Stress distribution in tooth resin core build-ups with different post-end positions in alveolar bone level under two kinds of load directions

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This study aimed to evaluate influence of different post-end positions in alveolar bone level on stress distributions in resin-core build-up tooth under different load directions. Three-dimensional mathematical models of a root-filled mandibular premolar tooth were constructed. Resin post and core were built-up with six post lengths: 0, 1, 2, 3, 4, and 6 mm. Finite element analysis calculated stress distributions with oblique load of 400 N to buccal cusp 45 degree from buccal side or from lingual side. The 3 mm-post length (post-end position equal to cancellous bone level) caused highest equivalent stress of post-end compared with the shorter or longer post length. When change of load direction, the direction of maximum shear stress became completely opposite at mesiodistal cervical edge of core-part without a change of the magnitude. Changing shear stress direction would increase risk of debonding at mesiodistal cervical edge.

Keywords: Equivalent stress distribution, Fiber post, Load direction, Post-end position, Shear stress distribution

INTRODUCTION

Adhesive resin post and core build-up systems fabricated with fiber posts have become a widely used alternative to the traditional non-adhesive cast post and core systems. Some researchers have reported that resin post and core build-ups incorporating fiber posts reduce catastrophic root fractures, compared with cast post and cores or resin cores with prefabricated metallic posts1-5). Resin post and cores incorporating fiber posts, which have similar elastic moduli to dentin can reduce stress concentration around the post-end, resulting in a reduction in the risk of catastrophic root fracture at the post-end6-8). Fiber posts are expected to improve the mechanical properties of resin post and cores, and to increase the retention of post and cores in the roots. However, incorporating fiber posts does not improve the fracture strength of resin core build-ups in teeth9-11). With regards to post length, some researchers have reported that a shorter post length reduced the fracture strengths of teeth incorporating resin cores11-13), while others have reported that post length did not affect them14,15). Therefore, the role of fiber posts and their length is still controversial in the resin core build-up method.

The post-end position in the root in relation to the level of the surrounding alveolar bone has also been shown to affect the fracture behavior of resin core build-ups. When the post-end position was above the alveolar bone level, a favourable fracture pattern occurred in resin core build-ups with the same post length in the root, although there were no differences in the fracture strength among cases with post-end position below the bone level compared to above the bone level16). Generally, fracture tests for teeth built up with resin cores are performed by embedding the root in an acrylic resin block simulating the alveolar bone. However, alveolar bone consists of two distinct layers (cortical bone and cancellous bone) with different morphological and chemical structures. Cancellous bone is covered with cortical bone, approximately 2 mm thick, which has a higher elastic modulus that might affect the stress distribution in resin core build-ups.

Many finite element analysis (FEA) experiments on the stress distribution in resin post and core build-ups have been performed with the application of an oblique load to the cusp from one direction6,8,11-18). Resin post and core systems incorporating fiber posts do not produce greater stress around the post-end, relative to the traditional cast post and core systems6,8,17). FEA is a series of computational simulations to estimate specific situations and obtains results by deconstructing complex structures into their discrete elements defined by a specific mesh. It is based on a mathematical model that approximates load conditions to geometry and structure. This analysis is useful for evaluating the mechanical aspects of biomedical and dental materials that can be difficult to measure in vivo. Some researchers have demonstrated that, when the post-end position

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was below the cancellous bone level, the magnitude of maximum stress concentration in resin core build-up teeth was affected by the alveolar bone loss\(^{19,20}\), but not by the post length\(^ {6,23}\). However, there has been little research on the stress distribution in tooth resin core build-ups when the post-end position is above and within the cortical bone layer. Moreover, the effect of different load directions on the cusp on the stress distribution in tooth resin core build-ups should be also investigated because teeth receive dynamic occlusal loading from various directions during function.

