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Changes in the physical properties of human premolar cementum after application of 4 weeks of controlled orthodontic forces

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SUMMARY This study was performed to assess the relationship between the magnitude of orthodontic force and physical properties of individual human cementum, and to identify the sites that may be predisposed to root resorption. The findings may assist in relating physical properties of dental root cementum and its susceptibility to root resorption.

Sixteen maxillary first premolar teeth were selected in eight orthodontic patients (three males and five females), mean age 14.8 years (range 11.2–17.5 years), requiring first premolar extractions. In each patient, a light orthodontic force of 25 cN was applied buccally using a sectional archwire on the first premolar on one side, while a heavy force of 225 cN was applied to the contralateral side. The teeth were extracted 4 weeks after initial force application. Hardness and elastic modulus were measured on the buccal and the lingual surfaces of the cementum at the cervical, middle, and apical third of the root.

The results showed that the mean hardness and elastic modulus of cementum in the light force group were greater than in the heavy force group at all positions. There were highly significant differences in both hardness and elastic modulus between the heavy and light force groups ($P < 0.01$). The mean hardness and elastic modulus of cementum gradually decreased from the cervical to the apical regions for buccal as well as lingual surfaces in both groups. There was, however, an insignificant difference between hardness and elastic modulus on the buccal surface compared with the lingual surface ($P < 0.05$). It was concluded that the hardness and elastic modulus of cementum were affected by the application of orthodontics forces.

Introduction

Root resorption is a common and unpredictable side-effect of orthodontic treatment. Many investigations have been carried out to elucidate factors which may act alone or in combination to possibly cause root resorption, including the type of orthodontic appliance (Linge and Linge, 1983, 1991), the magnitude of applied force (Reitan, 1974; Owman-Moll *et al.*, 1996; Chan and Darendeliler, 2004), the duration of force application (Linge and Linge, 1983; Reitan, 1985; McFadden *et al.*, 1989; Levander and Malmgren, 2000; Sameshima and Sinclair, 2001), type of tooth movement (Reitan, 1974; Linge and Linge, 1983; McFadden *et al.*, 1989; Parker and Harris, 1998), clinical factors (Sameshima and Sinclair, 2001), systemic factors (McNab *et al.*, 1999), the age of the patient (Brezniak and Wasserstein, 1993a,b), gender (McNab *et al.*, 1999), nutrition (Becks, 1936), previous trauma (Linge and Linge, 1983, 1991), and ethnicity (Sameshima and Sinclair, 2001).

Blake *et al.* (1995) defined root resorption as a physiologic or pathologic process resulting in the loss of cementum and dentine. Resorption of calcified dental tissues occurs if osteoclasts obtain access to the mineralized tissue by a breach in the formative cell layer covering the tissue (Tronstad, 1988; Craig, 1993; Darendeliler *et al.*, 2004). This occurs if the mineral and matrix surfaces coincide, or when the pre-cementum is mechanically damaged or scraped off (Tronstad, 1988). It has been documented that the uncalcified mineral tissues, osteoid, pre-cementum, and pre-dentine are resistant to resorption and may initially prevent the loss of root tissue (Reitan, 1985). However, continuous pressure will eventually lead to resorption of these areas (Reitan, 1985; Tronstad, 1988).

The magnitude of orthodontic force is believed to be an important factor, not only for the magnitude of the tooth movement but also for any dental root tissue damage (Reitan, 1964; King and Fischlschweiger, 1982). It is believed that excessive forces will cause increased damage, such as root resorption, to the engaged tissues. Several studies have supported findings that an increase in root resorption can be produced by an increase in the magnitude of orthodontic force (Vardimon *et al.*, 1991; Chan and Darendeliler, 2004, 2005). However, other studies (Stenvik and Mjör, 1970; Owman-Moll *et al.*, 1996) have demonstrated that heavy forces do not increase root resorption.

