Journal of Dental Sciences (2021) 16, 929—936

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Original Article

# The investigation of the stress distribution in abutment teeth for connected crowns

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Received 20 October 2020; Final revision received 2 November 2020
Available online 26 November 2020

**KEYWORDS**
Alveolar bone resorption;
Connected crowns;
Finite element analysis;
Polyetheretherketone;
Stress concentration

**Abstract** *Background/purpose:* With the advancement of an over aging society, the average number of remaining teeth has increased. However, these remaining teeth do not always have sufficient alveolar bone support, and sometimes fabricated connected crowns are applied. This study evaluated the influence of crown material, crown thickness, and alveolar bone resorption on the stress distribution within the abutment teeth of connected crowns.
*Materials and methods:* Using structural analysis software, a premolar crown model was fabricated. Three kinds of crown materials, two types of crown thickness, two types of post and core systems, and two levels of alveolar bone were assumed and evaluated for the stress distribution within the abutment teeth.
*Results:* The higher material properties crown was, the more stress was concentrated at the marginal area. The composite resin core showed larger stress values around the marginal area, and the metal core showed larger stress values at the tip of the post. Alveolar bone resorption progressed, the marginal area stress value increased.
*Conclusion:* The low elastic modulus crown material polyetheretherketone (PEEK) prevented stress concentrations at the marginal area of the crown and dentine, even with alveolar bone resorption. However, the amount of bone resorption has a great influence on the stress distribution around the tip of the post compared to the type of crown material.


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https://doi.org/10.1016/j.jds.2020.11.005

## Introduction

With the advancement of an ageing society and improvement in the status of dental health, the average number of remaining teeth in individuals has increased, especially in the elderly population. However, these remaining teeth do not always have sufficient alveolar bone support.[1–3] Therefore, sometimes fabricated connected crowns are applied in those cases to preserve the bone-supported teeth. There is also a possibility that the process of resorption of the alveolar bone might influence the prognosis of these restorations. However, few studies have investigated the influence of resorption of the alveolar bone on the stress distribution within the abutment teeth of the connected crowns.

Polyetheretherketone (PEEK) is a high-performance thermoplastic resin that has an aromatic polyether ketone. PEEK has excellent heat resistance, hydrolysis resistance, abrasion resistance, impact resistance, and radiation resistance.[4] PEEK is also extremely chemically stable and exhibits good biocompatibility.[5] Moreover, since it has corrosion resistance, it is also considered a metal substitute material in dentistry.[6–9] It is used in the frame and clasps of removable partial dentures[7,8] and complete dentures.[9] In restorations, PEEK is used as a crown and bridge material.[10–13] Furthermore, in the case of dental implants,[10,11,14–17] it is applied to fixtures,[14] abutments,[10,11,14,15] and gingival formers.[10,14] It was reported that when crown made of PEEK was applied for molars, the stress concentration at the cervical area of the dentine might be decreased.[18] This study aimed to evaluate the influence of crown materials, including PEEK, crown thickness, and alveolar bone resorption on the stress distribution around the crown margins and the end of posts, which are directly related to secondary caries and root fractures.

## Materials and methods

Using structural analysis software (MSC Marc Mentat 2013, MSC Software Corporation, Santa Ana, CA, USA), a root canal-treated premolar crown model, including the alveolar bone, was fabricated.[19,20] The model consisted of a crown, abutment teeth, luting agent, dentine, periodontal ligament, lamina dura, cancellous bone, and cortical bone and the hexahedral element was applied (Fig. 1). The model was made as a simulation of endodontically treated premolar teeth, 18 mm long, with a diameter of 6 mm cervical dentine. The length of the post was 8 mm, and the height of the coronal segment was 6 mm. The apical 12 mm of the root was surrounded with a 0.2-mm thick periodontal ligament and a 0.3-mm thick lamina dura. In addition, the height of the ferrule was 2 mm in all models. In addition, a model with a normal alveolar bone level (N model) and a model that assumed alveolar bone resorption of up to 1/3 of the roots (P model) were fabricated (Fig. 2). It was assumed that the crowns were connected and made of three materials, that is, Ag–Pd–Cu–Au Alloy (PD), hybrid resin composite (HR), and PEEK (PK). The taper of the abutment teeth was 6° on one side according to the CAD/CAM crown in the normal type of crown. Two types of crown models, depending on the thickness of the axial wall, were fabricated: normal thickness (NC) and reduced by half (HC) (Fig. 3). In addition, we assumed two types of post and core systems: a composite resin core with glass fiber post (RC) and a metal post and core made of Ag–Pd–Cu–Au alloy (MC). The material properties of each element and number of each element and node are shown in Table 1[21–29] and Table 2. In these models, the bottom of the mandibular bone was restricted completely and a three-dimensional mastication force (24 N in a mesial direction, 29 N in a buccal direction, and 164 N in an apical direction), was applied to the central node of the occlusal surface of the second premolar.[19,20,30,31] The analysis was for

