Finite element analysis of endocrown and post-core abutments for removable partial dentures with different framework materials

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ABSTRACT

**Purpose:** To evaluate the stress distribution in endocrowns and post-and-core crowns used as abutments for a Kennedy Class I removable partial denture constructed with different framework materials. **Materials and Methods:** 3D models of a Kennedy Class I mandible were constructed. Cobalt-chromium (Co-Cr) and polyether ether ketone (PEEK) frameworks were simulated for Models 1 and 2. An endocrown and a fiber post-and-core crown for the mandibular left and right second premolar abutments were simulated for both models, respectively. Lithium disilicate porcelain was defined for the crowns. A 200-N occlusal force was applied in the vertical and 30-degree oblique directions. **Results:** The von Mises stresses were evaluated for the abutments and prostheses, and the principal stresses for the cortical bone under vertical and oblique loadings. Endocrowns showed lower stress values than post-and-core crowns in both models. Post-and-core porcelain crowns generated the highest stress in Model 2 under vertical loading. PEEK framework caused higher stress values on abutments than Co-Cr. Compressive stresses were higher than tensile stresses in cortical bone. The highest compressive stress was observed around the left premolar cortical bone area in Model 1 under oblique loading. Oblique loading caused lower stress values than vertical loading, except for on the minor connectors and cortical bone. **Conclusion:** From a biomechanical perspective, endocrowns may be more advantageous than post-and-core crowns when used as abutments for a Kennedy Class I removable partial denture. In addition, Co-Cr frameworks show more favorable stress distribution on abutments than PEEK frameworks. *Int J Prosthodont* 2021. doi: 10.11607/ijp.7269

INTRODUCTION

Removable partial dentures (RPD) are widely indicated for rehabilitating tooth loss when financial constraints or contraindications for implant and fixed partial prosthesis are
present.\textsuperscript{1,2} Materials used in conventional RPD can be classified as metal and non-metal. Cobalt-chromium (Co-Cr) alloy is the most widely used metal for RPD. However, Cr-Co alloy has unsatisfactory esthetic results and leaves a metallic taste in the mouth.\textsuperscript{2,3} Polyether ether keton (PEEK) material, a semi-crystalline organic polymer, presents an alternative to metal with high temperature resistance and properties such as antiallergic properties, polishability, low plaque affinity and abrasion resistance, stable chemical properties, and high biocompatibility.\textsuperscript{3,4} Due to its color and other physical properties, it allows for the production of esthetic clasps.\textsuperscript{5}

The primary aim for endodontical treatment of teeth is to preserve the fractured root or crown and therefore, extracoronal restorations are recommended that protect the remaining dental tissues.\textsuperscript{6} If the coronal part of the tooth is severely damaged, restorations based on intraradicular retention such as post-core and crown restorations are recommended. Previous studies have shown that restorations with post-core or endocrown have long-term survival rates with lithium disilicate ceramic crown.\textsuperscript{6-8} However, root fracture may occur due to increased loading in post-core crowns when they used as an abutment.\textsuperscript{9} The main advantage of endocrowns is that it does not cause removal of the the root dentine during its preparation. Endocrowns derive their support from the pulp chamber such that root dentine is preserved during preparation and they are ideal alternatives full crowns and post-core restorations.\textsuperscript{8,10} In addition, the endocrown gains its macromechanical retention from the internal part of pulp chamber and its micromechanical retention from adhesive cementation. Retention problems can be seen when large coronal part of tooth was missing. This could be encountered as its disadvantage.\textsuperscript{8,11,12}

Using post-core crowns or endocrowns as abutments for RPD is controversial because the strength of endodontically treated teeth are compromised. Biomechanical evaluation is important in order to use endodontically treated abutments for RPD because stresses on these
abutments may result in fractures and failures in long terms. Finite element analysis is one of the most useful methods to determine the stress distribution on the tooth and surrounding tissues.\textsuperscript{13,14}

When treatment choices are restricted, endodontically treated teeth can be used as abutments in RPD. Two options come to minds to restore these teeth with endocrown or post-core restoration. However, it can be difficult to decide for a clinician if endocrown or post-core is advantageous in terms of biomechanical aspect. From this point of view, it was thought to conduct a study which evaluated the stress distribution on endocrown and post-core restored premolar abutments for a Kennedy Class I mandibular RPD. In addition, two different framework materials were analyzed under static occlusal forces.