Several literature reviews (Reitan, 1969; Andreasen, 1988, 1992) have suggested that the physical properties of cementum may influence resistance or susceptibility to root resorption. These properties of cementum, such as hardness and elastic modulus, may reveal important characteristics of root resorption. However, there are few investigations that have focused on the relationship between hardness and elastic modulus of cementum in human teeth and the magnitude of force applied (Darendeliler *et al.*, 2004).

An earlier interindividual investigation of hardness and elastic modulus between a control (0 cN), heavy force (225 cN), and light force (25 cN) group found that there were no significant differences in the hardness and elastic modulus of cementum between the groups (Darendeliler *et al.*, 2004). These results may be due to individual variations, uneven samples of upper and lower premolar teeth, and ethnic variations. Individual variations were substantial regarding the occurrence, surface extension, and depth of root resorption (Linge and Linge, 1983; Reitan, 1985; Kurol *et al.*, 1996; Darendeliler *et al.*, 2004).

The aim of the current study was to compare the effect of orthodontic force magnitude between light (25 cN) and heavy (225 cN) forces on changes in physical properties of cementum in an intraindividual sample and to identify the sites that may be predisposed to root resorption by measurement of their physical properties.

Subjects and methods

Ethical approval (No. X03–0246) was granted by the Ethics Review Committee (RPAH Zone), Central Sydney Area Health Service.

Sixteen maxillary first premolar teeth were selected from eight orthodontic patients (three boys and five girls, mean age 14.8 years, range 11.2–17.5 years) who required bilateral first premolar extraction as part of their orthodontic treatment. The selection criteria have been described previously (Malek *et al.*, 2001; Darendeliler *et al.*, 2004).

The teeth of subjects in the present study were bonded with 0.022-inch Speed brackets (Strite Industries, Ontario, Canada) on the first permanent molar and the experimental premolar tooth. The right or left first premolars were randomly selected to receive two levels of force. A light buccally directed orthodontic force of 25 cN was applied to the experimental tooth with a 0.016-inch Titanium–Molybdenum Alloy spring (TMA®, Ormco, Orange, California, USA), while a heavy force of 225 cN was applied on the contralateral side using a 0.017 × 0.025 inch TMA spring (Figure 1). The force magnitude was measured with a strain gauge (Dentaurum, Ispringen, Germany). Glass ionomer cement (GIC; Transbond, 3M Unitek™, Monrovia, California, USA) was bonded onto the occlusal surfaces of the lower first molar teeth to disengage the experimental premolars from occlusion and thereby prevent possible disturbance from additional forces. The force system designed for this study did not have an impact on the future orthodontic treatment of these subjects.

The experimental teeth were extracted 28 days after initial force application. There was no reactivation during this period. Extractions were performed by two oral surgeons who were requested to avoid any forceps contact on the cervical cementum. Immediately after extraction, the teeth were individually stored in sterilized deionised water (Milli Q®, Millipore, Bedford, Massachusetts, USA). The teeth were then placed in an ultrasonic bath for 10 minutes to remove all traces of residual periodontal ligament (PDL) and soft tissue fragments. After the ultrasonic bath, the teeth were gently swabbed with damp gauze until all visible signs of the PDL were removed. The teeth were then disinfected according to the protocol described previously (Malek *et al.*, 2001; Darendeliler *et al.*, 2004). After sterilization and debridement, the samples were mounted on a stainless steel diamond-coated high-speed long-shank chamfer bur, secured with GIC, and then stored in sterilized deionised water at an ambient room temperature of 23 ± 1°C and 50 ± 10 per cent relative humidity until experimentation.

