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RESEARCH ARTICLE

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Stress distribution of a novel bundle fiber post with curved roots and oval canals

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Abstract

Objective: The aim of this study was to compare the stress distribution of teeth with curved and straight roots with oval and round canals restored with the bundle and conventional post systems.

Material and methods: Six three-dimensional premolars were modeled with round and oval canals, and curved roots using the software. The bundle post and the round posts were modeled. All post models were placed on the canals. The models were subjected to 200 N oblique loading. The results were evaluated by von Mises stresses.

Results: This study demonstrated that the bundle post showed higher stress values compared to the conventional post. The stresses in the oval canal were higher than those in the round canal. The highest stress values were found in the curved roots. The stress distribution on the curved roots was observed in the middle and apical third of the canal.

Conclusion: The bundle post presented higher stress compared to conventional posts. Besides, a more uniform stress distribution was observed in the bundle groups.

Clinical significance: When a post was required in extremely irregular, wide canals and curved roots, the bundle post was the material of choice. Canal and root morphology influenced stress distribution.

KEYWORDS
curved root, endodontics, finite element analysis, post and core technique, prosthodontics

1 | INTRODUCTION

Advanced-stage dental trauma and caries can cause extensive loss of tooth structure.[1] Advanced losses of tooth structure generally require a post and core system to provide retention for a definitive coronal restoration.[2] Various post systems, including metallic and fiber posts, have been used to reconstruct endodontically treated teeth for decades. Nowadays, fiber posts are replacing cast metal posts due to their improved esthetic properties and similar elastic modulus to root dentin.[3–5] However, fiber posts require a prior preparation process in the root canal to increase the contact of the post and canal walls. Achieving maximal contact ensures high retention by forming a monoblock against masticatory forces.[6,7] For irregular canals, it may be difficult to maintain close contact between the canal walls and the post.[5]

Variations in root and canal morphologies are not uncommon.[8] Endodontic and prosthodontic rehabilitation of teeth with curved roots and oval canals represent one of the most challenging situations in dental clinics. The restoration of over curved roots with rigid post systems may result in perforation and canal transportation due to excessive removal of dentin and root fracture due to improper stress distribution.[6] Cone-shape canals with oval sections have a high prevalence in the general population.[9] A clinical study previously demonstrated that 73% of mandibular first premolars have an ovoid canal configuration at the cementoenamel junction.[10] In the case of oval canals, the canal morphology usually needs to be adapted to the circular shape of the post, aimed at reducing the mismatch between the post and canal walls. However, this treatment approach reduces tooth strength due to the need to sacrifice sound dentin tissue.[11] As the fracture strength of the tooth is directly related to the remaining tooth tissue, the tooth will be more vulnerable to fracture.[12,13]

To address this issue, oval fiber posts have been developed to ensure proper adaptation and to increase the bond strength to dentin walls.[10] However, several scientific studies[11,14-16] have concluded that oval posts did not improve fracture resistance and adaptation to canals, while other studies[17,18] demonstrated better cement thickness values between the post and canal space. Although oval posts are a preferable alternative for oval canals in the clinic, they are unfavorable for highly irregular root canal morphologies.[16] In recent years, a new type of fiber post system consisting of a bundle of fine individual posts (0.3 mm in diameter) has been introduced for atypical canal anatomies. These fine individual posts are distributed throughout the entire canal space. The manufacturer claims that this post system provides optimal adaptation to all canal geometries. This "customized - prefabricated" post system can be used in irregular oval canals and curved canals because of its flexural properties. However, the stress distribution of curved and oval canals with bundle posts has not yet been studied.

Finite element analysis (FEA) is a popular numerical method to assess stress distribution, which provides more detailed mechanical information due to the ability to control all of the variables.[19,20] The purpose of this study was to compare the dentinal stress distribution of 3-D FE models of mandibular premolars with curved and straight roots with oval and round canals restored with bundled and conventional round post systems. The hypothesis of our study was that the bundle post system decreases the stress in the root.

