Investigation of Dentin Hardness in Roots Exhibiting the Butterfly Effect

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Abstract

Introduction: Most vertical root fractures occur in root canal treated teeth, and they usually run in a buccolingual direction. The butterfly effect is an optical phenomenon seen in some sections of tooth roots. The aim was to investigate the microhardness of dentin in mesiodistal and buccolingual cross sections of roots exhibiting the effect. **Methods:** Thirty extracted single-rooted teeth were allocated according to patient age: group 1, 15–24 years; group 2, 25–44 years; and group 3, 45 years and older. Roots were embedded in acrylic and cut into ten 1-mm-thick cross sections. Sections were viewed under a light microscope and coded (1 or 2) according to presence or absence of the butterfly effect. A root scored 20 when all levels featured the butterfly appearance. The 2 teeth with the highest score from each group and 2 control teeth with the minimum score (10) were selected. Two adjacent, consecutive cross sections were chosen from the middle of the roots. Vickers microhardness testing was carried out on the dentin walls. **Results:** Mean hardness scores were highest mesiodistally (83.7 kgf/mm^2) and lowest buccolingually (56.4 kgf/mm^2), a significant difference (P = .028). This trend was found across all age groups. **Conclusions:** Root sections with the butterfly effect are harder mesiodistally. This might explain the high prevalence of vertical root fractures that run buccolingually. *(J Endod 2014;40:842–844)*

Key Words

Dentin, endodontics, vertical root fracture

The majority of vertical root fractures (VRFs) occur in root canal treated teeth, and they usually run in a buccolingual direction (1, 2). The butterfly effect is seen in some cross sections of tooth roots (3). Vasiliadis et al (4) reported that dentinal tubular sclerosis differed in mesiodistal and buccolingual directions, noting a characteristic butterfly shape. Sclerosed dentin is more translucent than normal dentin (5, 6). Russell et al (7) reported that teeth with the butterfly effect had a higher density of dentinal tubules buccolingually than mesiodistally, suggesting that this may affect hardness of dentin. A search of the literature revealed no previous studies examining hardness of dentin and the butterfly effect. The aim of this study was to investigate the hardness of dentin in mesiodistal and buccolingual cross sections of roots exhibiting the butterfly effect.

Materials and Methods

Ethical approval was granted from the University of Otago, Dunedin, New Zealand to collect 30 single-rooted human teeth of known age. They were divided into groups of 10: group 1, 15–24 years; group 2, 25–44 years; and group 3, 45 years and older. Roots were embedded in acrylic (Vertex Self Curing; Vertex-Dental BV, Zeist, The Netherlands) and cut into 1-mm-thick cross sections (Accutom 50 saw; Struers A/S, Ballerup, Denmark). Each root yielded 10 sections, which were marked to indicate orientation. These were viewed with a light microscope (EHT; Olympus, Tokyo, Japan) at ×10 magnification by 2 calibrated examiners and given a score. A score of 1 represented no butterfly effect where the dentin had uniform color, and 2 represented the butterfly effect with alternating shades of dentin (Fig. 1). Examiners reached a consensus for each section, and scores were summed. Twenty represented a tooth with the effect present in all sections, and 10 represented a tooth with the effect totally absent. From each age group, the 2 teeth with the highest overall scores were selected for further examination. As controls, 2 teeth with a score of 10 (no effect) were selected. For each of the 8 teeth, 2 adjacent sections were chosen from the middle of the root to give 16 specimens.

To remove surface defects, sections were polished with silicon carbide paper of increasing grit (P500 to P4000; 3M Europe, Diegem, Belgium) and reexamined with the microscope to identify any remaining scratch lines and need for further polishing. Each section was then indented with a square-based pyramid diamond indenter to determine Vickers hardness (Shimadzu Ltd, Tokyo, Japan). The indenter was set to 1 kg (10 N) load for 30 seconds. Four indents were made per specimen on the mid-mesial, mid-distal, mid-buccal, and mid-lingual aspects (Fig. 1). Indents were made a consistent distance from the lumen, with the tip of the diamond facing the luminal space. Sections were then placed in 1% aqueous methylene blue dye and rinsed with water to increase visibility.