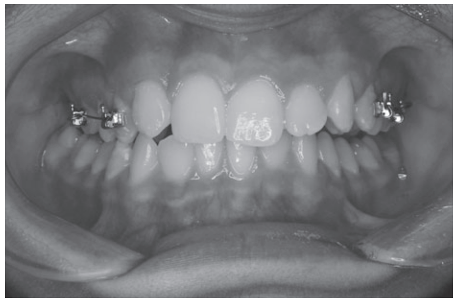

Figure 1 Intraoral view of force application: a light buccally directed orthodontic force of 25 cN was applied to the experimental tooth with a 0.016-inch Titanium–Molybdenum Alloy (TMA) spring while a heavy force of 225 cN was applied on the contralateral side using 0.017-inch TMA. The premolars are disengaged from occlusal contact.

The hardness and elastic modulus were measured in gigapascals using an ultra-micro-indentation system (UMIS-2000; Commonwealth Scientific and Industrial Research Organization, Lindfield, Australia) in conjunction with a specially designed jig assembly developed and tested for this purpose (Malek *et al.*, 2001; Darendeliler *et al.*, 2004). The root was equally divided into three horizontal regions (cervical, middle, and apical). One point, midway along the buccal and lingual surfaces of each region, was selected for testing. The points of indentation were selected at non-resorbed cementum immediately adjacent to resorption craters, if present, and were identified using ×10 and ×20 video magnification attached to the UMIS-2000 (Figure 2).

Statistical analysis

The Statistical Package for Social Sciences (SPSS software program for Windows, release 11, SPSS Inc., Chicago, Illinois, USA) was used for statistical analysis. The values of the hardness and elastic modulus of the enamel were not included in all the analyses. A multivariate general linear model for hardness and elastic modulus in terms of subjects, locations, forces, and their (second order) interactions was considered. A univariate analysis of variance (UNIANOVA) was also employed to investigate hardness and elastic modulus separately in cementum between the heavy and light force groups. The UNIANOVA model was constructed to allow for differences within position (buccal and lingual surfaces at the cervical, middle, and apical third), subjects, forces, and the interactions between positions and forces, between positions and subjects, and between forces and subjects. Pairwise comparisons were used to determine statistically significant differences between positions and strength of forces. A Bonferroni adjustment was made to allow for multiple comparisons. At this level, to allow for multiple comparisons, statistical significance was at the $P < 0.01$ level.

Results

The results showed that the mean hardness in the light force group slightly decreased from coronal to apical at both the buccal and lingual surfaces. There was a trend toward a higher mean hardness on the lingual surface compared with the buccal surface ($P < 0.05$; Table 1, Figure 3).

In the heavy force group, the mean hardness also decreased slightly from coronal to apical on both the buccal and lingual surfaces. On the lingual surface, there was a trend toward a higher mean hardness compared with the buccal surface ($P < 0.05$; Table 1, Figure 3).

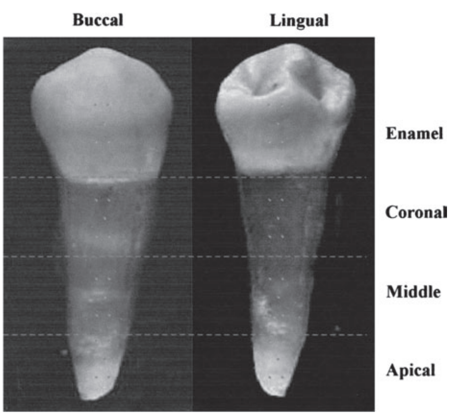

Figure 2 Locations of indentation on premolar cementum and enamel. Six positions on the buccal and lingual root surfaces and two enamel positions were used to allow for instrument calibration.

The elastic modulus in the light force group decreased slightly from coronal to apical at both the buccal and lingual surfaces. There was a trend toward a higher elastic modulus at the buccal surface compared with the lingual surface ($P < 0.05$; Table 2, Figure 4).

In the heavy force group, the elastic modulus slightly decreased from coronal to apical at both the buccal and lingual surfaces. There was no significant difference between the elastic modulus on the buccal surface compared with the lingual surface ($P < 0.05$; Table 2, Figure 4).