The null hypothesis is that endocrown restorations and prostheses using a PEEK framework may be advantageous over post-core restorations and a Co-Cr framework in terms of the stress distributions.

MATERIALS AND METHODS

A three-dimensional (3-D) model of a Kennedy Class I mandible was constructed using 3-D modeling software (Rhinoceros 4.0, Robert McNeel & Associates, Seattle, WA, USA). The first and second molars were removed in both sides of the mandible. The right and left second premolars were defined as endodontically treated teeth. The left second premolar was simulated with an endocrown restoration and the right second premolar was simulated as restored with a fiber-post and composite-core foundation and a porcelain crown. Lithium disilicate porcelain was used for the crowns in both restorations. All tooth anatomy, including the porcelain crowns, was constructed according to Wheeler’s Dental Anatomy.\textsuperscript{15} Periodontal ligament thickness of the simulated natural teeth was assumed to be 0.2 mm, as stated in other studies.\textsuperscript{16,17} The RPD was constructed with a lingual bar for the major connector and akers
clasps for the second premolars on both sides. Mesial occlusal rests were placed on a rest seat that simulated the porcelain crown. The length of the occlusal rests was defined as one third of mesiodistal length of the tooth, the width of the rests was defined as half the buccolingual width of the tooth, and the depth was fixed at 1.5 mm. An indirect retainer was seated on the mesial side of first premolar. Two materials were selected for the major connector, Co-Cr and PEEK.

The crown of second premolar tooth was assumed to be missing 3 mm above the cemento enamel junction (CEJ) for both restorations. Restorations were finished supragingivally, retaining 1 mm intact enamel height above the CEJ. The fiber post space for the right second premolar was simulated as the length of post was two-thirds the length of the root and the diameter was one third of root diameter. A 10-mm fiber post was placed in the root. The resin core was constructed over 2 mm of intact dentin and was simulated with a 1-mm ferrule. A lithium disilicate porcelain crown was simulated with a 3-mm occlusal thickness. An endocrown was designed for left second premolar. The root was simulated as prepared with a 2.5-mm endo-core length, measured from the coronal to the apical part of the root. A 1-mm supragingival margin and a 1-mm shoulder finish line was defined the same as the post-core design. All parts of the teeth were assembled in the modeling software (Fig 1).

Two models were designed for the analysis (Fig 2):

Model 1: Kennedy Class I model with Co-Cr major connector.

Model 2: Kennedy Class I model with PEEK major connector.

In both models, the left second premolar was assumed to be restored with an endocrown and the right second premolar with a post-core and a crown.

Materials were assumed to be linear elastic, homogeneous, and isotropic. The material properties are defined in Table 1. The 3-D models were meshed with a mesh generation software (VRMesh Studio, VirtualGrid, Bellevue, WA, USA) using 8-node brick elements.
The number of elements and nodes that used in both models were 1,277,445 and 288,149, respectively. Boundary conditions were defined for the mandible model along the posterior and inferior borders. The friction coefficient between the crown and clasp was defined as 0.1 µ, while that between the mucosa and prosthesis was 0.01 µ.19,26,27 Acrylic resin of RPD was assumed as 2 mm. The models were created as solid models and transferred in standard tessellation language (STL) format to the analysis software (ALGOR FEMPRO, ALGOR Inc., Pittsburgh, PA, USA). An occlusal force of 200 N was applied in both the vertical and 30° oblique directions14,16,17 to the first and second molar acrylic teeth of the prosthesis (Fig. 3).

