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Effect of Polyetheretherketone and Indirect Composite Resin Thickness on Stress Distribution in Maxillary Premolar Teeth Restored With Endocrown: A 3D Finite Element Analysis

Polietereterketon ve İndirekt Kompozit Rezin Kalınlığının, Endokronla Restore Edilmiş Maksiller Premolar Dişteki Stres Dağılımına Etkisi: 3 Boyutlu Sonlu Elemanlar Analizi

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Özet

Amaç	Mevcut çalışmanın amacı, polietereterketon alt yapı ve indirekt kompozit rezin üst yapı materyallerinin kalınlıklarının, endodontik tedavisi yapılmış ve endokronla restore edilmiş maksiller premolar dişlerdeki stres dağılımına etkisinin incelenmesidir.
Yöntem	Çalışmada kontrol grubu olarak, sağlam maksiller premolar diş kullanılmıştır. Tüm gruplarda endokron materyali olarak polietereterketon alt yapı materyali ve indirekt kompozit rezin vener materyali kullanılmıştır. Çalışma gruplarında, endokronun okluzal kalınlığı 3 mm olarak sabitlenmiştir. Polyetheretherketone ve indirek kompozit rezin vener materyalinin kalınlığı; 1, 1,5 ve 2 mm olarak belirlenmiştir. 200 N büyüklüğünde vertikal ve oblik kuvvet altında, maksiller premolar dişteki stres dağılımı analiz edilmiştir.
Bulgular	Tüm gruplarda, Von Mises stres dağılımlarının aynı olduğu görülmüştür. Ayrıca, mine ve dentindeki von Mises stres değerleri, tüm endokron gruplarında aynı ve sağlam dişten daha yüksek bulunmuştur. Restoratif materyaldeki en düşük von Mises stres değerleri, 2 mm polietereterketon alt yapı ve 1 mm indirek kompozit vener materyalinden oluşan çalışma grubunda görülmüştür.
Sonuç	Polietereterketon ve indirek kompozit materyallerinin kalınlıkları, mine ve dentindeki von Mises stres dağılımları ve stres değerlerini etkilememiştir.
Anahtar kelimeler	Sonlu Elemanlar Analizi, Dental Restorasyonlar, Endodonti, Protetik Diş Tedavisi

Abstract

Aim	*The objective of this study was to evaluate the influence of polyetheretherketone substructure and indirect composite resin veneering material thicknesses on stress distribution in endodontically treated maxillary premolar teeth restored with endocrowns.*
Methods	*A sound maxillary premolar teeth was used as control group. Polyetheretherketone substructure and indirect composite resin veneering materials were used as endocrown materials in all study groups. The occlusal thicknesses of the endocrowns were fixed at 3 mm in study groups. Thicknesses of polyetheretherketone and indirect composite resin veneering material were determined as; 1, 1.5 and 2 mm. Stress distributions of maxillary premolar teeth under 200 N vertical and oblique loads were analyzed.*
Results	*Von Mises stress distributions were same in study groups. Von Mises stress values in enamel and dentin were same in all study groups and they were higher than sound teeth. The lowest Von Mises in restorative material were found in a study group with 2 mm PEEK substructure and 1 mm indirect composite resin veneering material thickness.*
Conlusion	*Difference in polyetheretherketone and indirect composite resin veneering materials' thickness didn't affect von Mises stress values and distributions in enamel, dentin.*
Key words	*Finite Element Analysis, Dental Restorations, Endodontics, Prosthodontics*

INTRODUCTION

The restoration of endodontically treated teeth has been a controversial issue for many years. The loss of vitality of teeth causes physical and structural changes that affect the properties of the dentin, such as micro-hardness, modulus of elasticity, and fracture toughness.[1] In endodontically treated teeth, it is important to preserve the integrity of the remaining dental tissue and to select the appropriate restorative material for both restoration and the structural strength of the tooth.[2]

Endodontically treated teeth with excessive substance loss are typically restored by the post-core system.[3] However, while inserting a post, complications such as perforation in the root, weakening and fracture of the root structure can be observed.[2,4]

Along with the development of adhesive techniques and the emergence of minimally invasive dentistry, a new form of treatment has emerged as an alternative to the post-core system in the restoration of endodontically treated teeth. Endocrown restorations are monolithic ceramic restorations based on the principles of adhesive dentistry, containing a central retention cavity in the pulp chamber.[5] Additionally, the retention of endocrowns is also based on macro-mechanical fixation in the pulp chamber.[6]

Polyether ether ketone (PEEK) is an increasingly applied material in dentistry in recent years. It has high mechanical properties, resistance to heat, chemical stability, low weight and high biocompatibility. PEEK is used as a framework material in fixed and removable dentures.[7] As PEEK has grey, brown, pink or opaque white color as a framework material, so that composite resins can be used as a suprastructure material to enhance aesthetic properties of restorations.[8]

Finite element analysis (FEA) is a computational tool that is used to model tooth, surrounding tissues and restorations, to simulate occlusal loading conditions, and to determine the stress and strain distribution of teeth against these loads.[9,10]