Comparison of the mean hardness for cementum between the light and heavy force groups at the buccal and lingual surfaces at the cervical, middle, and apical third are given in Table 1. There was a slightly significant difference in mean hardness between the light and the heavy force groups at the buccal-coronal ($P < 0.01$), buccal-middle ($P < 0.01$), buccal-apical ($P < 0.01$), lingual-coronal ($P < 0.01$), lingual-medial ($P < 0.05$), and lingual-apical ($P < 0.01$) sides (Table 1, Figure 3).

The mean elastic modulus of cementum in the light and heavy force groups are presented in Table 2. The mean elastic modulus in the light force group was significantly higher than in the heavy force group at the buccal-coronal ($P < 0.01$), buccal-medial ($P < 0.05$), buccal-apical ($P < 0.05$), lingual-coronal ($P < 0.01$), lingual-middle ($P < 0.01$), and lingual-apical ($P < 0.05$) sides (Table 2, Figure 4).

In the comparison of hardness and elastic modulus between the heavy and the light force groups, hardness and elastic modulus in the heavy force group were significantly lower than in the light force group (Figures 3 and 4).

Discussion

Traditionally, root resorption has been considered to be affected initially by force magnitude (Stenvik and Mjör, 1970; Reitan, 1974; Vardimon *et al.*, 1991; Owman-Moll *et al.*, 1996) and light forces have long been recommended (Reitan, 1975, 1985; King and Fischlschweiger, 1982; Poolthong *et al.*, 1996) to reduce adverse tissue reactions. Properties of root structure, such as hardness and elastic modulus of cementum and mineral content, have been cited as possible factors influencing resistance or susceptibility to

Table 1 Means and standard errors (SE) for variations in hardness of cementum (GPa) and comparison of hardness (*P*-value) between light (L) and heavy (H) force groups on the buccal and lingual surfaces at three positions (coronal, middle, and apical).

Position on tooth	L		H		Difference (L − H)		*T*-ratio	
	Mean	SE	Mean	SE	Mean	SE	35 df	*P*-value
Buccal-coronal	0.325	0.012	0.246	0.012	0.079	0.017	4.691	0.000
Buccal-middle	0.260	0.012	0.206	0.012	0.054	0.017	3.201	0.003
Buccal-apical	0.221	0.012	0.165	0.012	0.056	0.017	3.350	0.002
Lingual-coronal	0.379	0.012	0.300	0.012	0.079	0.017	4.691	0.000
Lingual-middle	0.301	0.012	0.256	0.012	0.045	0.017	2.680	0.011
Lingual-apical	0.255	0.012	0.190	0.012	0.065	0.017	3.872	0.000

root resorption (Reitan, 1974; Andreasen, 1992). It has been reported that individual variation plays a role in the phenotype of physical properties of root cementum (Malek *et al.*, 2001; Darendeliler *et al.*, 2004). Individual susceptibility is also considered as a major factor in determining root resorption potential with or without orthodontic treatment. This variation also affects the occurrence, surface extension, and depth of root resorption (Kurol *et al.*, 1996).

The current study showed that there were significant differences in hardness and elastic modulus in the light force group compared with the heavy force group. This confirms the results from an earlier investigation (Darendeliler *et al.*, 2004) that if the hardness is directly related to root resorption then it could be expected that harder teeth resorb less after application of orthodontic forces. If the hardness of cementum is inversely related to root resorption, then reduced orthodontic forces are recommend to avoid root resorption.