RESULTS

The von Mises stresses (maximum equivalent stress) were evaluated in the porcelain crowns, teeth, posts and connectors. The maximum principal stresses (tensile stresses) and minimum principal stresses (compressive stresses) at the cortical bone were also determined for both models. All stress values and patterns were determined under vertical and oblique forces. A color-coded scale was developed with red areas indicating maximum stresses and blue areas indicating minimum stresses. All components of models, except minor connectors experienced higher von Mises stress values when the PEEK major connector was used.

Vertical Loading

The maximum von Mises stress (225.70 MPa) was seen in Model 2 at the buccal cervical border of the porcelain crown in the post-core restoration. The minimum von Mises stress (0.077 MPa) was seen in Model 1 on the coronal third of the fiber post. When the stresses on the dentin were examined, the abutment restored with an endocrown had lower stress values than that of the post-core restoration in both models. It was seen at the buccal part of the dentin in cervical area (41.41 MPa). Endocrown restorations showed lower stresses than post-core crown restorations in both models. The von Mises stress values of Model 2
were higher than Model 1, except in the minor connectors. The stress on the minor connector of the PEEK prosthesis (right: 50.15 MPa, left: 53.9 MPa) was less than that of the Co-Cr (right: 135.06 MPa, left: 164.50 MPa) under right and left vertical loadings. The stress patterns are shown in Figure 4 and the stress values of Model 1 and Model 2 are illustrated in Figure 5.

The tensile stresses at the cortical bone around the second premolar were lower than those of the compressive stresses in both models. Compressive stresses in Model 1 were higher than those in Model 2. The highest compressive stress (12.74 MPa) was seen in the cortical bone around the left premolar in Model 1 and the lowest (11.03 MPa) was in the cortical bone around the right premolar in Model 2. The stress patterns are shown in Figure 6 and stress values illustrated in Figure 7.

**Oblique Loading**

The maximum von Mises stress value (143.15 MPa) was seen in Model 1 at the buccal cervical border of the post-core crown. The minimum von Mises stress value (0.096 MPa) was seen in Model 2 on the coronal third of the post. When the stresses on the dentin of the teeth were compared, the highest stress (47.59 MPa) was seen on the dentin of the post-core abutment in the area of the disto-palatinal cement junction in Model 1. Endocrowns had lower stress distribution than post-core crowns in both models. When the minor connectors were compared, the stress values on the Co-Cr framework (right: 191.26 MPa; left: 301.6 MPa) were higher than those on the PEEK framework (right: 54.01 MPa; left: 69.12 MPa). The stress patterns are shown in Figure 8 and the stress values of Model 1 and Model 2 are illustrated in Figure 5. The von Mises stress values were lower under oblique loading than those of vertical loading, except minor connectors in both models. The compressive stresses were higher than the tensile stresses in both models. The highest compressive stress (15.56 MPa) was concentrated on the cortical bone around the left second
premolar in Model 1. The lowest compressive stress (14.05 MPa) was seen on the cortical bone around the right second premolar in Model 1. The stress patterns are shown in Figure 6 and stress values are illustrated in Figure 7. The tensile stresses were lower under oblique loading than those of vertical loading in both models.

DISCUSSION

The null hypothesis was partially accepted. When placed under occlusal forces, the endocrown restorations were found to cause less stress on both the tooth structure and the porcelain than post-core crowns when used as abutment for RPD analyzed with two different framework materials. However PEEK material caused higher stresses on abutment teeth and porcelains than those of Co-Cr material.

The mechanical aspects of the porcelain selected for the endocrown and post-core restorations are especially important when restored teeth are used as abutments for RPD. Lithium-disilicate glass-ceramic was preferred for the crown restorations in this study because it is accepted as a reliable material with high flexural strength and great resistance to compressive forces.\textsuperscript{6,8,11} Finite element analysis studies comparing endocrowns and post-core crowns in terms of their stress distribution and failure risk have concluded that endocrowns are better than post-core crowns.\textsuperscript{22,28} Our study has found endocrowns are advantageous compared to fiber post resin core restorations as an abutment for RPD in terms of stress distribution with both frameworks, corroborating previous studies. The reason for this was assumed to be that the post reduces the dentin’s resistance to stress because the root structure has been weakened.