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Dimensions of the indents were measured with the microscope. Measurements were taken twice by 2 examiners working independently. If results differed (less than 5% of the sections), indents were re-measured. Data were entered into a formula to calculate hardness scores.

A 2-tailed Student *t* test was used with an alpha value of 0.05 to analyze the data (StataCorp, College Station, TX).

Equation	Key
$HV = \frac{2F \sin\times\frac{136}{2}}{d^2}$	HV = Vickers hardness F = Load in kgf d = mean diagonal distance

Results

Hardness testing results appear in Table 1. In teeth with the effect, the hardness scores were significantly higher (mean, 83.7 kgf/mm^2; standard deviation, 11.7) in the mesial and distal surfaces and lowest in the buccal and lingual surfaces (mean, 56.4 kgf/mm^2; standard deviation, 6.7) regardless of the age group (P = .028). This trend was not observed in control teeth (P = .079).

Discussion

The aim of this study was to investigate the microhardness of mesiodistal and buccolingual cross sections of roots of different ages exhibiting the butterfly effect. Previous research suggested that teeth with the butterfly effect may be weaker and thus more prone to VRF in the buccolingual direction (7). Studies have shown that higher densities of dentinal tubules correlate with lower tensile strengths of dentin (8, 9). The present investigation confirms that teeth with the effect have significantly lower hardness scores in the buccolingual direction, supporting the suggestion that they could be more susceptible to fracture. The literature shows that VRF occurs more frequently in a buccolingual direction (10, 11), with craze lines or cracks on root sections more common buccolingually (12).

Lertchirakarn et al (10) investigated VRF patterns and found that the buccolingual dentin wall thickness is greater than that of the mesiodistal wall and that stresses are greater in the thickest part of the dentin. Cracks propagate from the buccal or lingual surfaces more readily than mesial or distal. This pattern is consistent with other clinical and experimental observations and is often regarded as counterintuitive (11, 13). The fact that many tooth roots feature the butterfly effect and have higher densities of dentinal tubules (7) and lower hardness scores in the buccolingual direction, regardless of dentin thickness, may help explain the unexpected pattern of VRF.

Canal shape and root morphology have been linked to VRF, with ovoid canals associated with higher stress concentration and a greater occurrence of cracks (11–13). A limitation of our study is that canal shape and root morphology were not examined. Mechanical preparation of root canals is known to introduce craze lines and increase the risk of VRF (11, 13, 14). A smoothly rounded canal is favorable, eliminating stress concentration to decrease fracture susceptibility (13, 14). Thus, for teeth showing the butterfly effect, conservative root canal preparation and maintaining a circular canal shape may be very significant.

Root canal preparation, ultrasonic irrigation, obturation techniques including lateral condensation of gutta-percha, and post placement may produce unfavorable stresses and crack propagation in canals (10, 12, 15). Studies investigating cracked teeth have found that there is a significant correlation between VRF and endodontically treated teeth (16). Even the use of chelating agents such as 17% EDTA for prolonged periods has a significant effect on dentin microhardness, leading to VRF (17).

Dentin microhardness increases with increasing distance from the pulp (18). In this study the hardness was measured an equal distance from the canal lumen. Dentin is a hydrated substance, and although we attempted to maintain this, drying of specimens may have had an effect on hardness properties.

The present study investigated teeth of different ages but did not consider the tooth type. Von Arx et al (12) examined the different characteristics of root sections and described the presence of "frosted dentin," which was more common in premolars and molars than in anterior teeth. The clinical significance of our findings may therefore be more applicable to posterior teeth. Our investigation shows that teeth with the butterfly effect have lower hardness scores buccolingually than mesiodistally. This potentially helps to explain VRFs occurring more commonly in the buccolingual direction. In addition to microhardness, there are other mechanical properties impacting on VRFs. These include fracture toughness, flexural strength, fracture energy, and elasticity, factors that were not investigated in this study.