2 | MATERIALS AND METHODS

A mandibular premolar of 8.5 mm crown length and 14.0 mm root length was modeled using modeling software. The modeled premolar was transferred to the Design Modeler module in ANSYS software (Ansys, Swanson Analysis System, Canonsburg, PA), a FEA program. The model was divided into the crown and root at the cementoenamel junction. Five different models were created by duplicating the root with the copy method. One of these roots was chosen to create a curved root. Canals with an oval cross-section were modeled to have two straight roots, while round cross-section canals were modeled to have the other two straight roots. Canal filling (gutta-percha) was performed from the apical foramen to 5 mm coronal in all roots. The coronal part of the canal space without gutta-percha was considered the post space. The bundle post system and conventional post were designed according to the properties of the material (Figure 1). All material properties are listed in Table 1.[21,22] The fiber group of the bundle post, which contains six fibers, was designed in its true size in

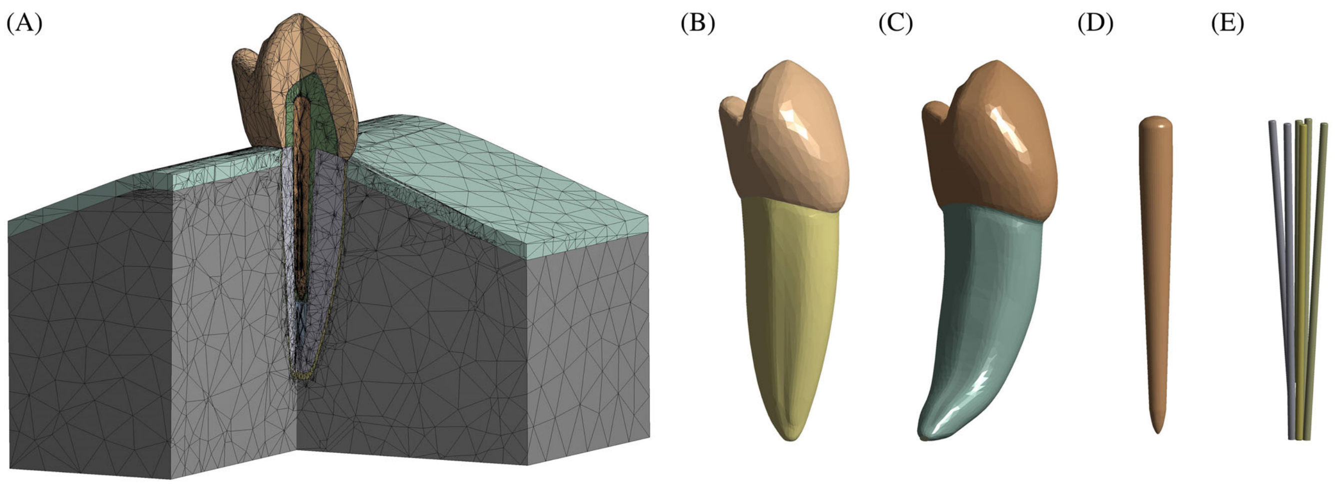

FIGURE 1 Finite element analysis models. (A) Finite element mesh. (B) Mandibular premolar with straight root, and (C) with curved root. (D) Conventional round post (E) bundle post

TABLE 1 Mechanical properties of materials simulated in the present study

Materials	Young's modulus (GPa)	Poisson's ratio	Reference
Cortical bone	13.7	0.3	17
Trabecular bone	1.37	0.3	17
Dentin	18.6	0.31	17
Periodontal-ligament	0.0689	0.45	17
Gutta percha	0.00069	0.45	17
Resin cement	95	0.3	18
Bundle fiber post	31.5	0.25	18
Conventional fiber post	45	0.25	18