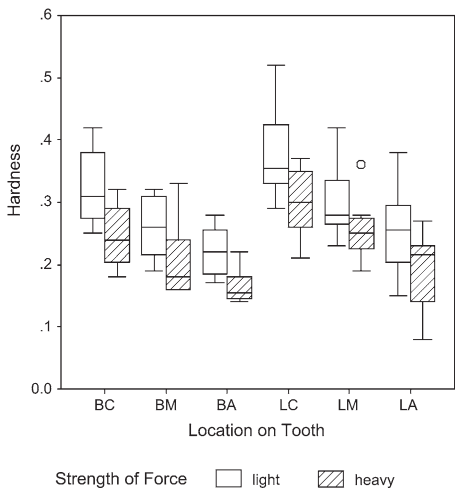

Figure 3 Box plot comparison of the hardness of cementum between the light (25 cN) and heavy (225 cN) force groups on the buccal and lingual surfaces at three positions. Thick horizontal bars indicate the median, the box extends from the first to the third quartile, and lines extend to minimum and maximum values (BC, buccal-coronal; BM, buccal-middle; BA, buccal-apical; LC, lingual-coronal; LM, lingual-middle; and LA, lingual-apical).

It is interesting to note that Owman-Moll *et al.* (1996) reported findings that were contrary to the current study. In their clinical trial, a similar intraindividual approach was designed to investigate the effect of a light (50cN) and heavy (200cN) force on adverse tissue reactions (root resorption) of maxillary first premolars. Histological measurement of surface extension and depth of root resorption revealed that, compared with light force loading, heavy forces did not trigger any significant increase in root resorption. The different methodologies in localizing and identifying root resorption between the two studies may account for the conflicting conclusions. Compared with the approach in the current study where hardness and elasticity of root cementum were examined at every aspect of the root to indicate the susceptibility to root resorption, the limited number of sections cut from the teeth and two-dimensional observation might not render reliable information to indicate the overall root resorption situation. Commenting on the method of Owman-Moll *et al*. (1996), Chan and Darendeliler (2004) assumed that, due to the fact that resorption craters could vary excessively in size and depth, some irregular C-shaped craters and small craters could be partially or totally missed or miscalculated.

The findings in the present study revealed that there was a decreasing gradient in hardness and elastic modulus in both groups from the cervical to the apical third. This can be explained either by the natural structure of human cementum or by the effect of orthodontic force. According to the physical properties of untreated human premolar teeth, apical cementum exhibits the least elastic modulus and hardness values (Linge and Linge, 1991; Clark, 1997; Malek *et al.*, 2001). The hardness and elastic modulus also vary within teeth, depending on the direction of structural arrangement (Berkovitz *et al.*, 1992; Ten Cate, 1998) and different mineral content in the structure of cementum (Henry and Weimann, 1951; Rygh and Reitan, 1964; Jones and Boyde, 1972; Rex *et al.*, 2005). The cervical two-thirds of the root is covered by acellular extrinsic fibre cementum that consists of only mineralized layers (Selvig and Selvig, 1962), while cellular cementum is less mineralized and mainly found toward the apical third of the root (Mjör and

Table 2 Means and standard errors (SE) for variations in elastic modulus of cementum (GPa) and comparison of elastic modulus (*P*-value) between light (L) and heavy (H) force groups on the buccal and lingual surfaces at three positions (coronal, middle, and apical).

Position on tooth	L		H		Difference (L − H)		*T*-ratio	
	Mean	SE	Mean	SE	Mean	SE	35 df	*P*-value
Buccal-coronal	3.629	0.219	2.674	0.219	0.955	0.309	3.088	0.004
Buccal-middle	2.714	0.219	1.929	0.219	0.785	0.309	2.538	0.016
Buccal-apical	1.914	0.219	1.278	0.219	0.636	0.309	2.057	0.047
Lingual-coronal	5.069	0.219	3.291	0.219	1.778	0.309	5.747	0.000
Lingual-middle	3.728	0.219	2.475	0.219	1.253	0.309	4.050	0.000
Lingual-apical	2.463	0.219	1.921	0.219	0.541	0.309	1.750	0.089