Regarding the resin core build-up method, good adhesion between dentin and the resin material is important for improving the retention of the post and core and the fracture strength of the restored tooth\(^ {22-26}\). A previous study on fracture testing demonstrated that adhesion at the cervical interface plays a critical role in maintaining the integrity of the resin build-up tooth more than that of the post cavity interface\(^ {10}\). The finite element method can analyze the shear stress distribution on the surface between two materials. Concentrations of shear stress cause the debonding of post and cores from root dentin and increase the fracture risk of root and/or resin core materials\(^ {17,21}\). The maximum shear stress has been reported to be located at the mesiodistal edge of the cervical surface between root dentin and the resin core\(^ {27}\).

The post-end positions in the root in the alveolar bone might affect the shear stress distribution in resin core build-ups under different load directions. Therefore, the purpose of this study was to evaluate the influence of the different post-end positions in the alveolar bone at different levels (contains cortical bone and cancellous bone) on shear stress distributions in resin-core build-ups under two kinds of load directions using FEA, and also to investigate the effect of incorporating a fiber post in them.

**MATERIALS AND METHODS**

The finite element model in this study consisted of a mandibular second premolar tooth with a root filling, periodontal ligament and surrounding alveolar bone. A three-dimensional intact tooth model (Fig. 1-1)

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![Fig. 1](image_url)  
**Fig. 1** Three-dimensional finite element model of the mandibular second premolar tooth.  
(1) Tooth and surrounding bone model (buccolingual cross-section image): root (r), post and core foundation (f), the crown restoration (c), gutta-percha (gp), the periodontal ligament (pdl), fiber post (fp), cortical bone (co) and cancellous bone (ca) were modeled for support of the tooth structures. The red lines represent the cortical bone level, while the orange lines represent the cancellous bone level. (2) The loading and boundary conditions of a mesiodistal slice of the tooth model with symmetric boundary conditions and meshes. Blue arrow indicates an off-axis 45° oblique load of 400 N applied to the buccal cusp from buccal side (A direction) and red arrow indicates an off-axis 45° oblique load of 400 N applied to the buccal cusp from lingual side (B direction). The triangles represent the fixation of the lower surface of bone. This Figure was modified from Kainose et al. 2014.
was composed, based on the anatomical image of an adult tooth (Dental Anatomy & Interactive 3-D Tooth Atlas, Brown & Herbranson Imaging, Portola Valley, CA, USA). Various stresses were estimated through a three-dimensional model to predict failure risk of tooth-restoration structures. The mandibular bone was modeled with 2 mm cortical bone and cancellous bone and covered the tooth root. The modeled root structure was embedded in the alveolar bone 1 mm below the cement-enamel junction (CEJ).

The post preparation was modeled with a simplified circular external cross-section 2 mm in diameter at the cervical area, and with a taper of approximately 1.9 degrees. Part of the tooth structure was replaced by a full coverage ceramic crown, 6 mm in height with shoulder margin form, without ferrule around the cervical region of the root, with four post lengths: 0 mm (no post), 1 mm (the post-end position is equal to the cortical bone level), 2 mm (the post-end position is between the cortical bone level and the cancellous bone level), 3 mm (the post-end position is equal to the cancellous bone level), 4 mm (the post-end position is 1 mm below cancellous bone level), 6 mm (the post-end position is 3 mm below the cancellous bone level). The 3, 4 and 6 mm post models were divided into two groups: with or without placement of a fiber post, 1.7 mm in diameter, which was completely embedded in the resin composite.

Each model had symmetrical mesiodistal boundary conditions applied, and was meshed by approximately 125,000 hexahedral elements, determined by preliminary convergence tests (ANSYS 11.0, ANSYS, Canonsburg, PA, USA). All materials were considered homogenous, linearly elastic and isotropic, except for the orthotropic glass fiber post (Table 1). All the materials were assumed to be perfectly bonded and the simulations of this study were performed based on linear elastic analysis. A total load of 400 N was applied to the tip of the buccal cusp 45 degrees obliquely from the buccal side (A direction) or from the lingual side (B direction) (Fig. 1-2). In each model, the movement of the outer surface bone was restricted by cortical bone.