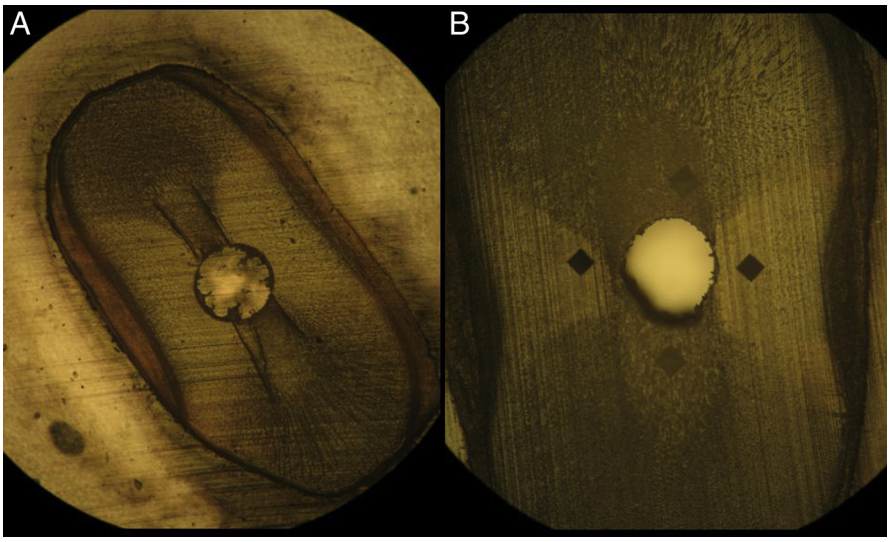

Figure 1. Root section under light microscope showing the butterfly effect (*A*). Microhardness indentations in a section with the effect (*B*).

TABLE 1. Mean Vickers Hardness Scores in Buccolingual and Mesiodistal Aspects of Root Sections of Differing Ages

Mesiodistal				Buccolingual			
Age group*	HV (kgf/mm^2)	Mean hardness score	Combined mean hardness score	Age group*	HV (kgf/mm^2)	Mean hardness score	Combined mean hardness score
1a	109.179	95.432		1a	87.051	63.994	
	99.962				83.090		
	93.338				54.354		
	96.739				58.639		
1b	93.337			1b	59.472		
	96.739				58.025		
	85.217				58.229		
	88.946				53.089		
2a	87.051	72.015		2a	58.025	54.168	
	71.581				52.040		
	68.880				62.989		
	74.740		83.704†		57.823		56.443†
2b	68.880			2b	47.0828		
	74.74				54.171		
	63.917				50.854		
	66.329				50.359		
3a	105.603	83.665		3a	52.912	51.166	
	114.048				47.985		
	72.991				48.292		
	66.827				55.475		
3b	87.425			3b	52.912		
	90.506				47.985		
	65.591				48.292		
	66.329				55.475		
Control a	51.357		74.159‡	Control a	49.548		71.673‡
	47.231				40.817		
	54.910				56.631		
	51.868				52.912		
Control b	78.430			Control b	71.581		
	73.278				68.099		
	120.456				117.478		
	115.744				116.318		

HV, Vickers hardness of 32 indents from 16 sections.

*1 = young (15–24 years); 2 = middle-aged (25–44 years); 3 = old (45 years and older).

†$P = .028$.

‡$P = .079$.

Conclusion

Root sections with the butterfly effect have higher hardness scores on their mesial and distal surfaces, corresponding to the wings of the butterfly. This pattern was observed in teeth from all age groups and was absent in controls. There may be clinical implications regarding an increased susceptibility to VRFs in the buccolingual direction.

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The authors deny any conflicts of interest related to this study.

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