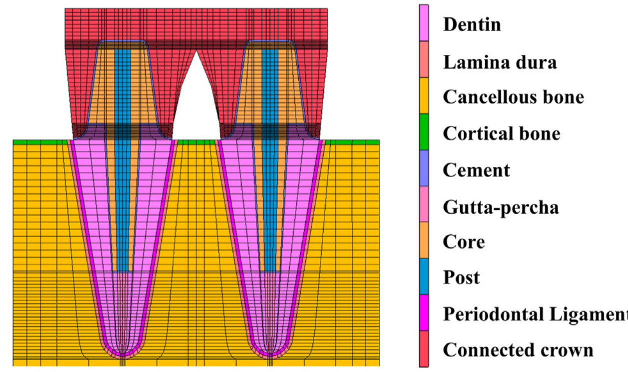


**Figure 1 Details of each element.** A root canal-treated mandibular premolar-connected crown model including the alveolar bone was fabricated on the personal computer. The model consisted of a crown, abutment tooth, luting agent, gutta-percha, dentin, core, post, periodontal ligament, lamina dura, cancellous bone, and cortical bone and the hexahedral element was applied.

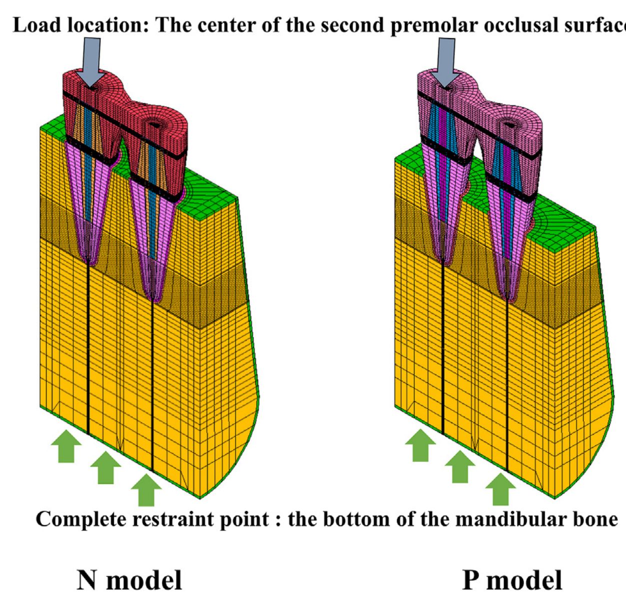


**Figure 2 Normal alveolar bone model (N model) and alveolar bone resorption model (P model).** Considering the alveolar bone level, A model with a normal alveolar bone level (N model) and a model that assumed alveolar bone resorption up to 1/3 of the roots (P model) were fabricated.

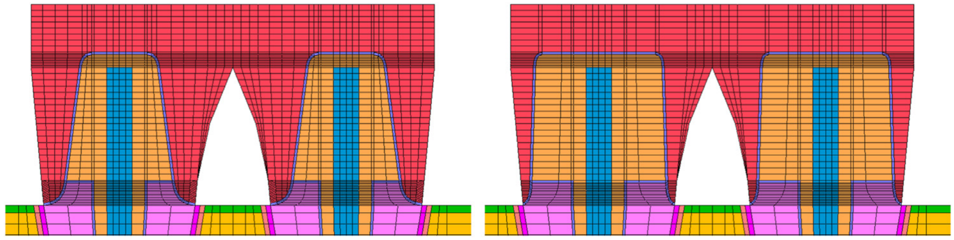


**Figure 3 Normal thickness connected crown (NC) and half thickness connected crown (HC).** Two types of the crown models were fabricated depending on the thickness of the axial wall of the crown: a connected crown with a normal thickness (NC) and with the crown thickness reduced by half (HC).