The equivalent stress distributions in the root dentin and in the post and core were calculated for all simulations. The shear stress distributions at the interface between the post and core and dentin were calculated in the XY and XZ planes (Fig. 2). The maximum shear stress on the post surface in XY and YZ planes, and on the cervical surface of the core in the XZ plane were highlighted and analyzed. The directions and magnitudes of the compressive (third principal) stress and tensile (first principal) stress in resin post and core were analyzed to estimate the movement of the resin post and core in the root.

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### Table 1  Material properties used in the study and their elastic moduli

| Material                          | Elastic modulus (MPa) | Poison’s ratio | References                  |
|----------------------------------|-----------------------|----------------|-----------------------------|
| Dentin¹⁸                          | 18,000                | 0.31           | Kinney et al. (2003)        |
| Porcelain¹⁹                       | 70,000                | 0.19           | Käse et al. (1985)          |
| Cortical bone¹⁰                   | 14,700                | 0.3            | Moroi et al. (1993)         |
| Cancellous bone¹⁰                 | 490                   | 0.3            | Moroi et al. (1993)         |
| Gutta-percha¹¹                    | 140                   | 0.49           | Friedman et al. (1977)      |
| Periodontal ligament¹²            | 0.71                  | 0.4            | Xia et al. (2013)           |
| Composite resin¹³                 | 12,000                | 0.33           | Lanza et al. (2005)         |
| Glass fiber¹⁴                     | 9,500                 | 0.27           | Lanza et al. (2005)         |
|                                   | longitudinal          | 37,000         |                             |

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Fig. 2  The plane used to analyze shear stress. X axis is buccal-lingual direction, Y axis is crown-root direction, Z axis is mesial-distal direction. The maximum shear stress on the cervical surface of core in the XZ plane were analyzed.
RESULTS

Figure 3 shows the equivalent stress distributions in the buccolingual cross-sections of the root dentin. In all models, loading from the buccal side (A direction) produced the equivalent stress concentration in root dentin below the cancellous bone level on the lingual side (Fig. 3-a, c), while loading from lingual side (B direction) produced the stress concentration below the cancellous bone level on the buccal side (Fig. 3-b, d). Loading from the lingual side (B direction) caused a larger magnitude of maximum equivalent stress in root dentin than that from the buccal side (A direction) (Fig. 3-1, 2). The incorporation of a fiber post and the post length did not affect the equivalent stress distribution in the root dentin.

Figure 4 shows the equivalent stress distributions in the resin post and core. In all models, loading from buccal side (A direction) produced maximum equivalent stress concentration in the resin post and core at the lingual cervical area of the core part (Fig. 4-a, c), while loading from the lingual side (B direction) produced the maximum equivalent stress concentration at the buccal cervical area of the core part (Fig. 4-b, d). Loading from the lingual side (B direction) resulted in a larger magnitude of the maximum equivalent stress in resin post and core than that from buccal side (A direction) (Fig. 4-1, 2). The incorporation of fiber post and the post length did not affect the equivalent stress distribution in the core part. Additionally, the other equivalent stress concentrations in resin post and core were observed at the basal part of post and the end of post. In the basal part of post, incorporation of a fiber post and the post length did not affect the magnitude of equivalent stress concentration (Fig. 4-3). On the other hand, in the post-end, the 3 mm post model increased the magnitude of the stress concentration compared with the 1, 2, 4 and 6 mm post models (Fig. 4-4), leading to similar magnitudes.
The equivalent stress distributions in resin post and core were shown, (a) in a buccolingual cross-section of the resin post and core when load was applied from buccal side (A direction), (b) in the resin post and core when load was applied from lingual side (B direction). Red areas represent the highest stress, as indicated by the color bar. The high equivalent stress concentrations were observed in cervical area of resin core part and were highlighted ((c), (d)). The red lines represent the cortical bone level, while the orange lines represent the cancellous bone level. The magnitude of equivalent stress in resin post and core at lingual cervical area of core part (1), buccal cervical area of core part (2), the basal part of post (3) and the post-end part (4) were shown. The comparisons with the magnitude of equivalent stress between the basal part of post and the post-end part were shown, when oblique load was applied from buccal side (A direction) (5) and from lingual side (B direction) (6).