accordance with the post-space base diameters reported by the manufacturer. The fiber group (consisting of six fibers) was placed in the models with oval and round canals. Cement was modeled to fill the remaining parts in the post space. The core structure was designed as a prepared premolar form for full ceramic crowns. Similar designs were also carried out for conventional post models. The conventional round fiber post was designed in its true size as reported by the manufacturer. Conventional post models were placed in root models with oval and circular cross-sections. The remaining gaps were filled with cement. The core structure was designed as in other models. The root was designed to be covered with a 0.25-mm layer of the periodontal ligament. The root model, which was chosen to form a curved root, was transferred to Autodesk Meshmixer software (AutoCad 12, Autodesk Inc., Neuchatel, Switzerland). The root model was prominently inclined distally, with the curve beginning in the middle of the root. The curved root model was transferred to the design modeler and copied. The oval canal was modeled in one of these two models and the round canal in the other. Gutta-percha was modeled from the apical foramen to 5 mm coronal in all roots, and the coronal part of the canal was considered the post space. The bundle post (consisting of six fibers) was created following the root curvature and placed in both types of canals. The cement, core structures, and periodontal ligament were designed as in previous models. The models in the present study are as follows;

Model 1. Oval canal-straight root with bundle post.

Model 2. Oval canal-straight root with conventional round post.

Model 3. Round canal-straight root with bundle post.

TABLE 2 The average number of elements and nodes of models

Materials	Node	Element
Cortical bone	20,800	9991
Trabecular bone	29,001	16,084
Dentine	50,439	28,768
Periodontal ligament	50,106	25,512
Gutta percha	2010	1054
Resin cement (for crown cementation)	36,206	17,742
Resin cement (for post cementation)	194,512	113,173
Bundle fiber post	28,303	14,773
Conventional fiber post	18,248	9245

TABLE 3 Maximum equivalent von Mises values of models

Experimental models	von Mises values (MPa)
Model 1 (oval canal-straight root-bundle post)	74.9
Model 2 (oval canal-straight root-conventional post)	68.4
Model 3 (round canal-straight root-bundle post)	65.5
Model 4 (round canal-straight root-conventional post)	62.8
Model 5 (oval canal-curved root-bundle post)	83.2
Model 6 (round canal-curved root-bundle post)	70.5

