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Physical properties of human premolar cementum: hardness and elasticity

Wanjira Chutimanutskul,* M. Ali Darendeliler,* Michael V. Swain,* Gang Shen* and Peter Petocz*†

Faculty of Dentistry, Sydney Dental Hospital, The University of Sydney,* and Macquarie University,† Australia

Aims: To determine if the cementum on the maxillary right and left first premolars has identical physical properties.
Methods: Ten normal maxillary first premolar teeth, extracted from five orthodontic patients with a mean age of 14.0 years, were used. The teeth had not been subjected to an orthodontic force. The hardness and elastic modulus of the cementum were measured on the buccal and lingual surfaces of the roots at three locations: cervical third, middle third and apical third.
Results: There were no significant side-to-side differences in cementum hardness (Mean side-to-side difference: 0.0063 GPa; SD: 0.0279; $p = 0.525$) or elastic modulus (Mean side-to-side difference: –0.027 GPa; SD: 0.111; $p = 0.814$). The hardness and elastic modulus of the cementum decreased from cervical to apical regions on both root surfaces.
Conclusions: Similar physical properties of the cementum on the maxillary right and left first premolars suggest that intra-arch comparisons can be used to investigate root resorption caused by orthodontic forces.
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Introduction

Cementum, which has been described as a non-uniform mineralised connective tissue covering the root surface, has many features in common with bone.[1,2] Cementum provides both attachment for the periodontal ligament fibres, and contributes to repair of a root surface damaged by orthodontic tooth movement. Cementum is less densely mineralised than dentine and enamel.[3-5] It contains no blood vessels, and does not undergo physiologic remodeling. However, it continues to increase in thickness throughout life. Human cementum occurs in several different physiological forms, which differ with respect to structure, location, function, and rate of formation.[6]

More cementum is formed apically than cervically. In addition, cementum thickness shows characteristic variations among tooth groups and tooth surfaces.[7] There is a tendency for cementum to be deposited in root surface concavities. Thus, thicker layers of cementum may form in root surface grooves and in the furcations of multirooted teeth. Variations in the widths of the incremental layers indicate that the rate of cementum formation varies from time-to-time.[7] The chemical composition of cementum may vary. Morphologically, cementum has been classified as cellular and acellular.[8] Cellular cementum is found covering the apical third of the root and is less densely mineralised than acellular cementum, which covers the cervical two thirds of the root and consists of mineralised layers.[8,9]

Past studies have suggested that changes in physical properties of cementum, such as hardness and elastic modulus, are associated with root resorption.[10,11] Recently, we used the hardness and elastic modulus of cementum to evaluate root resorption following the application of light (25 cN) and heavy (225 cN) orthodontic forces to the right and left maxillary first premolars in each subject.[12,13] In studies such as this it would be advantageous if the cementum covering the right and left first premolars had identical physical properties. To date there have been no published studies determining if side-to-side similarities in cementum hardness and elastic modulus exist.

Differences in the hardness and elastic modulus of the cementum covering different thirds of a premolar root

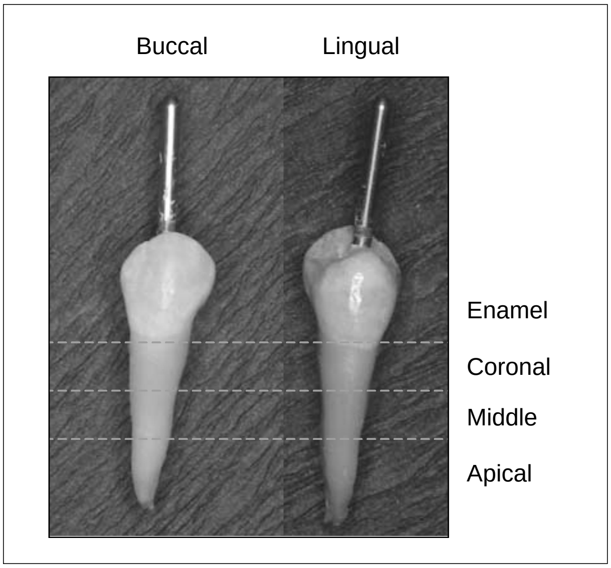

Figure 1: Location of indentations on premolar cementum and enamel. Six positions on the buccal and lingual root surfaces were used. Two enamel positions were used for instrument calibration.