Figure 5-a, b show the principle stress distributions in the resin post and core and Fig. 5-1 to 5-10 show the arrows indicating the direction and magnitude of the tensile and compressive stresses in the resin post and
The principle stress in resin post and cores without a fiber post are shown ((a), (b)). The stress arrow graphics for the principal stress distribution were highlighted in the resin post part. The black arrows indicate the direction and magnitude of the first principal (tensile) stress, while the blue arrows indicate those of the third principal (compressive) stress. In the 3, 4 and 6 mm post models ((3)–(5), (8)–(10)), the arrows were placed in the form of a circular arc around the central part of the post in the cortical bone-supported root (pointer), and in the 1 and 2 mm post models ((1), (2), (6), (7)), the placement of arrows did not form a circular arc in the post part. The letters ‘A’ and ‘B’ in the Figures indicate the load direction from A direction or from B direction. The red lines represent the cortical bone level, while the orange lines represent the cancellous bone level.

Figure 6 shows the shear stress distribution in the XZ plane on the cervical interface between the root dentin and the resin core part. In all the models, the maximum shear stress concentrations were located at the cervical surface on the mesiodistal side (Fig. 6-c, d), regardless of post length and with/without fiber post. Positive values (red, orange and yellow) indicating shear stress directions from the lingual side to the buccal side occurred, and negative values (blue, light blue and light green) indicating shear stress direction from the buccal side to lingual side occurred. When the load direction changed from A direction (from buccal) to B direction (from lingual), the shear stress direction at the mesiodistal side on the cervical surface became completely opposite.

Figure 7 shows the shear stress distributions in the XY plane on the post surface of the resin post and core. The shear stress concentrations on the post surface were located at the basal part of the mesiodistal side (Fig. 7-a, b), the magnitude of which, was lower than on the cervical surface of the core part and not affected by the post lengths and the incorporation of a fiber post. The change of the load direction from the A direction (from buccal) to the B direction (from lingual) changed the shear stress direction at the basal part of the mesiodistal side and slightly increased their magnitudes.
Fig. 6  The shear stress distribution in the XZ plane at cervical area in the resin post and cores (a, c) when load was applied from buccal side (A direction), (b, d) when load was applied from lingual side (B direction). The highest shear stress was indicated as red or blue depending on whether one follows the shear stress in clockwise or counterclockwise directions. The magnitude of the maximum shear stress at the cervical interface on the mesiodistal side were shown (1). The letters ‘A’ and ‘B’ in the Figures indicate the load direction from A direction or from B direction.

Fig. 7  The shear stress distribution in the XY plane on the post area of the resin post and cores when load was applied from buccal side (A direction) (a) or when load was applied from lingual side (B direction) (b). The highest shear stress was indicated as red or blue depending on whether one follows the shear stress in clockwise or counterclockwise directions. The magnitude of the maximum shear stress at the cervical interface on the mesiodistal side were shown (1). The shear stress concentrations were observed in lingual side at basal part of post when load was applied from buccal side (A direction), and in buccal side at basal part of post when load was applied from lingual side (B direction). The letters ‘A’ and ‘B’ in the Figures indicate the load direction from A direction or from B direction.
DISCUSSION