**Table 1** Mechanical properties of materials.

| | Elastic Modulus (MPa) | Poisson's Ratio | References |
|---|---|---|---|
| Dentin | 15,000 | 0.31 | 21 |
| Periodontal Ligament | Nonlinear | Nonlinear | 22 |
| Lamina Dura | 13,700 | 0.30 | 23 |
| Cancellous Bone | 345 | 0.31 | 21 |
| Cortical Bone | 13,700 | 0.30 | 23 |
| Gutta-percha | 0.69 | 0.45 | 24 |
| Composite Resin Core Material | 12,000 | 0.33 | 25 |
| Glass Fiber Post | 29,200 | 0.30 | 26 |
| Resin Luting Agent | 18,000 | 0.30 | 27 |
| Ag—Pd—Cu—Au Alloy | 86,000 | 0.33 | 28 |
| Hybrid Resin Composite | 21,000 | 0.27 | 27 |
| Polyetheretherketone (PEEK) | 4100 | 0.40 | 29 |

**Table 2** Number of each Element and node.

| | Element | Node |
|---|---|---|
| Dentin | 13,760 | 18,880 |
| Periodontal Ligament (N[a] -model) | 3840 | 7604 |
| Periodontal Ligament (P[b] -model) | 3120 | 6164 |
| Lamina Dura (N-model) | 3920 | 7764 |
| Lamina Dura (P-model) | 3200 | 6324 |
| Cancellous Bone (N-model) | 26,224 | 29,965 |
| Cancellous Bone (P-model) | 23,272 | 26,338 |
| Cortical Bone (N-model) | 4080 | 8426 |
| Cortical Bone (P-model) | 3648 | 7576 |
| Gutta-percha | 3840 | 7764 |
| Metal core (NC[c]) | 22,720 | 23,176 |
| Metal core (HC[d]) | 22,560 | 23,174 |
| Resin core | 13,600 | 18,502 |
| Fiber post (NC) | 9120 | 9396 |
| Fiber post (HC) | 8960 | 9396 |
| Cement (NC) | 7920 | 15,448 |
| Cement (HC) | 7840 | 15,448 |
| Connected crown (NC) | 23,560 | 27,735 |
| Connected crown (HC) | 11,320 | 15,655 |

[a] Model with a normal alveolar bone level.
[b] Model assumed alveolar bone resorption.
[c] Connected crown with a normal thickness of axial wall.
[d] Connected crown with axial wall reduced by half.

four parts shown in Fig. 4. Then, the von Mises stress values were calculated.

## Results

The results show the stress distribution of the abutment teeth and crowns in the sagittal cross-section view (Figs. 5 and 6). Fig. 7 shows the stress distribution within the crowns made of PD. Fig. 8 shows the stress distribution on the outer surface of the crowns made of PD and the abutment teeth. The magnitude of the von Mises stress value is shown in Table 3.

In the comparison of the crown materials, the higher the material properties of the crown, the more stress was concentrated at the marginal area of the crown and dentine. In addition, there was the same tendency at the tip of the post. However, the value of the material property has a greater influence on the stress concentration around the marginal area of the crowns compared to the stress concentration around the tip of the posts. In the case of PD, more stress concentration was observed at all analysis points, and stress concentration was reduced in the PK at all analysis points. In the case of PD, when the crown thickness was reduced, the magnitude of stress around the cervical area of the crown increased significantly. On the