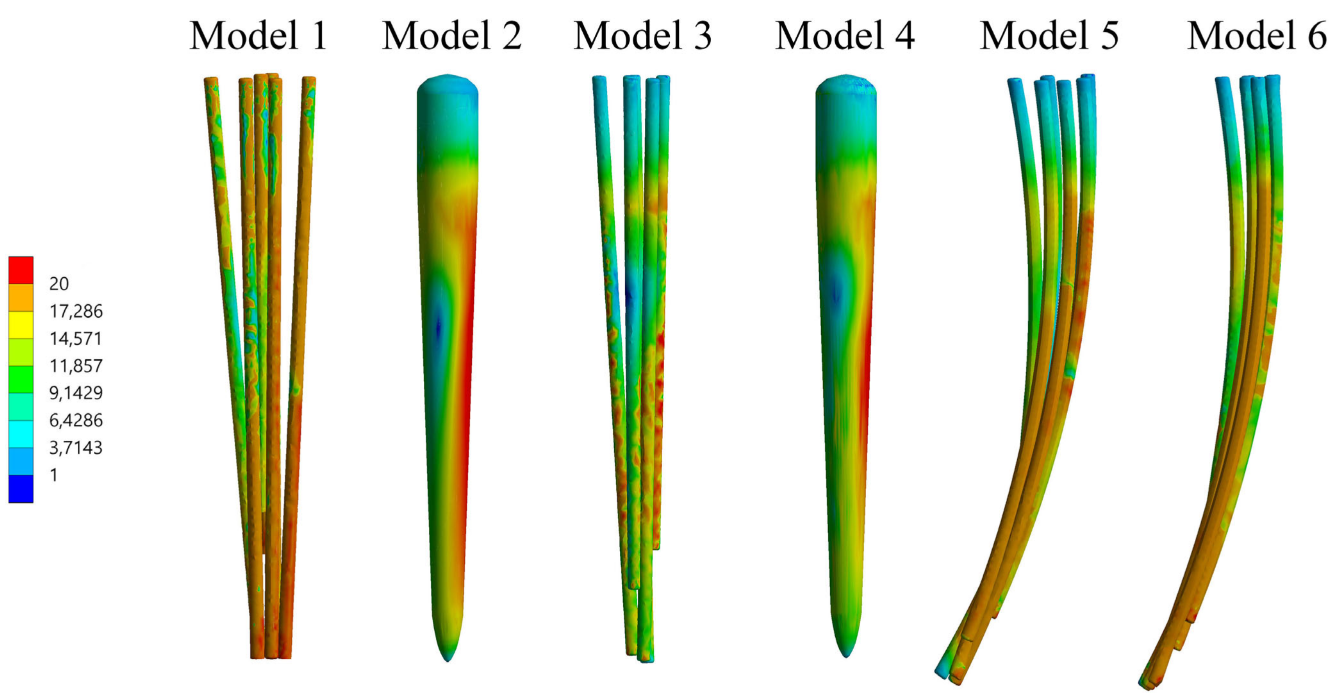

FIGURE 2 von Mises stress results of the bundle and conventional fiber post models 1–6

Model 4. Round canal-straight root with conventional round post.

Model 5. Oval canal-curved root with bundle post.

Model 6. Round canal-curved root with bundle post.

The cement film thickness and the size and shape of the core and crown were standardized in all models. Trabecular and cortical bone structures around the root were modeled. The connection type between parts of models has been defined as "bonded." Tooth structures and other materials were considered isotropic and 100% homogeneous. Quadratic elements were used in the meshing process. To optimize mesh quality, convergence analysis was performed on the models. The models were considered converged when the inter-analysis stress variation was less than 4%. The average number of elements and nodes obtained as a result of the meshing process are provided in Table 2. The models were fixed rigidly from the cut surfaces of the cortical and trabecular bone so that they cannot move along the x, y, or z coordinates. To simulate occlusal forces, 200 N in an oblique direction (45° to the tooth axis) was applied to the palatal surface of the buccal tubercle (Figure 2).[23] The stress distribution was analyzed using equivalent von Mises values. The findings were evaluated with tables and images. To facilitate comparison of stress distributions in the figures, the upper and lower stress limits in the color bar have been adjusted to be the same for all models.

3 | RESULTS

The stress distribution analysis was conducted according to the von Mises criteria. The stress distributions of the root structure, bundle, and conventional posts are summarized in Table 3 and Figures 2 and 3. The bundle post showed high stress values in both canal shapes compared to the conventional round post. However, the bundle post also showed more homogeneous stress distribution compared to when a conventional round post was used in an oval canal (Figure 3 models 1 and 2). The heterogeneity of stress distribution in the round canal was similar in both types of posts (Figure 3 models 3 and 4).

Canal morphology influenced the stress distribution, especially in curved roots. For the oval canal with a straight root, the bundle post (74.9 MPa) showed higher stress values than those for the round canal (65.5 MPa). The same difference in stress values was shown for curved roots (Table 3 models 5 and 6). Higher stress values were also recorded for oval canals in the conventional post groups (Table 3 models 2 and 4). A comparison of the root morphology demonstrated that the curved root presented increased stress on the root dentin. On the other hand, stresses on curved roots were mostly observed in

