<0.001	0.829	<0.001	0.769	<0.001	0.769	<0.001
Second premolar	0.877	225.3	– 19.98	<0.001	0.883	<0.001	0.883	<0.001	0.832	<0.001	0.832	<0.001
First molar	0.854	479.0	– 38.33	<0.001	0.856	<0.001	0.857	<0.001	0.737	<0.001	0.737	<0.001
Second molar	0.861	368.1	– 31.10	<0.001	0.861	<0.001	0.861	<0.001	0.778	<0.001	0.778	<0.001
Mandible												
Central incisor	0.881	156.6	– 12.70	<0.001	0.883	<0.001	0.884	<0.001	0.789	<0.001	0.789	<0.001
Lateral incisor	0.887	178.5	– 15.91	<0.001	0.888	<0.001	0.889	<0.001	0.808	<0.001	0.808	<0.001
Canine	0.821	261.8	– 20.13	<0.001	0.823	<0.001	0.823	<0.001	0.749	<0.001	0.749	<0.001
First premolar	0.903	230.7	– 19.32	<0.001	0.909	<0.001	0.909	<0.001	0.882	<0.001	0.882	<0.001
Second premolar	0.875	205.2	– 18.04	<0.001	0.882	<0.001	0.882	<0.001	0.768	<0.001	0.768	<0.001
First molar	0.839	435.9	– 34.27	<0.001	0.839	<0.001	0.839	<0.001	0.731	<0.001	0.731	<0.001
Second molar	0.819	326.5	– 27.56	<0.001	0.819	<0.001	0.819	<0.001	0.782	<0.001	0.782	<0.001

R^2, coefficient of determination; formula y (root surface area) $= b_0+b_1x$ (attachment level).

Table 3. Coefficient of determination of five functions fitted to relate simulated attachment level to percent root surface area attached to the periodontal ligament

	Linear				Quadratic		Cubic		Exponential		Growth	
	R^2	b_0	b_1	p	R^2	p	R^2	p	R^2	p	R^2	p
Maxilla												
Central incisor	0.964	97.4	– 8.52	<0.001	0.969	<0.001	0.969	<0.001	0.830	<0.001	0.830	<0.001
Lateral incisor	0.965	97.7	– 8.73	<0.001	0.969	<0.001	0.970	<0.001	0.815	<0.001	0.815	<0.001
Canine	0.973	99.4	– 7.09	<0.001	0.973	<0.001	0.973	<0.001	0.908	<0.001	0.908	<0.001
First premolar	0.965	98.2	– 8.53	<0.001	0.968	<0.001	0.968	<0.001	0.858	<0.001	0.858	<0.001
Second premolar	0.975	96.6	– 8.67	<0.001	0.983	<0.001	0.983	<0.001	0.910	<0.001	0.910	<0.001
First molar	0.969	102.4	– 8.28	<0.001	0.971	<0.001	0.972	<0.001	0.827	<0.001	0.827	<0.001
Second molar	0.978	99.8	– 8.49	<0.001	0.978	<0.001	0.978	<0.001	0.844	<0.001	0.844	<0.001
Mandible												
Central incisor	0.963	98.2	– 8.00	<0.001	0.965	<0.001	0.965	<0.001	0.841	<0.001	0.841	<0.001
Lateral incisor	0.978	98.9	– 8.90	<0.001	0.980	<0.001	0.981	<0.001	0.875	<0.001	0.875	<0.001
Canine	0.966	98.7	– 7.67	<0.001	0.968	<0.001	0.968	<0.001	0.880	<0.001	0.880	<0.001
First premolar	0.977	97.2	– 8.16	<0.001	0.983	<0.001	0.983	<0.001	0.925	<0.001	0.925	<0.001
Second premolar	0.968	96.5	– 8.56	<0.001	0.976	<0.001	0.976	<0.001	0.842	<0.001	0.842	<0.001
First molar	0.971	100.7	– 7.99	<0.001	0.971	<0.001	0.971	<0.001	0.836	<0.001	0.836	<0.001
Second molar	0.975	98.9	– 8.42	<0.001	0.977	<0.001	0.977	<0.001	0.882	<0.001	0.882	<0.001

R^2, coefficient of determination; formula, y (root surface area) $= b_0+b_1x$ (attachment level).

and the tooth types with larger total root surface area exhibited steeper slopes.

The slope for the linear function relating percent root surface area to attachment level ranged from – 8.90 (mandibular lateral incisors) to – 7.09 (maxillary canines) (Table 3, Figs 3 and 4), and those tooth types with shorter root lengths had steeper slopes.

Discussion

The area of remaining periodontal ligament was determined from simulated attachment levels using a computer-aided membrane technique applied to extracted teeth. The data were fitted to five functions to determine an appropriate formula to relate attachment level to remaining area of periodontal ligament attachment for each tooth type. Overall, the linear function was most appropriate, suggesting that current linear measurements in use, such as probing attachment level, may accurately reflect the amount of remaining periodontal supporting tissue.

Using the linear function, the slope of the line relating simulated attachment level to net area of periodontal ligament attachment remaining varied by tooth type. Teeth with a higher mean total root surface area exhibited a steeper slope, suggesting that the area of periodontal ligament lost per 1 mm of attachment loss depends on the total root surface area of the tooth. For percent remaining root surface area, the slope was gentler for tooth types with longer roots. For example, the maxillary canine, with the longest root of all tooth types (16.6 mm), had the gentlest slope (– 7.09) of all tooth types. Thus, the percentage of root surface area lost per 1 mm of attachment loss depends on the root length of the tooth.