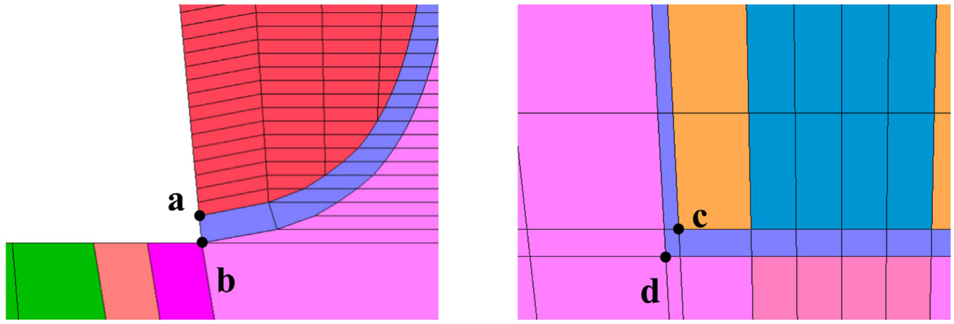


**Figure 4** **Analysis points.** The analysis four points: crown(a) and dentin (b) around the crown margin of the second premolar and post (c) and dentin (d) around tip of the post.

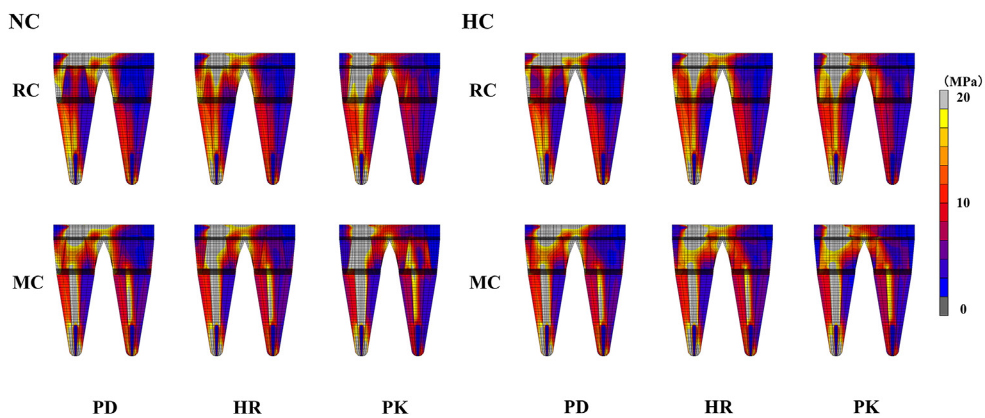


**Figure 5** **Stress distribution of the abutment teeth and crowns in N model (Sagittal cross-section).** The equivalent stress of sagittal cross section of abutment teeth in three kind of crown materials, two types of crown thickness models and two types of post and core system in N model. Gray and yellow represent the high stress concentration area as indicated by the color legend. Stress concentration was observed at the top of crown, cervical area of abutment tooth and tip of the post.

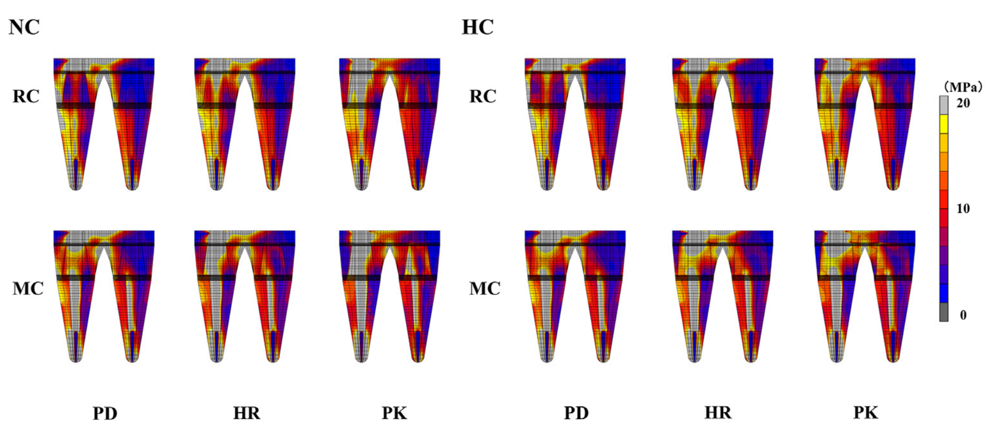


**Figure 6** **Stress distribution of the abutment teeth and crowns in P model (Sagittal cross-section).** The equivalent stress of sagittal cross section of abutment teeth in three kind of crown materials, two types of crown thickness models and two types of post and core system in P model. Gray and yellow represent the high stress concentration area as indicated by the color legend. Stress concentration was observed at the top of crown, cervical area of abutment tooth and tip of the post.