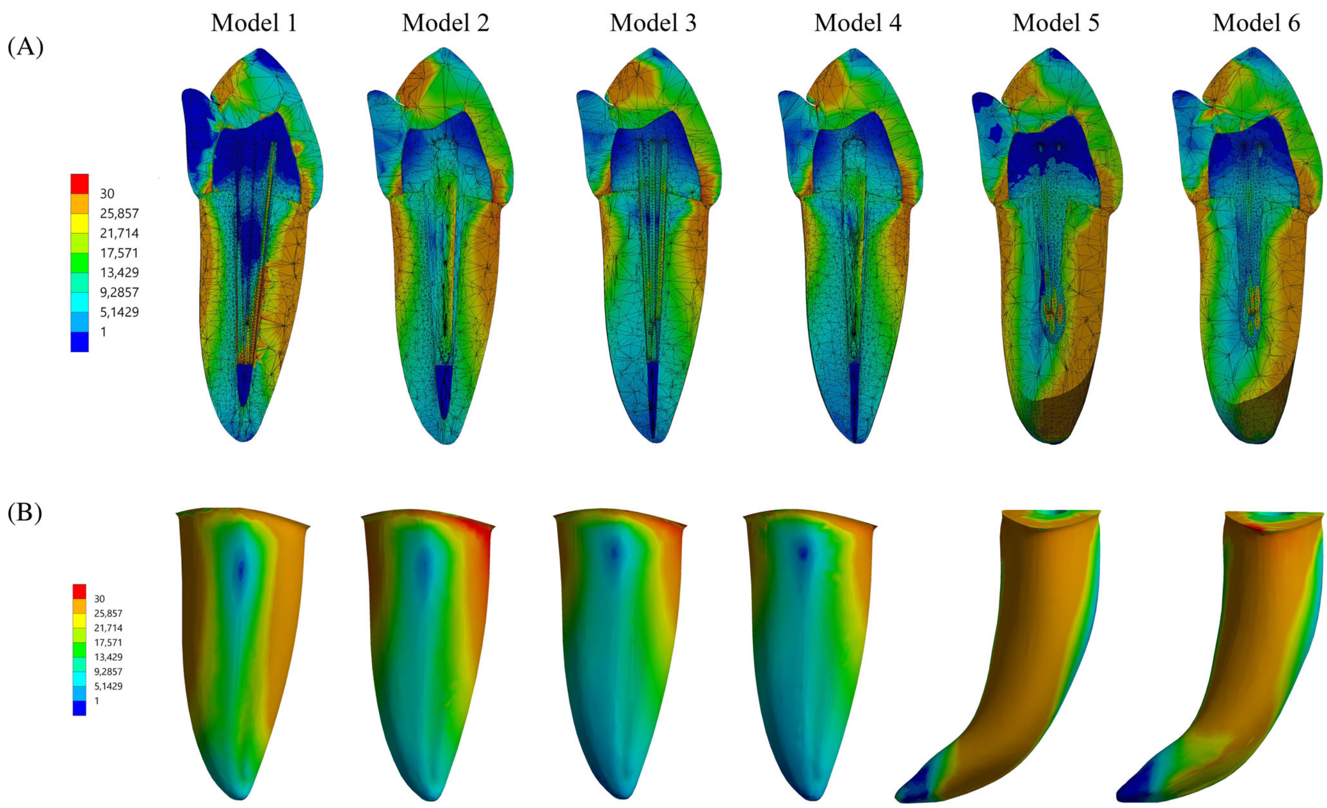

FIGURE 3 von Mises stress results. (A) Model 1: oval canal/straight root/bundle post. Model 2: oval canal/straight root/conventional post. Model 3: round canal/straight root/bundle post. Model 4: round canal/straight root/the conventional post. Model 5: oval canal/curved root/bundle post. Model 6: round canal/curved root/bundle post. (B) Stresses in mesiodistal plane models 1–4, in the buccal plane in model 5 and 6

the middle and apical parts of the post in both canal shape groups. The stresses on the curved roots were concentrated in the buccal area of the external surface of the root (Figure 3 model 5). The highest stress concentration, 83.2 MPa, was found in the oval canal with a curved root with the bundle post.

4 | DISCUSSION

In our study, the biomechanical behavior of teeth restored with a bundle post was evaluated. As the bundle post is a novel fiber post system, there is still insufficient information in the literature, and the effects of the bundle post on stress distribution have not yet been demonstrated. The present study is based on a three-dimensional model of mandibular premolars with two different canal cross-sections and two different root configurations. The stress distribution of models was evaluated using FEA. FEA was first introduced in the 1950s as a computer simulation technique that uses a mathematical matrix analysis of structures to simulate the stress behavior of materials.[24] It is an advantageous method for studies investigating the influence of root and canal anatomy due to its unique morphological standardization ability.[25] This numerical analysis rules out the consequences that arise from a nonstandardized canal and root configuration.

In FEA, the von Mises stresses are used as indicators of possible failures.[26] The von Mises criterion (theory of the maximum distortion energy) is used to evaluate ductile materials based on the determination of energy related to changes in form.[24] Dentin exhibits various types of deformation and behaves as a ductile substance under compressive force.[27] Because premolars and molars are subjected to compressive stress, dentin was considered a ductile solid.[28] Thus, the current study investigated the stress distribution according to the von Mises criterion.