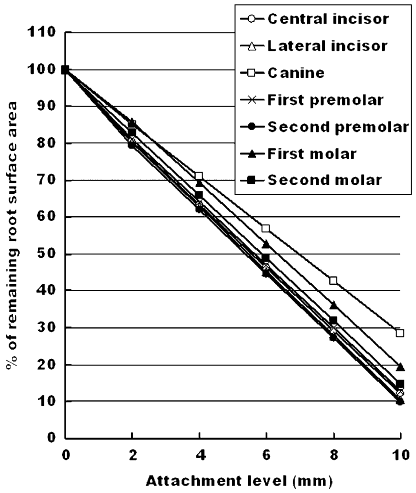

Fig. 3. Relationship between simulated attachment level and percent of the remaining root surface attached to the periodontal ligament for each maxillary tooth type.

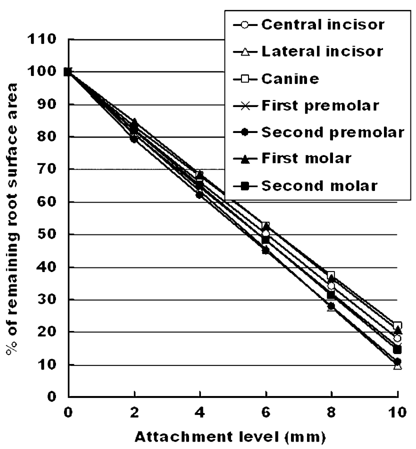

Fig. 4. Relationship between simulated attachment level and percent of the remaining root surface attached to the periodontal ligament for each mandibular tooth type.

The formulae derived in the present study provide clinicians with a guide to understanding the clinical impact of loss of periodontal supporting tissue from various tooth types. For example, if the attachment level of a maxillary canine is 8 mm, a clinician can suppose that the tooth has about 43% (= 99.4–7.09 × 8) of supporting tissue remaining (Table 2). However, if the same attachment level is observed in a maxillary second premolar, only 27% (= 96.6–8.67 × 8) of the supporting tissue is likely to remain.

A sixth power polynomial function for each tooth type has been previously used to estimate the surface area of the dentogingival epithelium (i.e. sulcular and junctional epithelium) based on linear measurements of clinical periodontitis (Hujoel et al. 2001). The formulae for the previous study were derived from results of a meta-analysis of root surface areas (Hujoel 1994), published values of root length (Kraus et al. 1969), and results of a study relating the percent of root surface area to the percent of remaining root length (Despeignes 1979). Application of the function provided an estimate of the root surface area between the cemento-enamel junction and a plane perpendicular to the long axis of the tooth. To reflect the clinical situation more accurately, attachment levels were simulated using lines drawn parallel to the cemento-enamel junction rather than using a straight line perpendicular to the long axis of the tooth.

Formulae derived in the previous study (Hujoel et al. 2001) tended to be more curved than those in the current study. This discrepancy might be ascribed to differences in the anatomy of teeth and the method used between the studies. Despeignes (1979) selected natural teeth or sculpted teeth using previously published proportions, dimensions, and morphological characteristics (Marseillier 1965). The present study estimated remaining root surface area based on a simulated attachment loss of 0–10 mm. Beyond 10 mm simulated attachment loss, the data are not likely to fit a linear function, as the taper of root is sharper (Despeignes 1979, Klock et al. 1993). However, teeth with more than 10 mm level of attachment loss are likely to be extracted (Yamamoto et al. 2004) and thus data on the remaining root surface with this level of attachment loss are not clinically relevant.

The total root surface area calculated for each tooth type in the current study was within the 95 percentile of that reported in a previous meta-analysis (Hujoel 1994) and, except for the mandibular molars and first premolar, the root length of each tooth type was similar to that reported previously (DuBrul 1980). This suggests that the extracted teeth used in this study provide an accurate representation of each tooth type.

Various methods have been previously used to measure root surface area including the weight conversion method (Klock et al. 1993) and division planimetry (Dunlap & Gher 1985, Gher & Dunlap 1985). Division planimetry does not allow accurate measurement from the curve of the cemento-enamel junction, and the coefficient of variation of repeated measurement using the weight conversion method has been found to be between 0.10 and 0.12 (Klock et al. 1993). This is twice that found in the present study, where the membrane method (Jepsen 1963, Matsuura et al. 1989), the most commonly used method, was used together with computer-aided image analysis.

In the clinical situation, the clinical attachment level is normally not equal at the various aspects of a tooth. When applying the present results we should keep in mind the limitation. Also, to determine a total prognosis and treatment plan for teeth with periodontal disease, an accurate assessment of the factors influencing each tooth must be made. In addition to remaining periodontal support, the other factors such as mobility, oral hygiene, degree of inflammation, and occlusion must all be carefully considered.

In conclusion, the linear function was most appropriate for estimating the amount of periodontal ligament from the simulated attachment level for all tooth types. The slope of the linear function varied by tooth type.

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Clinical Relevance

Scientific rationale for study: The remaining area of periodontal attachment provides an estimate of the amount of tooth supporting tissue. This study used formulae to estimate this remaining area of periodontal attachment from measures of attachment level using extracted teeth.

Principal findings: A linear function provides the most appropriate estimate of the remaining area of periodontal attachment. However, the slope of the line differed by tooth type.

Practical implications: The remaining area of periodontal attachment is a useful measure of tooth prognosis.