contrary, the magnitude of stress around the cervical area of the crown was decreased in the PK even when the crown thickness was reduced. The magnitude of the stress around the cervical area of dentine increased slightly in HR when the crown thickness was reduced. Meanwhile, the thickness of the crowns did not influence the magnitude of stress at the tip of the post and dentine around the tip of the post. Concerning the post and core systems, RC showed larger

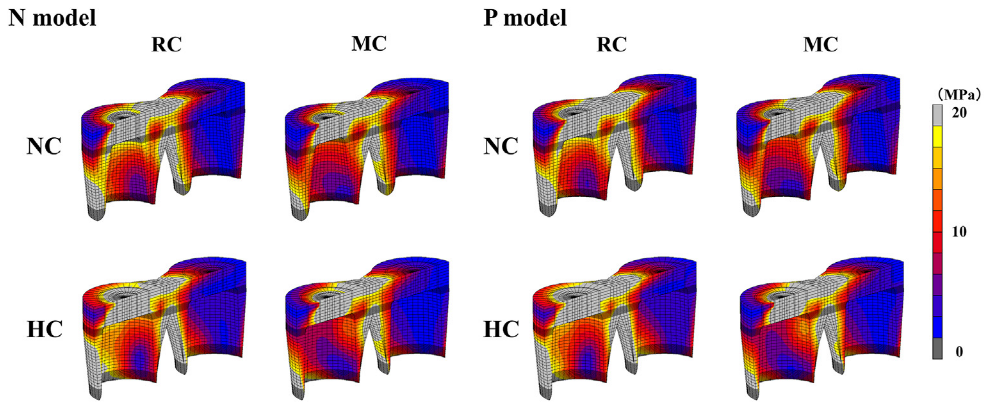


**Figure 7 Stress distribution within the crowns made of PD.** The equivalent stress of sagittal cross section in connected crowns made of PD, two types of crown thickness models and two types of post and core system in N and P model. Gray and yellow represent the high stress concentration area as indicated by the color legend. Stress concentration was observed at the top of crown and at the cervical area of crown, especially in the cases of PD—HC—RC.