The design of an endocrown is an important factor. The fracture resistance is increased when the thickness of the ceramic at the occlusal part of the endocrown is increased.\textsuperscript{16,29} An endocrown design that combines long axial walls, a 3 mm or more occlusal ceramic thickness,
and that preserves the tooth structure above the CEJ ought to have the most advantages.\textsuperscript{16,20} Pedrollo-Lise et al.\textsuperscript{30} evaluated the biomechanical behaviors of different endocrowns designs for premolars and found that an endocrown core length of 2.5 mm was the optimum when used with lithium disilicate ceramic. In the light of these findings, the dentinal walls were preserved, and the finish line was set at 1 mm above the CEJ to reduce stress on the tooth in this study. Additionally, our endocrown design was constructed with thick (3 mm) occlusal porcelain and a 2.5-mm endocrown core length to achieve optimum results.

Different materials can be used for the framework of RPD. PEEK is a polymeric material that has found wide usage in dentistry. It is an alternative to the standard Co-Cr alloy for esthetic reasons, its low weight, and for allergic patients.\textsuperscript{25,31,32} There have been some in-vivo and in-vitro studies on the usage of PEEK and other materials in RPD.\textsuperscript{5,25,33} Our study also compared the biomechanical stress distribution in PEEK and Co-Cr using finite element analysis. According to our results, a PEEK major connector caused more stress on abutments and prosthetic components than a Co-Cr major connector. The reason was assumed to be related to the difference in the elasticity modulus of the two major connector materials. PEEK is more flexible than Co-Cr; hence, more occlusal forces are transmitted to the second premolars abutments and to the cortical bone compared to Co-Cr. However, the Co-Cr framework is rigid and can absorb more occlusal forces such that less stress is seen on the abutment tooth and components. Stresses in the Co-Cr major connector were found to be higher than in the PEEK major connector in this study. The low elasticity modulus of PEEK caused bending in framework and directly transmitted the stresses to the abutment teeth and bone.

Our results are supported by those of Sirandoni et al.\textsuperscript{25}, who evaluated the stress distribution of different framework materials for implant-supported mandibular prostheses.
They concluded that polymeric materials, such as PEEK, which have lower elasticity moduli could lead to higher stresses on distal implants, and that rigid frameworks, such as Co-Cr, lead to a better stress distribution. They also found that PEEK decreases the amount of stress occurring in the framework. As also stated by Sirandoni et al.\textsuperscript{25}, the stress absorption of PEEK was low and it could only be seen under compressive stresses, similar to our study. Chen et al.\textsuperscript{2} also compared removable denture frameworks and found that Co-Cr showed higher stresses on the denture bearing area and in the framework itself than PEEK, concurring with our study.

The tolerance of bone is higher for compressive stresses than for tensile stresses.\textsuperscript{25} When the tensile and compressive stresses on cortical bone were compared under both loading conditions, it was seen that compressive stresses were higher than tensile stresses for both Model 1 and Model 2. Tensile stresses on cortical bone were slightly higher with the PEEK framework than with the Co-Cr framework, but the compressive stresses were lower for PEEK than Co-Cr. It may be the flexibility of PEEK that leads to higher tensile stresses compared to Co-Cr alloy. The shock absorption effects of PEEK had only a minor effect on the compressive stresses in cortical bone, as similarly stated by Lee et al.\textsuperscript{34}

Oblique loadings caused lower von Mises stress values than vertical loadings in both the abutments and the prosthesis components except for the connectors. With both framework materials, minor connectors had higher stress values under oblique loadings than vertical loadings. To the contrary, compressive stresses in cortical bone were higher under oblique loadings compared to vertical loadings. The difference in the results between oblique and vertical forces may depend on the movement of the prosthesis. When vertical loading was applied, higher stresses were seen on the abutments where the force was applied. Prosthesis is embedded in the mucosa and become more stable and strictly seated on the teeth under
vertical forces compared to oblique forces. Oblique forces caused the prosthesis to move not only vertically, but also in the anteroposterior and mediolateral directions. This free swinging motion resulted in high stresses in the removable prosthesis, connectors, and cortical bone compared to the abutments and teeth. The friction coefficient between the prosthesis and the mucosa and between the clasps and crowns of the abutments may affect the movement under oblique forces more than under vertical forces. As a result, the stresses were distributed in other areas around the abutment teeth and appeared in the contralateral cortical bone side as tensile stresses.