Leucite or lithium disilicate reinforced ceramic materials and indirect composite resins which had high mechanical strength and also were capable of being acid etched and allied with the adhesive systems can be used as endocrown materials especially in molar teeth.[2,11] Both of reinforced ceramic and indirect resin materials have ensure enhanced marginal fit, ideally proximal contacts, increased wear resistance, reduced polymerization shrinkage and optimal aesthetic properties.[6,12]

It has been also stated in a short time (22 months) clinical report that, a modified PEEK framework material with light-polymerized indirect composite resin veneering material was used for the fabrication of an endocrown restoration in a maxillary molar teeth.[13] However, there is no FEA study using PEEK as an endocrown material, nor a study investigating how thickness of PEEK and the indirect composite materials affect stress formation in endodontically treated teeth. The aim of this study is to investigate the effects of different thicknesses of PEEK substructure and indirect composite resin veneering materials on stress distribution in maxillary premolar teeth restored with endocrowns.

The null hypothesis of this study is that the different thicknesses of PEEK substructure and indirect composite resin veneering material will not affect the von Mises stress (VMS) distribution and values in teeth's enamel and dentin.

MATERİAL and METHODS

Three dimensional FEA model of a maxillary premolar tooth constructed to evaluate the VMS distribution at the endocrown and the tooth structure. This study was conducted using a 3D scanner (Activity 880; Smart Optics Sensortechnik GmbH), 3D modeling softwares (Rhinoceros 4.0; McNeel),a meshing software (VR Mesh Studio;

VirtualGrid Inc) and an analysis program (Algor Fempro; Algor Inc).

Shape of the solid model was obtained by scanning a plastic maxillary premolar teeth with a 3D scanner (SmartOptics; SensortechnikGmbH). Morphology of the dental model was designed in accordance with the geometry in the Wheeler's atlas by using a 3D modeling software (Rhinoceros 4.0; McNeel).[14]

Endocrowns were designed as using PEEK (Juvora Dental Disc; Juvora Inc.) as substructure material and indirect composite resin as suprastructure material (Signum Ceramis; Heraeus Kulzer). A flowable composite resin material (Tetric Flow; Ivoclar Vivadent AG) was designed between the gutta percha and the cement layer. A dual-cure resin cement (Multilink Automix; Ivoclar Vivadent AG) will be used for the bonding of endocrowns to the tooth. Mechanical properties of materials and tissues used in this study are listed in Table 1.

Table 1. The mechanical properties of materials and tissues used in the finite element model

Material	Elastic Modulus (GPa)	Poisson Ratio
Polyetheretherketone	3.519	0.36
Indirect composite resin	4.8520	0.30
Stainless steel	20020	0.30
Gutta percha	0.0721	0.40
Flowable composite resin	5.3022	0.28
Dual-cure resin cement	5.0023	0.29
Enamel	84.1024	0.33
Dentin	18.6024	0.31
Pulp	0.006821	0.45
Periodontal ligament	0.0725	0.45
Trabecular bone	1.3725	0.30
Cortical bone	13.725	0.30

Central retention cavity was designed as 5 mm in depth as suggested in the literature.15 Occlusal thickness of endocrown was determined as 3 mm. In this study, thickness of PEEK and indirect composite resin were differed in groups. Also a sound teeth was used as a control group (Table 2).[16]

Table 2. Tested materials and study groups in this study

Groups	Material
Group C	Sound Tooth
Group P1	1 mm Indirect Composite +2 mm PEEK
Group P2	1.5 mm Indirect Composite+1.5 mm PEEK
Group P3	2 mm Indirect Composite+ 1 mm PEEK

Different 3D models created for each study group (Fig 1). After that, mesh design was made for the mesh procedures was made by using VR Mesh Studio software (Virtual Grid Inc). 228016 nodes and 1235775 elements were formed in all of the models, in this study. All models were assumed to have perfect bonding. The tissues and materials in this study were considered as homogeneous, isotropic, and with linear elasticity and all models had perfect bonding.

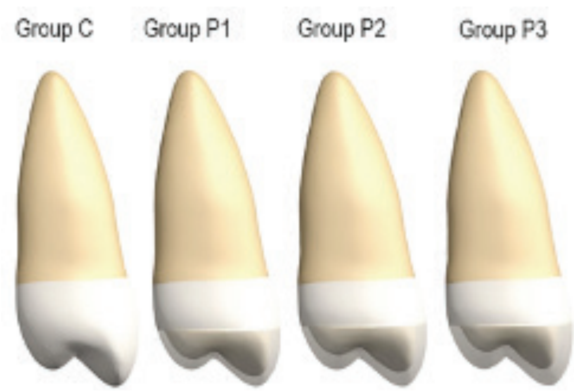

Fig.1. Finite element models

For the application of the stress analysis, all datas were transferred to an analysis program (Algor Fempro; Algor Inc). In stress analysis program, a 8.6 mm diameter stainless steel ball was used to stimulate foodstuff (Fig 2).[17,18] 2 different condition was applied in this study. In the first condition, a vertical force applied parallel to the long axis of tooth. This force was composed of two components and each of components were applied to buccal and palatal cusp surfaces. In the second condition, an oblique force, which was at 30 degrees to the long axis of the tooth and applied to palatal cusp surface.[16] The VMS distributions and values in enamel, dentin and endocrown were analysed.