have been reported: cementum covering the apical third of a premolar root has lower values of hardness and elastic modulus than cementum covering the middle and cervical thirds of the root.[14–16] Although cementum on teeth extracted from female subjects is harder than cementum from male subjects there are no differences in cementum hardness between maxillary and mandibular premolar teeth, buccal and lingual root surfaces, and first and second premolars.[16] The elastic modulus of human cementum was not affected by gender, arch, tooth position and tooth surface differences.[16]

The aim of the present study was to determine if the cementum on the right and left maxillary first premolars has identical physical properties. Specifically, we aimed to determine if side-to-side similarities in cementum hardness and elastic modulus exist.

Materials and methods

Ten maxillary first premolar teeth were obtained from five orthodontic patients (3 males and 2 females; Mean age: 14.0 years, Range 12.2–18.8 years) who had the teeth extracted as part of their orthodontic treatment. The selection criteria have been previously published.[17,18] The patients were diagnosed with Class I malocclusion with moderate crowding, and had not had previous orthodontic treatment.

The teeth were extracted by one of two oral surgeons who were requested to avoid damage to the cervical cementum with the forceps. Immediately after extraction the teeth were stored in individual containers filled with sterilised deionised water (Milli Q, Millipore, Bedford, USA). The teeth were then placed in an ultrasonic bath for 10 minutes to remove the periodontal ligament (PDL) and soft tissue fragments. After the ultrasonic bath, the teeth were gently swabbed with a damp gauze swab until all visible signs of the PDL were removed. The teeth were then sterilised according to the protocol described in previous publications.[17,18] After debridement and sterilisation, the samples were mounted on a stainless steel diamond coated high-speed long shank bur with glass ionomer cement (Transbond, Unitek 3M, USA), and stored in deionised water at ambient room temperature and humidity (23 degrees ± 1 degree Celsius; 50 per cent ± 10 per cent relative humidity) until required.

The hardness and elastic modulus were measured with an Ultra Micro Indentation System (UMIS-2000, Commonwealth Scientific and Industrial Research Organization, Lindfield, Australia) in conjunction with a jig designed and developed for this purpose.[17,18] The root was equally divided into thirds (cervical, middle and apical). A point mid-way along the buccal and lingual surface of each third was selected for testing (Figure 1).

The Statistical Package for Social Sciences (Release 11 for Windows, SPSS Inc., USA) and Minitab (Version 14 for Windows, Minitab, Inc., USA) were used for the analyses. Bland and Altman's[19] limits of agreement method was used to assess the agreement of measurements of hardness and elasticity between the right and left sides in each subject. After agreement was confirmed, an analysis of variance model was constructed for hardness and elasticity with tooth location (lingual, buccal; cervical, middle, apical) and side (left, right) as fixed factors and subject as a random factor.

Results

Bland and Altman[19] have suggested plotting differences against means as a way of assessing agreement between two methods of measuring the same quantity. They have pointed out that the usual approach based on correlation coefficients is misleading at best and incorrect in many situations. Their approach can be used in the present study, where the left and right side measurements of hardness and elasticity were used as two methods of measuring the same quantity. If the

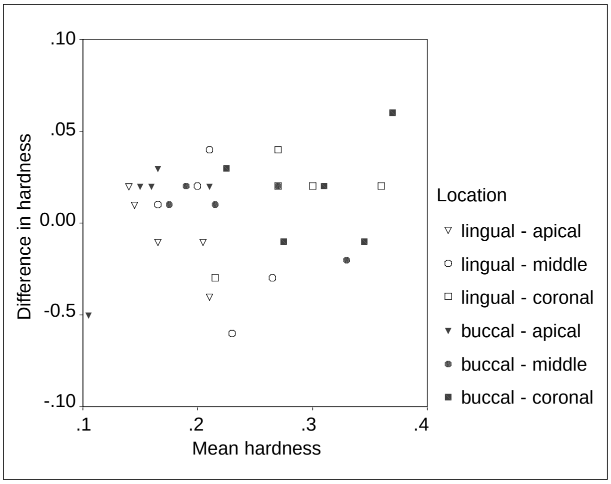

Figure 2: Difference and mean hardness of cementum, by tooth position.