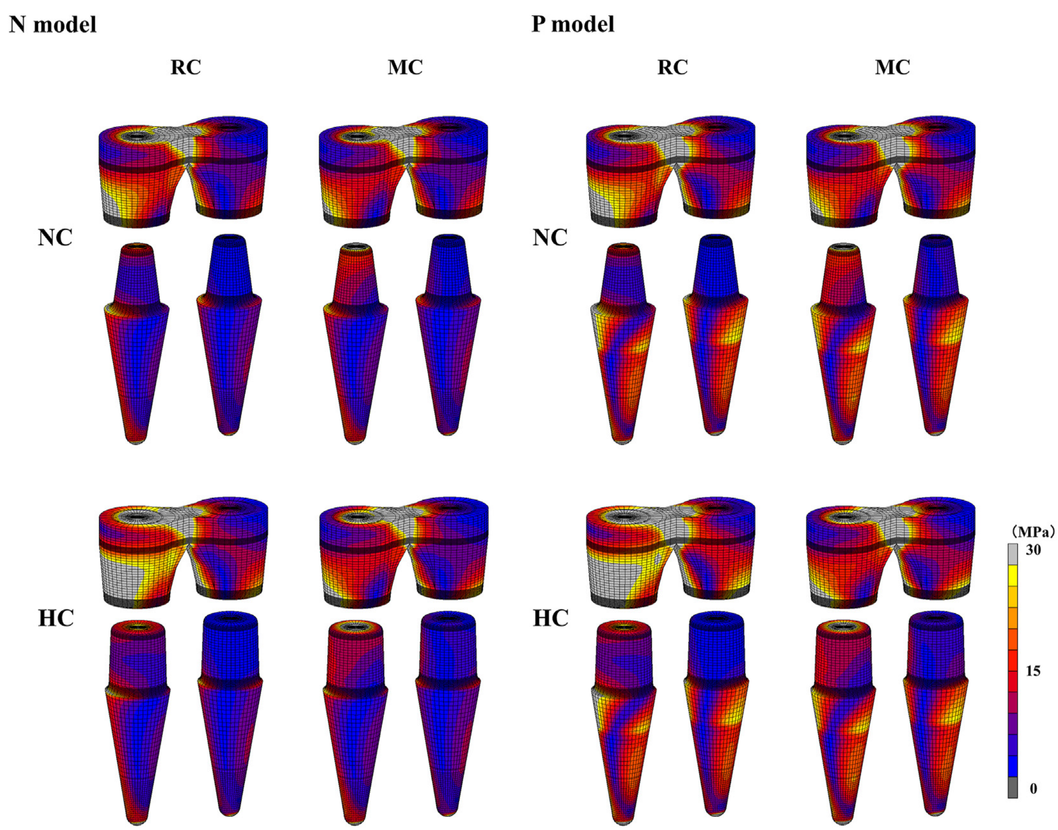


**Figure 8 Stress distribution of the outer surface of crowns and the abutment teeth made of PD.** The equivalent stress of connected crowns made of PD, two types of crown thickness models and two types of post and core system in N and P model. Gray and yellow represent the high stress concentration area as indicated by the color legend. Stress concentration was observed at the top of crown and at the cervical area of crown, especially in the cases of PD—HC—RC.

stress values in the crowns and dentine around the marginal area than MC. Meanwhile, MC showed larger stress values at the tip of the post and dentine around the tip of the post. At the marginal area of the crown, the magnitude of stress tends to increase slightly in the crown as alveolar bone resorption progresses. However, these stress values are slightly decreased in HC-MC-PD and HC-MC-HR, even when alveolar bone resorption progresses. As alveolar bone resorption progressed, the stress value of dentine at the marginal area increased compared to the marginal area of the crown. The stress value of the post and dentine around the tip of the post also increased.

Table 3 Stress value in MPa at each analysis point.

| Model | Crown Type | Post and core systems | Crown materials | Stress value | | | |
|---|---|---|---|---|---|---|---|
| | | | | (a[j]) | (b[k]) | (c[l]) | (d[m]) |
| N[a] | NC[c] | RC[e] | PD[g] | 11.5 | 7.32 | 8.40 | 8.75 |
| | | | HR[h] | 8.97 | 6.50 | 8.04 | 8.34 |
| | | | PK[i] | 6.49 | 4.74 | 7.47 | 7.68 |
| | | MC[f] | PD | 9.82 | 6.12 | 17.11 | 10.15 |
| | | | HR | 6.96 | 5.09 | 16.56 | 9.80 |
| | | | PK | 4.07 | 3.43 | 15.74 | 9.26 |
| | HC[d] | RC | PD | 18.21 | 9.24 | 8.36 | 8.70 |
| | | | HR | 10.34 | 6.95 | 8.02 | 8.32 |
| | | | PK | 3.97 | 4.61 | 7.53 | 7.75 |
| | | MC | PD | 14.35 | 7.27 | 17.10 | 10.15 |
| | | | HR | 8.02 | 5.53 | 16.60 | 9.82 |
| | | | PK | 3.03 | 3.76 | 15.85 | 9.34 |
| P[b] | NC | RC | PD | 12.52 | 10.60 | 9.91 | 10.54 |
| | | | HR | 9.40 | 9.38 | 9.46 | 10.07 |
| | | | PK | 7.29 | 7.29 | 8.58 | 9.19 |
| | | MC | PD | 10.32 | 8.58 | 20.31 | 12.30 |
| | | | HR | 7.01 | 7.06 | 19.57 | 11.88 |
| | | | PK | 4.49 | 5.10 | 18.09 | 11.09 |
| | HC | RC | PD | 18.78 | 12.85 | 9.86 | 10.48 |
| | | | HR | 10.52 | 9.78 | 9.44 | 10.05 |
| | | | PK | 4.26 | 6.87 | 8.67 | 9.29 |
| | | MC | PD | 14.23 | 9.71 | 20.30 | 12.29 |
| | | | HR | 7.77 | 7.42 | 19.63 | 11.91 |
| | | | PK | 5.32 | 3.07 | 18.32 | 11.23 |
| | | | | | | | (MPa) |

