# The Butterfly Effect: An Investigation of Sectioned Roots

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## Abstract

**Introduction:** The butterfly effect is an optical phenomenon seen in some sections of tooth roots. The aim of this work was to investigate the density of dentinal tubules in mesiodistal and buccolingual cross-sections of roots exhibiting the butterfly effect and to determine if the effect is featured throughout the length of roots and is age related. **Methods:** Thirty extracted single-rooted teeth were allocated to the following groups according to patient age: group 1: 15–24 years, group 2: 25–44 years, and group 3: 45 years and over. The teeth were decoronated, and their 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 exhibited the butterfly appearance. The 2 teeth with the highest score from each group and 2 control teeth with the minimum score (of 10) were selected. Two adjacent, consecutive cross-sections were chosen with the most coronal cut mesiodistally and the other buccolingually. Scanning electron micrographs (×850) were taken of the central portion of their canal lumina and the density of the dentinal tubules determined. **Results:** The butterfly effect was found at all levels in the roots of the affected teeth. The tubule density was highest in the buccolingual root sections (45,348 $mm^{-2}$) and lowest mesiodistally (12,605 $mm^{-2}$), a significant difference ($P$ = .02). This trend was found across all age groups. **Conclusions:** Root sections with the butterfly effect have a lower density of dentinal tubules mesiodistally corresponding to the wings of the butterfly. The pattern was observed in teeth from all age groups and was absent in controls. *(J Endod 2013;39:208–210)*

## Key Words

Dentin bonding, dentinal tubule, root canal, sclerosis

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The "butterfly" effect was photographed by Beust (1) in 1931 as an optical phenomenon in some cross-sections of tooth roots. In 1983, Vasiliadis et al (2) reported that dentinal tubular sclerosis differs in the mesiodistal and buccolingual directions, noting a characteristic butterfly shape in transverse sections of the roots caused by different shades of dentin. Sclerosed dentin is more translucent than normal dentin (3, 4). Literature on the butterfly effect is limited. A recent study (5) proposes that the presence of dentinal tubules causes light to refract and scatter. A decrease in the number of dentinal tubules results in greater light transmission to give a translucent appearance. The mechanism behind dentin translucency remains unclear (5). The aim of this study was to investigate the density of dentinal tubules in mesiodistal and buccolingual cross-sections of tooth roots exhibiting the butterfly effect and to determine if the effect is featured throughout the length of roots and is age related.

## Materials and Methods

Ethical approval was granted from the University of Otago, Dunedin, New Zealand, to collect 30 single-rooted human teeth of a known age. These were divided into 3 groups of 10: group 1: 15–24 years old, group 2: 25–44 years, and group 3: 45 years and over. The teeth were decoronated, and their roots embedded in acrylic (Vertex Self Curing; Vertex-Dental BV, Zeist, The Netherlands) and cut into 1-mm-thick cross-sections with a saw (Accutom 50; Struers A/S, Ballerup, Denmark). Each root yielded 10 sections that were marked to indicate orientation. Sections were viewed under 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; a score of 2 represented the butterfly effect defined as a section displaying 2 shades of dentin (Fig. 1).

Examiners reached a consensus for each section. The scores for each tooth were summed. A score of 20 represented a tooth in which the effect was present in all sections, whereas 10 represented a tooth in which the effect was totally absent. From each age group, the 2 teeth with the highest overall scores were selected (6 teeth) for further examination. As controls, 2 teeth with a score of 10 (no butterfly effect) were selected. For each of the 8 teeth (6 experimental and 2 controls), 2 adjacent sections were chosen. The more coronal section was cut in a mesiodistal direction using a fine finishing bur (Komet 956EF 314010; Brasseler, Lemgo, Germany) in a high-speed handpiece. The other was cut in a buccolingual direction (Fig. 2). Because of the size and fragility of the sections, each was reduced incrementally to yield 1 usable half, giving a total of 16 specimens.

To remove organic material and cutting debris, the specimens were placed in 4% sodium hypochlorite for 5 minutes in an ultrasonic bath followed by EDTA (EDTA 18%; Ultradent, South Jordan, UT) for a further 5 minutes. They were then rinsed and stored in 0.9% saline until scanning electron microscopic (SEM) analysis.

The specimens were mounted with the canal lumina upward (Fig. 3). An SEM image (850×) of the center of each canal lumen was taken (JSM 6700F; JEOL Ltd, Tokyo, Japan). Images were coded and printed on A4 size paper, and the number of tubule orifices per square millimeter was counted on the prints, the area of which represented 9,216 $\mu m^2$. Tubules were counted twice by 2 examiners working independently who were unaware which root/section was under consideration. In cases in which the results differed (under 5% of the micrographs), the tubules were recounted to reach a consensus. A Student's $t$ test was used with an alpha value of 0.05 to analyze the data.