In general, many FEA studies have investigated the stress distributions using resin core build-up models with fiber posts, in which the post-end position is set beneath the cortical bone level with approximately 6 to 10 mm of post length in the root\(^{[6-8,15-18]}\). In the 6 mm post model (the post-end position was set 3 mm below the cancellous bone level) with a fiber post, the equivalent stress in the root dentin was not severely concentrated at the bottom of the post cavity (Fig. 3). Moreover, loading from the buccal side (A direction) produced an equivalent stress concentration in root dentin below the cancellous bone level on the lingual side (Fig. 3-a), while loading from the lingual side (B direction) produced stress concentration below the cancellous bone level on the buccal side (Fig. 3-b), regardless of incorporation of a fiber post. These results are in agreement with previous studies\(^{[8,20,21,27,35]}\). On the other hand, loading from the lingual side (B direction) caused a greater magnitude of maximum equivalent stress in root dentin than that from a buccal side (A direction) (Fig. 3-1, 2). This might be due to the difference in distance between the loading position (buccal cusp) and the stress concentration area in the root dentin (cervical side near the cortical bone level). In all the models, the post length and with/without fiber post did not change the magnitude and location of the equivalent stress in the root dentin. This result indicated that the equivalent stress distribution in the root dentin was influenced by the load direction to the cusp, but not the post length and with/without fiber post. Research on the influences of alveolar bone level and post type on the biomechanical behavior of endodontically treated teeth has shown that the stress concentration at the side of the root dentin near the alveolar bone level dramatically increased as a result of alveolar bone loss regardless of the post type (i.e. cast post and core or resin post and core with fiber post)\(^{[19]}\). This finding might be due to the top of the alveolar bone acting as the fulcrum when an oblique load was applied. Therefore, the level of the alveolar bone or amount of bone loss might be more of an important factor affecting the equivalent stress distribution in the root dentin than the post length and/or the incorporation of a fiber post.

In the resin post and core, the equivalent stress concentration was located at the lingual cervical region of the core part when a load was applied to the buccal cusp from the buccal side (A direction) (Fig. 4-a) and at the buccal cervical region when the load was applied from the lingual side (B direction) (Fig. 4-b) regardless of the post length and with/without fiber post. Loading from the lingual side (B direction) caused a larger magnitude of maximum equivalent stress in the resin post and core than that from the buccal side (A direction) (Fig. 4-1, 2). This might be due to the difference in distances between the loading position (buccal cusp) and the stress concentration area in resin post and core (buccal or lingual cervical region of the core part). Additionally, the post length and the incorporation of a fiber post did not affect the magnitude of the maximum equivalent stress in resin post and core. On the other hand, other equivalent stress concentrations were also observed at the basal part of the post and end of post, although their magnitudes were lower than that of the cervical region of the core part (Fig. 4-3, 4). In the basal part of the post, the equivalent stress distribution was not changed by the post length and the incorporation of a fiber post (Fig. 4-3). However, at the post-end, the magnitude of the equivalent stress at the post-end increased with the reduction of the post length of 6 mm (post-end position 3 mm below the cancellous bone level) and 4 mm (post-end position 1 mm below the cancellous bone level) to 3 mm (post-end position equal to the cancellous bone level) with/without fiber post (Fig. 4-4), in which the magnitude of the equivalent stress at the post-end became similar to that of the basal part of post (Fig. 4-5, 6).