[a] Model with a normal alveolar bone level.
[b] Model assumed alveolar bone resorption.
[c] Connected crown with a normal thickness of axial wall.
[d] Connected crown with axial wall reduced by half.
[e] Composite resin core with glass fiber post.
[f] Metal post and core made of Ag—Pd—Cu—Au alloy.
[g] Ag—Pd—Cu—Au alloy.
[h] Hybrid resin composite.
[i] Polyetheretherketone (PEEK).
[j] The analysis four points: crown(a) and dentin (b) around the crown margin of the second premolar and post(c) and dentin(d) around the tip of the post.
[k] The analysis four points: crown(a) and dentin (b) around the crown margin of the second premolar and post(c) and dentin(d) around the tip of the post.
[l] The analysis four points: crown(a) and dentin (b) around the crown margin of the second premolar and post(c) and dentin(d) around the tip of the post.
[m] The analysis four points: crown(a) and dentin (b) around the crown margin of the second premolar and post(c) and dentin(d) around the tip of the post.

## Discussion

The primary causes of the detachment of crown restoration are secondary caries or root fractures. Stress concentrations at the marginal area of the crown and dentine fail the interfacial luting agent of the crown and result in microfractures in the dentine. Eventually, it leads to an increase in the risk of secondary caries development. Similarly, excessive concentration of stress around the tip of the post can lead to failure of the interfacial luting agent.[32] This kind of stress concentration may cause microfractures of the dentine around the tip of the post leading to a vertical root fracture.[32] The reduction of the stress concentration around the marginal area of the crown and the tip of a post may not only reduce the risk of dislocation of the restorations, but also increase the survival rate of the treated teeth. The stress concentration is greatly affected by the type of luting agent, post and core system, and crown material.[19,20,29–31,33–35] In addition, the thickness of the crown affects the distribution of the stress around the crown margin.[18,36] It has been reported that PEEK has a lower elastic modulus and higher flexibility than conventional crown materials. Crowns made of PEEK may reduce the concentration of stress at the marginal area of the crown compared to the conventional crown materials.[18,36] Therefore, PEEK may reduce the risk of secondary caries.

For the different crown materials, the order of the magnitude of stress at all four analysis points is PD, HR, and PK, and this order is coincident with the order of the value of the elastic modulus of these materials. In particular, the stress concentrations around the cervical area of the crown are more influenced by the elastic modulus compared to the tip of a post. Concerning the difference in crown materials, PD had a higher elastic modulus and was not deformed compared to other crown materials. The applied force is directly transmitted to the marginal area of the crown as well as the top of the occlusal surface of the crown and core. Meanwhile, as the elastic moduli of HR and PK are low compared to PD, HR and PK are easy to deform under the applied force. Because of these deformations of connected crowns, stress concentration at the marginal area of the crowns was released. Therefore, reducing the stress concentration at the marginal area of the crowns was observed in the case of HR and PK, rather than PD.