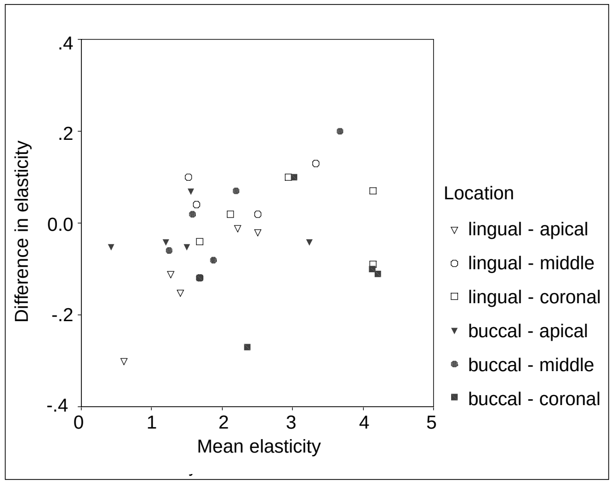

Figure 3: Difference and mean elastic modulus of cementum, by tooth position.

measurements on the two sides are in general agreement, one of them can be used as a control while the other is subjected to an experimental condition.

The differences in hardness are plotted against the means for hardness, and the differences in elasticity are plotted against the means for elasticity (Figures 2 and 3). In each case there is no systematic pattern relating the differences to the means. Linear regressions of the differences on the means confirmed that the slopes of the relationships were not significantly different from zero, and that the residuals showed no significant pattern.

Bland and Altman suggest that the 'limits of agreement' can then be calculated based on the summary statistics of the differences (Mean difference ± 2 SD difference).[19] The mean difference for hardness is 0.0063 GPa with a standard deviation of 0.0279 GPa. Since the mean hardness across the whole sample is 0.228 GPa this translates into 'percentage limits of agreement' between -24 per cent and +25 per cent.

The mean difference for elastic modulus is -0.027 GPa with a standard deviation of 0.111 GPa. Since the mean elastic modulus across the whole sample is 2.253 GPa, this results in percentage limits of agreement between -11.1 per cent and +8.7 per cent. It can be seen that the elasticity values display fairly narrow limits of agreement, while the hardness values are wider by a factor of between two and three.

Finally, univariate ANOVA models were set up for hardness and elasticity with subject as a random factor and tooth location (lingual, buccal; cervical, middle, apical) and side (left, right) as fixed factors. The factor of side is not significant in each case (Table I).

Table I. Between-subjects effects.

Source	Dependent variables	F	p
Corrected models	H	15.248	0.000
	E	28.353	0.000
Intercept	H	2131.162	0.000
	E	1519.867	0.000
Subject	H	8.783	0.000
	E	44.014	0.000
Location	H	23.387	0.000
	E	21.483	0.000
Side	H	0.411	0.525
	E	0.056	0.814

H: Hardness E: Elasticity
ANOVA between-subjects
a. R Squared = 0.757 (adjusted R Squared) = 0.707
b. R Squared = 0.858 (adjusted R Squared) = 0.823

The results showed that there was no significant difference between the mean hardness of the cementum on the right and left sides (Right side mean: 0.231 GPa; Left side mean: 0.225 GPa; p = 0.525). There was also no significant side-to-side difference in the mean elastic modulus of cementum (Right side mean: 2.239 GPa; Left side mean: 2.267 GPa; p = 0.814) (Table II).

Table II. Hardness and elasticity of cementum, by side, surface and position.