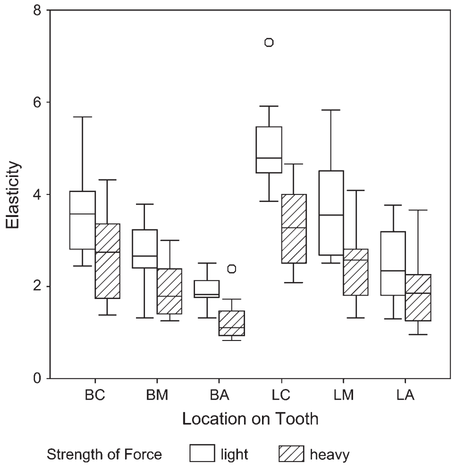

Figure 4 Box plot comparison of elastic modulus of cementum between the light (25 cN) and heavy (225 cN) force groups on the buccal and lingual surfaces at three positions. Thick horizontal bars indicate the median, the box extends from the first to the third quartile, and lines extend to minimum and maximum values (BC, buccal-coronal; BM, buccal-middle; BA, buccal-apical; LC, lingual-coronal; LM, lingual-middle; and LA, lingual-apical).

Pindborg, 1973; Freeman, 1998). Several studies (Rautiola and Craig, 1961; Brear *et al.*, 1990; Mahoney *et al.*, 2000; Malek *et al.*, 2001) concluded that hardness and elastic modulus were positively correlated with mineralization in mineralized tissues. Cellular cementum is less calcified and has a lower hardness and elastic modulus than acellular cementum, which is more highly calcified (Rautiola and Craig, 1961).

Variations in hardness and elastic modulus may be caused by different approaches in force application. Such factors include (1) concentration of force at the root apex because orthodontic tooth movement is never entirely translatory, and the fulcrum is usually occlusal to the apical half to the root (Harris, 2000) and (2) the PDL fibres assume a different direction at the apical end, which might explain the increased stress in the region.

It must be emphasized that, although this intraindividual study found hardness and elastic modulus to be highly associated with the magnitude of orthodontic force, the hardness and elastic modulus may also differ between individual teeth and between different areas of each tooth (Rautiola and Craig, 1961; Malek *et al.*, 2001) and the structural arrangement of cementum may also be unique to each individual tooth (Spears, 1997). Rautiola and Craig (1961) and Malek *et al.* (2001) reported extremely wide variations in hardness among different locations of the same cementum of the same tooth. The very nature of cementum would allow for not only natural variation but also intralayer (location) differences (Reitan, 1969; Malek *et al.*, 2001).

One study (Clark, 1997) concluded that there were no significant differences in the hardness and elastic modulus of cementum between the buccal and lingual surfaces or between the upper and lower teeth. It was also assumed that there were no differences in the physical properties between the left and right teeth. However, no previous studies have compared the physical properties between the left and right sides.

It appears that cementum is a biological material with a heterogenous structure that changes throughout life (Berkovitz *et al.*, 1992). It should not be considered as an engineering material that has an absolute value for hardness and elastic modulus. The results of UMIS testing also depend on the layers tested (Clark, 1997). The UMIS-2000 was intended to be used as a microprobe of material properties in the surface layer. Depths greater than one-third of the 20-μm radius of indentation could not be investigated. A flat surface of each sample was required during indenting which was difficult to find due to the irregular surface nature of human cementum. Also, due to the random placement of indents, the area tested may not be within a resorption area.

Taking into account the various factors that influence the measurement of hardness and elasticity of cementum, there was a significant difference in the physical properties between different areas of root cementum. The properties of root cementum were also affected by the application of orthodontic forces.

Further research is required to clarify the differences in the physical properties in untreated human first premolar teeth between the left and right sides and the mineral composition of human premolar cementum (intraindividual) after application of orthodontic forces.

Conclusions

1. Hardness and elastic modulus of human maxillary first premolar cementum gradually decreased from the cervical to the apical regions at both the buccal and lingual surfaces, regardless of the orthodontic force applied.
2. Heavy forces decrease elasticity of cementum more than light forces.
3. Heavy forces decrease hardness of cementum more than light forces.

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