The finite element model in this study was based on the research by C. Shin et al.[18] Therefore, it is possible to compare the value of stress in the case of RC—N model in this study. The magnitude of stress at the marginal area of NC of PD, HR, and PK were 26.4, 21.3, and 14.2 MPa, respectively, and the magnitude of stress at the marginal area of dentine were 17.5, 16.0, and 14.4 MPa, respectively. Meanwhile, the magnitude of stress at the marginal area of HC of PD, HR, and PK were 50.6, 26.1, and 13.3 MPa, respectively, and the magnitude of stress at the marginal area of dentine were 23.2, 16.9, and 14.9 MPa, respectively. Therefore, according to the comparison between the previous study and our study, in case of NC, the magnitude of stresses decreased from 40—46% at the marginal area of the crown and 33—42% at the marginal area of dentine compared to a single crown. In addition, in the case of the HC, the magnitude of stress decreased by 30—36% at the marginal area of the crown and 31—40% at the marginal area of dentine. Therefore, a connected crown is effective in reducing the stress around the marginal area of the crown, especially in the case of PK. Regarding the stress concentration at the tip of the post, the type of post and core material had a greater influence on the magnitude of stress than that of the crown material. RC showed larger stress values at the marginal area of the crown and dentine than MC, whereas MC showed larger stress values around the tip of the post and the root dentine than RC. This is probably because the elastic modulus of RC is close to that of the root dentine. The occlusal force is transmitted to the core and post via the glass fiber post. However, the elastic modulus of the composite resin core and glass fiber is not remarkably high; therefore, this type of post and core is easily deformed compared to a metal post and core. Because of this deformation, stresses are dispersed and prevent excessive stress concentration around the tip of the post. Meanwhile, in the case of MC, the elastic modulus is too high, and the root is easily deformed. Therefore, the stress is transmitted to the core directly and might subsequently be transmitted to the post. Therefore, stress concentration along the post was observed that decreased the stress at the marginal area of the crown. To prevent fatal vertical root fracture of teeth, the type of post and core system is more important than the type of material. Restoration with a composite resin core with a glass fiber post is preferable to the metal post and core because the stress concentration at the tip of the post is not excessive. In the case of HC, the magnitude of stress at the marginal area of the crown increased remarkably in PD and increased slightly in HR, whereas it decreased in PK. Therefore, in the case of PD, it is not appropriate to reduce the amount of axial wall of the crown. Conversely, in PK, the thickness of crown of the axial wall can be reduced.

With resorption of the alveolar bone, the stress concentration increased at the marginal area of dentine, although the stress concentration at the marginal area of crown increased slightly.

The material property of PD and HR are quite higher than that of periodontal ligament or cancellous bone that related to the teeth movement. In the resorption model, the abutment teeth might be easy to move during function and connected crown made of PD or HR is not so distorted compared to PK. Therefore, stress is more concentrated at the marginal area of crown made of PD or HR in the resorption model.

Meanwhile, stress concentration around the end of the post and dentine increases regardless of the type of post and core system. In the case of PK with P model, nearly prevented stress concentration around the marginal area of the crown and the end of the post. In addition to this, in the case of the P model, PK—MC almost prevented the stress concentration at the marginal area of the dentine, and PK—RC also prevented the stress concentration around the tip of the post and dentine. When the risk of secondary caries is reduced, a metal post and core should be applied to the post and core system. Meanwhile, to reduce the risk of vertical root fracture, a composite resin core with glass fiber post is preferable to a metal post and core.[32] The thickness of the connected crown did not affect the stress distribution around the end of the post, which is why HC—PK is the most preferable restoration to reduce the stress concentration around the marginal area of the crown and around the end of the post.

Concerning the difference in the level of alveolar bone, stress is more concentrated around the end of the post in the entire P model compared to that of the N model, regardless of the type of crown material, post and core system, and crown thickness. It is considered that the amount of bone resorption has a greater influence on the stress distribution around the end of the post compared to the crown material.

In conclusion, in the case of connected crowns, the magnitude of stresses decreases at the marginal area of the dentine compared to single crowns, regardless of crown thickness. Among the type of crown material, PK prevents stress concentrations at the marginal area of the crown and dentine the most. However, the type of crown material does not affect the stress concentration around the end of the post and dentine. The type of post and core system affect the stress distribution around the end of the post and dentine. When the thickness of the axial wall is reduced, PK prevents the stress concentrations at the marginal area of the crown and dentine. In the case of the P model, PK prevents the stress concentration around the marginal area of the crown. The amount of bone resorption has a greater influence on the stress distribution around the end of the post compared to the type of crown material.

## Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

## Acknowledgment

This work was supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Number JP15K20428.

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