**Figure 1.** A root section under a light microscope showing the butterfly effect.

## Results

An example of the dentinal tubules in the root of a tooth showing the butterfly effect is shown in Figure 4. Whenever it occurred, the effect was featured consistently throughout the length of the roots, with no difference in the apical, middle, and coronal parts of the root (Table 1).

The SEM results are shown in Table 2. The density of dentinal tubules was significantly higher in the root sections cut mesiodistally (45,348 $mm^{-2}$ representing the buccolingual surface) and lowest in those cut buccolingually (12,605 $mm^{-2}$ representing the mesiodistal surface) regardless of the age group ($P = .02$). This trend was consistent across all age groups.

## Discussion

The aim of this observational study was to investigate the density of dentinal tubules in roots with the butterfly effect and to determine if the effect is featured throughout the root length and whether it is influenced by age. Manual counting increased accuracy in situations in which the images showed tubules either at an angle or with shades of gray that might not have been captured by computer imaging software. The

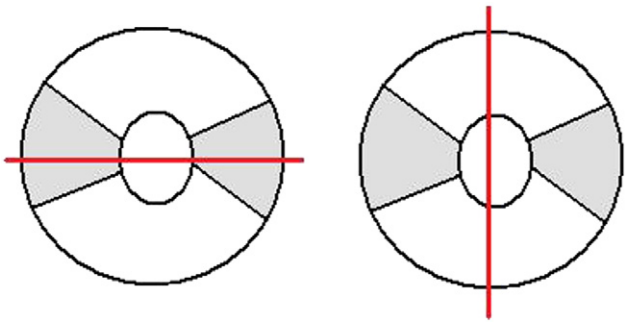

**Figure 2.** The mesiodistal (*left*) and buccolingual (*right*) cuts to root sections.

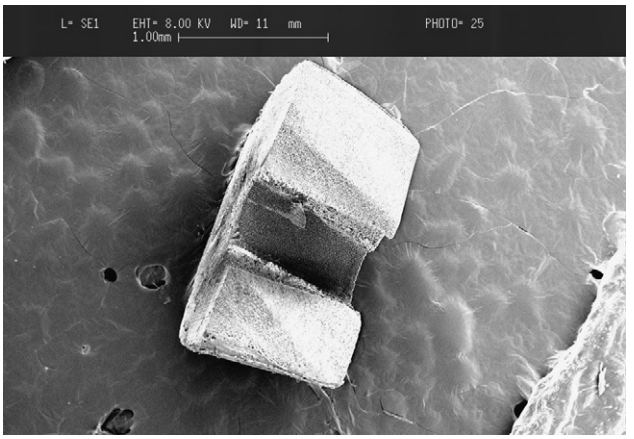


**Figure 3.** An SEM image of a mounted specimen showing lumen region studied.

butterfly effect is related to sclerosis (2), but it appears that tubule density also plays a role. A potential limitation of our study is decalcification of canal walls during cleaning; seeing and counting a tubule does not imply that the entire tubule is open. Nevertheless, the difference in the density of tubules between the mesiodistal and buccolingual aspect throughout the entire length of the root and regardless of tooth age may have significant clinical implications.

A study of dye penetration in dentinal tubules (6) showed a distinctive barbell-shaped pattern, with more dye entering tubules in the buccolingual aspects. Because teeth of unknown patient age were used, the permeability and butterfly-like shape described were attributed to sclerosis (6). This finding might also be explained by the greater number of tubules found buccolingually as noted in our results.

The presence of sclerosed dentin and obliterated tubules negatively affects the formation of resin tags required for the adhesion of composite restorative materials. Restorations placed on sclerosed dentin with few dentinal tubules do not perform as well as those placed on dentin with patent tubules (3). Considering the difference in dentinal tubule density and sclerosis in teeth with the butterfly effect, it seems logical that radicular restorations on buccal or lingual surfaces may achieve better retention and longevity than those on proximal surfaces.

Similarly, the performance of resin-based root canal sealers and the cementation of root canal posts with some luting agents might be influenced by the presence of fewer tubules mesiodistally. A recent review (7) highlights that self-etching adhesives do not rely on resin tags to adhere to dentin, but polymerization shrinkage means that micromechanical retention into dentinal tubules is still required. Thus, the use of adhesive resins in root canal obturation may also be compromised in teeth featuring the butterfly effect.

The present study investigated the butterfly effect in teeth of different ages but did not consider the tooth type. Von Arx et al (8) 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. Furthermore, there was no difference between age groups (8). Therefore, the clinical significance of the butterfly effect may be more applicable in posterior teeth. The literature consistently reports that root fractures are more common in a buccolingual direction (9, 10) with craze lines or cracks on root sections more common buccolingually (8). The lower densities of dentinal tubules correlate with higher tensile strengths of dentin (11, 12). Thus, teeth with the butterfly effect may be weaker buccolingually than mesiodistally, implying that microcracks are more likely to form buccolingually.