Dependent variable	Side/ location	Mean	SEM	95 per cent CI Lower	Upper
H	R	0.231	0.007	0.217	0.245
	L	0.225	0.007	0.211	0.239
E	R	2.239	0.082	2.075	2.245
	L	2.267	0.082	2.075	2.404
H	b-c	0.305	0.012	0.281	0.329
	b-m	0.236	0.012	0.212	0.260
	b-a	0.158	0.012	0.134	0.182
	l-c	0.283	0.012	0.259	0.307
	l-m	0.214	0.012	0.190	0.238
	l-a	0.173	0.012	0.149	0.197
E	b-c	3.078	0.142	2.794	3.362
	b-m	2.115	0.142	1.831	2.399
	b-a	1.583	0.142	1.299	1.867
	l-c	3.006	0.142	2.722	3.290
	l-m	2.133	0.142	1.849	2.417
	l-a	1.603	0.142	1.319	1.887

H: hardness, E: elasticity, R: right, L: left, b-c: buccal-cervical, b-m: buccal-middle, b-a: buccal-apical, l-c: lingual-cervical, l-m: lingual-middle, l-a: lingual-apical

Discussion

The present study is the first to establish that there are no side-to-side differences in the physical properties of the cementum on the buccal and lingual surfaces of human maxillary first premolars. Our findings support an earlier investigation that reported there were no significant differences in the hardness and elasticity of cementum on the maxillary and mandibular premolars, and on the buccal and lingual surfaces of premolar roots.[16] In agreement with other studies the present study also demonstrated that there was a decreasing gradient in the hardness and elasticity of cementum in both groups from the cervical to apical third.[16,18,20]

Cementum is a biological material with heterogeneous structure that changes throughout life.[21] It should not be considered as an engineering material with a uniform structure and absolute values for hardness and elastic modulus through the full depth of the material. The UMIS was designed as a microprobe to test material properties in the surface layer. It is only possible to test small, shallow areas with this instrument: depths greater than one third of the 20 μm radius of indentation could not be investigated. Furthermore, because the indents were placed as close as possible to the midpoint in each divided third of the root, small resorption areas in experimental teeth could be missed. Finally, testing could only be carried out in flat areas, and these were often difficult to find because of the irregular surface of the cementum.

The hardness and elasticity of cementum depend on the direction of structural arrangement1,[21] and the mineral content of the cementum.[22–25] The cervical two thirds of the root is covered by acellular extrinsic fibre cementum that consists of mineralised layers.[5] Apical cementum, on the other hand, is predominately cellular, less densely mineralised and has lower hardness and elastic modulus values than the more densely mineralised acellular cementum found in the middle and cervical thirds of the root.[9,8,15] Several studies have reported that the hardness and the elastic modulus of mineralised tissues were positively correlated with the extent of mineralisation.[15,18,26,27] Extremely wide variations in cementum hardness have been reported.[18,28] Some of this variation will be natural variation and some may be due to variations in sampling.[18,28]

The present study provides important baseline information when intra-individual comparisons of different orthodontic force levels are undertaken. Previous experimental studies of root resorption have assumed that there were no confounding side-to-side differences in the hardness or elasticity of cementum. For example, recent studies on orthodontically-induced root resorption have used a light and a heavy force in the same subject.[12,13] It is obviously important to know if side-to-side differences in hardness and elasticity are present. Experimental-control comparisons in the same subject can now be undertaken in the knowledge that the results are unlikely to be confounded by right-left differences in hardness and elasticity.

Conclusions

1. There are no significant right side - left side differences in the hardness and elastic modulus of human maxillary first premolar cementum.

2. The hardness and elastic modulus of human maxillary first premolar cementum gradually decreases from the cervical to apical regions on both the buccal and lingual surfaces.

3. Similar physical properties of the cementum on maxillary right and left first premolars suggest that intra-arch comparisons can be used to investigate root resorption caused by orthodontic forces.

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Corresponding author

Professor M. Ali Darendeliler
Discipline of Orthodontics
Faculty of Dentistry
Sydney Dental Hospital
The University of Sydney
Level 2, 2 Chalmers St
Surry Hills NSW 2010
Australia
Tel: (+ 61 2) 9351 8314
Fax (+61 2) 9351 8336
Email: adarende@mail.usyd.edu.au

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