According to the results of our study, the stress concentration in the teeth with the bundle post was higher than that with the conventional post. Thus, the hypothesis was rejected. However, more homogeneous stress distribution was observed in roots with the bundle post compared to the conventional post. In our opinion, heterogeneity of stress distribution in conventional post models was related to incompatibility between the conic shape of the canal and the parallel design of the post. On the other hand, the bundle post acts like a customized post, filling the prepared post space with fine individual posts to ensure better juxtaposition into the canal space than conventional posts with a single block structure.

As seen in our results, regardless of post type, the stress values for teeth with oval canals were higher than those with round canals. As a lower concentration of stress was observed, conventional fiber posts can be used in canals with regular morphology. However, irregular canals are frequently encountered during routine endodontic treatment.[29] In teeth that require a post, the irregular canal space is diverted away from its original axis to place the prefabricated post inside the canal. Changing the canal shape with excessive post space preparation results in canal transportation, perforation, and a compromised apical endodontic seal.[30] Furthermore, the fiber post did not be entirely adapted to the canal. The sound dentin structure that provides resistance against physiological occlusal forces is removed during conventional post space preparation.[31] It has been demonstrated that substance loss is the main factor determining the survival rate of endodontically treated teeth.[20] Individual fine posts of the bundle system are evenly distributed across the canal space due to its geometric structure, enabling a more conservative preparation. Hence, the bundle post affects fracture resistance of teeth with irregular canals. Future studies should test the influence of the bundle post on fracture resistance in an irregular-shaped canal. Fiber and cast posts are also used for the reconstruction of large, irregular, and oval canals. Cast posts have many drawbacks, such as the need for an additional appointment and laboratory procedures, together with their high elastic modulus, which produces improper stress distribution.[32] Fiber posts have a modulus of elasticity similar to dentin, ensuring uniform stress distribution along the dentin walls.[30,33] However, because of the irregular and large diameter of canals, fiber posts do not fit properly into the post space. A previous study showed that fracture strength is not affected by post adaptation, while another study reported that posts that are not fully adapted to the canal can potentially create a lever.[34,35] Recently, custom fiber posts have been manufactured using computer-aided design and computer-aided manufacturing (CAD/CAM) milling techniques to provide better adaptation.[36] However, it requires more chair time than the bundle post. In the present study, the stress in one-piece fiber posts was found to be concentrated in certain areas, not evenly distributed. Thus, these areas will be more prone to root fractures. The bundle posts create a mesh-like structure in the canal space, supporting all aspects of the dentin walls. However, further studies are needed to investigate the adaptation properties of this bundle system.

The highest stress among all models, 83.2 MPa, was observed in teeth with a curved root and oval canal with the bundle post. In our study, for curved root models, the stress was primarily concentrated in the middle and apical parts of the post. The regions where the stress was concentrated are shown in Figure 2. In the apical and middle thirds of post space, the canal narrows, and thin individual posts are located closer together in this region. In our opinion, this explains why the stress was concentrated in the apical and middle parts of the post. The stress in the curved root surfaces was concentrated in the buccal area (Figure 3 model 5). This finding, as expected, is the result of oblique loading and is in agreement with a previous study.[37] The concentration of stress on the buccal side of the external root surface indicates that this area is a potential fracture origin. Further studies that evaluate the nature of fracture related to the bundle post are needed to understand whether it causes a favorable fracture or catastrophic.

The limitation of this study was the inability of the FEA method to adequately replicate clinical conditions. The FEA method only demonstrates the stress distribution caused by an instantaneous force. Clinical studies are needed to understand the cyclic fatigue behavior of this post system in the oral environment.

5 | CONCLUSION

Within the limitations of this current study, it was concluded that; the stress in the bundle post was high than the conventional posts, but the stress in the bundle post was homogeneous compared to the conventional post. The stress was high in teeth with oval canal morphology than the round canal. The highest stress value occurred in curved roots with the bundle post.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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