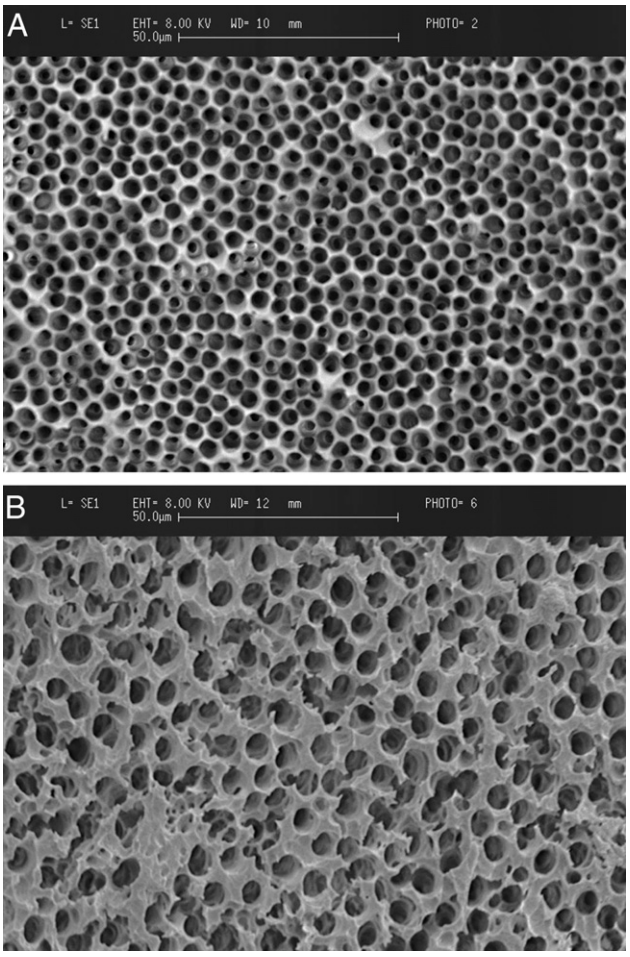


**Figure 4.** SEM images (×850) of a canal lumen of a tooth with the butterfly effect showing dentinal tubules (*A*) buccolingually and (*B*) mesiodistally.

Dentin hypersensitivity can occur on all tooth surfaces but is mostly on the cervical part of the buccal surface (13). Investigations of hypersensitivity indicate a range of causal factors including gingival recession, abrasion, erosion, cracked teeth, bleaching, and genetic predisposition (14). The greater number of tubules on the buccolingual surfaces of teeth with the butterfly effect may render them more susceptible to hypersensitivity.

**TABLE 1.** The Presence of the Butterfly Effect in Root Sections

| Age group* | Cut section | Butterfly effect† |
|---|---|---|
| 1 | A | 2 |
| 1 | M | 2 |
| 1 | C | 2 |
| 2 | A | 2 |
| 2 | M | 2 |
| 2 | C | 2 |
| 3 | A | 2 |
| 3 | M | 2 |
| 3 | C | 2 |
| Control | A | 1 |
| Control | M | 1 |
| Control | C | 1 |

A, apical; C, coronal; M, middle.
*1 = young; 2 = middle; 3 = old.
†1 = absent; 2 = present.

**TABLE 2.** Mean Number of Tubules in Mesiodistal and Buccolingual Root Sections of Differing Ages

| Age group* | Section ($n$ = 16) | No. of tubules per mm$^2$ | Mean no. of tubules per mm$^2$ | Combined mean no. of tubules per mm$^2$ |
|---|---|---|---|---|
| 1 | BL | 52,952 | 50,945 | 45,348 |
| 1 | BL | 48,938 | | |
| 2 | BL | 46,388 | 55,638 | |
| 2 | BL | 64,888 | | |
| 3 | BL | 36,133 | 29,460 | |
| 3 | BL | 22,787 | | |
| Control a | BL | 20,616 | 22,570 | |
| Control b | BL | 24,523 | | |
| 1 | MD | 16,656 | 12,668 | 12,605 |
| 1 | MD | 8,680 | | |
| 2 | MD | 11,664 | 18,311 | |
| 2 | MD | 24,957 | | |
| 3 | MD | 6,836 | 6,836 | |
| 3 | MD | † | | |
| Control a | MD | 16,656 | 27,290 | |
| Control b | MD | 37,924 | | |

BL, buccolingual; MD, mesiodistal.
*1 = young; 2 = middle; 3 = old.
†Tubules could not be counted because of the occlusion of specimen lumen.

## Conclusion

Root sections with the butterfly effect have a lower density of tubules mesiodistally, corresponding to the wings of the butterfly. This pattern was observed in teeth from all age groups, and it was absent in controls. There may be clinical implications when performing endodontic treatment or restoring affected teeth.

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

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