In order to understand the mechanism of stress concentrations in resin post and cores, it is important to investigate the movement of the resin post and core\(^{[36]}\), which could be evaluated by the arrows indicating the magnitude and direction of the principal stress (tensile and compressive stress). In the 6 mm post (post-end position 3 mm below the cancellous bone level), the 4 mm post (post-end position 1 mm below the cancellous bone level), and the 3 mm post (post-end position equal to the cancellous bone level) models with/without fiber post, the arrows are placed in the form of a circular arc around the central part of the post in the cortical bone-supported root (Fig. 5-3, 4, 5, 8, 9, 10). Therefore, an oblique load would induce a rotational movement around the central part of the post in the cortical bone-supported root. The post-end position of the 3 mm post model is closer to the center of rotation movement than that of the 4 and 6 mm post models and would be a reason why a larger equivalent stress at the post-end was produced in the 3 mm post model than the 4 and 6 mm post models (Fig. 4-4). On the other hand, the 1 mm post model (post-end position equal to the cortical bone level) and the 2 mm post model (post-end position between the cortical bone level and the cancellous bone level) exhibited a reduced magnitude of equivalent stress at the post-end compared with the 3 mm post model. In the 1 and 2 mm post models, the placement of arrows did not form a circular arc in the post part (Fig. 5-1, 2, 6, 7). It is speculated that in the 1 mm and 2 mm post models, an oblique load produced different movements (e.g. linear movement) of post and core on the root from the other post length models, because these post part lost a support of the cortical bone with a high elastic modulus. The change of the movement of the post and core might be the reason why the 1 and 2 mm post models showed lower magnitude of stress at the post-end than the 3 mm post model. These results indicate that the different post-end positions for the cortical bone and the cancellous bone level may have been an important factor on the equivalent stress concentration at the post-end.

As for the resin post and core, many researchers have demonstrated that good bonding to root dentin is an important factor for maintaining the integrity of the resin build-up tooth\(^{[22,26]}\). It has been reported that the
risk of debonding at the adhesive interface between the resin post and core and the root dentin was increased by the high shear stress concentrations\[17,20\]. In this study, the maximum shear stress concentration in the core part was observed at the mesiodistal cervical edge to be approximately 25 MPa (Fig. 6-1, 2), and in the post part, another shear stress concentration was observed at the basal part of post of approximately 20 MPa (Fig. 7-1). The post length and the incorporation of a fiber post did not affect the magnitude of the shear stress at the mesiodistal edge in the resin post and core. On the other hand, the incorporation of a fiber post could reduce the magnitude of the shear stress concentration (20 MPa) to 18 MPa in the basal part of the post (Fig. 7-1). Many researchers have reported variable data on micro shear bond strength to dentin when using various adhesive systems. The systematic review, in which these data (evaluating 134 tests over the past 5 years) were reevaluated, indicated that the overall mean micro shear bond strength to dentin was calculated to be approximately 30 MPa\[17\]. This result (approximately 30 MPa) is higher than the magnitudes of the shear stress concentration (25 MPa at the mesiodistal edge of the core part and 20 MPa at the basal part of the post) in the present study, and therefore the risk of adhesive failure might be low under static oblique loads. On the other hand, fatigue investigation of the adhesive interface could provide a clinically relevant insight on dentin bond durability. One previous study on the shear fatigue strength to dentin has reported that under the repetitive load from one direction, the shear fatigue strength value was calculated to be approximately 20 MPa\[20\], which was lower than the magnitudes of shear stress concentration at the mesiodistal cervical edge of core part (25 MPa) in the present study. This suggests that the repetitive load might cause fatigue failure at the adhesive interface of the mesiodistal cervical edge in the resin post and core. Moreover, when the load direction to the buccal cusp was changed from the buccal side to lingual side, the magnitude and location of the shear stress concentration did not change, but the shear stress direction at the mesiodistal cervical edge of the core became completely opposite. The repetitive shear stress with changing forward and reverse directions might further increase the risk of fatigue failure at the adhesive interface. Further research is necessary to resolve the debonding mechanism at the adhesive interface in resin core build-ups of teeth and also to investigate the stress distribution after partially debonding.

**CONCLUSION**

Within the limitations of this study, it was concluded that a change of the load direction from buccal side to lingual side at buccal cusp increased the magnitude of maximum equivalent stresses in root and in resin post and core with a change of the location from lingual cervical side to buccal cervical side. The 3 mm-post length (post-end position equal to cancellous bone level) caused highest equivalent stress of post-end compared with the shorter or longer post length. Furthermore when change of the load direction, the direction of maximum shear stress became completely opposite at mesiodistal cervical edge of core part without a change of the magnitude, which was neither influenced by with/without fiber post nor post-end position.

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