Mesial rests were preferred instead of distal rests due to their ability to direct the applied forces in a more vertical direction as declared in the previous studies\textsuperscript{9,35}. In a study by Mizuno et al.\textsuperscript{9}, it was stated that the stresses were decreased when using a fiber post resin core restoration in the second mandibular premolar abutment with Akers and mesial rest. As similar with these studies mesial rests were preferred to reduce the stresses. The reason for using an Akers retainer instead of a bar retainer is that the continuous dislodge forces acting on the abutments can cause the crown removal or debonding with bar retainers.\textsuperscript{36}

Finite element analysis is the most used method for confirming predictions about the stress distribution in clinical scenarios with some limitations.\textsuperscript{25} The main limitations of our study were assuming the bone properties were homogenous and that it was a static analysis. Different endocrown designs and different materials in other Kennedy classifications with different retainers and designs could be studied further.

CONCLUSION

From a biomechanical perspective, endocrowns can be used instead of post-core crowns as a second mandibular premolar abutment for Kennedy Class I removable dentures.
Greater stresses were transferred to the abutment teeth and porcelain crowns with PEEK framework than Co-Cr framework. As a consequence, Co-Cr alloy may be preferred instead of PEEK for the major connector when distal abutments are post-core crowns or endocrowns.

ACKNOWLEDGMENTS

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REFERENCES


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Figure 1. A, B: Right second premolar abutment simulated with post-core treatment. C, D: Right second premolar abutment with endocrown. E: Prosthesis with Co-Cr alloy framework. F: Prosthesis with PEEK framework.
Figure 2. A: Model 1, Kennedy Class 1 mandibular prosthesis modeled with a Co-Cr major connector. B: Model 2, Kennedy Class 1 mandibular prosthesis modeled with a PEEK major connector.
Figure 3. A: Vertical loading points at 40 N each, for a sum of 200 N. B: Arrows indicating oblique loading with each arrow representing 66.6 N, for a sum of 200 N.
Figure 4. A, B, C, D, E, F, G: Model 1 von Mises stress patterns under vertical loading for the endocrown porcelain, left second premolar, post-core crown porcelain, right second premolar, prosthesis minor connector (right), prosthesis minor connector (left), and the fiber post, respectively. The same locations are labeled H, I, J, K, L, M, N for Model 2.
Figure 5. Graphic illustration of comparing the von Mises stress values for the endocrown porcelain, left second premolar, post-core crown porcelain, right second premolar, prosthesis minor connector (right), prosthesis minor connector (left), and the fiber post under vertical and oblique loading conditions for Model 1 and Model 2.
Figure 6. A, B, C, D, E, F, G, H: Model 1 maximum and minimum principal stresses under vertical and oblique loading. I, J, K, L, M, N, O, P: Model 2 maximum and minimum principal stresses at the same locations.
Figure 7. Graphic illustration of comparing the principal stress values in cortical bone around the right and left second premolars under vertical and oblique loading conditions for Model 1 and Model 2.
Figure 8. A, B, C, D, E, F, G: Model 1 von Mises stress patterns on the endocrown porcelain, left second premolar, post-core crown porcelain, right second premolar, prosthesis minor connector (right), prosthesis minor connector (left), and the fiber post under oblique loading.

The same locations are labeled as H, I, J, K, L, M, N for Model 2.
**Table 1.** Properties of Materials.

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<th>Poisson’s Ratio (ν)</th>
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RPD= removable partial denture; Co-Cr = cobalt-chromium; PEEK = polyether ether ketone