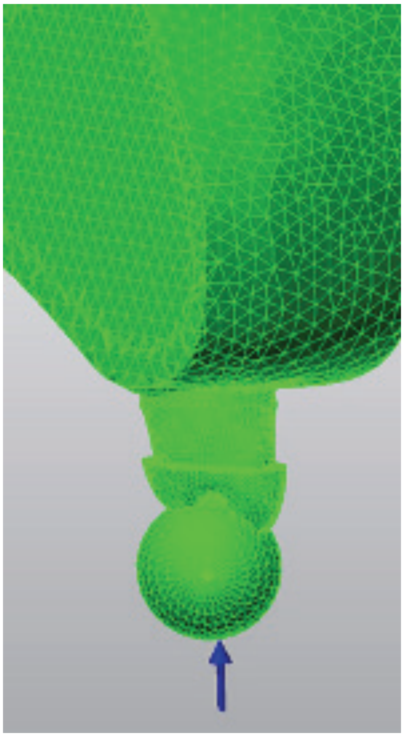

Fig. 2. A spherical rigid material which was 8.6 mm in diameter was loaded

RESULTS

In this study, when vertical forces were applied, VMS stress distributions in enamel, dentin and were found similar in group P1, P2 and P3. VMS distribution in enamel was concentrated at cervical enamel in group P1, P2 and P3, while it was concentrated at cervical enamel and occlusal loading area in group C. Furthermore, VMS was concentrated at cervical dentin in all groups. In addition, VMS was concentrated at occlusal loading area of endocrowns in group P1, P2 and P3 (Fig. 3).

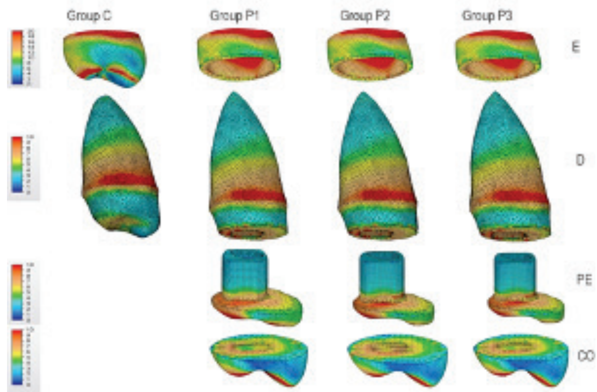

Fig. 3. Von Mises stress distributions in Control Group, Group P1, P2 and P3 under vertical load

When vertical forces were applied, VMS, maximum principle and minimum principle stress values in enamel and dentin were same in group P1, P2 and P3 and they were higher than group C. In addition, lowest VMS values in PEEK and composite parts of endocrowns were found in group P1, while highest in group P3 (Table 3).

When oblique forces were applied, VMS distribution in enamel was concentrated at along the palatal surface and cervical region of enamel in group P1, P2 and P3. However, VMS distribution in enamel was concentrated at along the palatal surface including palatal cusp, cervical region and occlusal loading area of group C. Also, VMS was concentrated along palatal part of coronal dentin and also extending coronal 1/3 part of root dentin both in all groups. Additionally, VMS was concentrated at occlusal loading area of endocrown, along the palatal surface of endocrown extending coronal 1/3 of central retainer in group P1, P2 and P3 (Fig. 4).

When oblique forces were applied, VMS, maximum principle and minimum principle stress values in enamel and dentin were same in group P1, P2 and P3 and they were higher than group C. Additionally, VMS values in PEEK and composite parts of endocrowns were found lowest in group P1 and highest in group P3 (Table 4).

Table 3. Maximum values of von Mises stress, maximum principle stress, minimum principle stress in enamel, dentin and restorative material under vertical forces (MPa)

Group	Enamel			Dentine			Restorative Material		
	Von Mises	Maximum principle	Minimum principle	Von Mises	Maximum principle	Minimum principle	Von Mises	Maximum principle	Minimum principle
Control	46.32	11.52	-0.29	11.65	3.91	-0.41			
P1	52.28	26.58	1.02	13.09	5.23	4.12	PE:13.89	PE:2.32	PE:-0.06
							CO:29.56	CO:3.49	CO:0.46
P2	52.28	26.58	1.02	13.09	5.23	4.12	PE:16.11	PE:4.44	PE:-0.16
							CO:31.04	CO:4.15	CO:0.52
P3	52.28	26.58	1.02	13.09	5.23	4.12	PE:16.18	PE:5.09	PE:-0.24
							CO:32.53	CO:4.76	CO:0.67
*PE: Peek, CO: Composite									

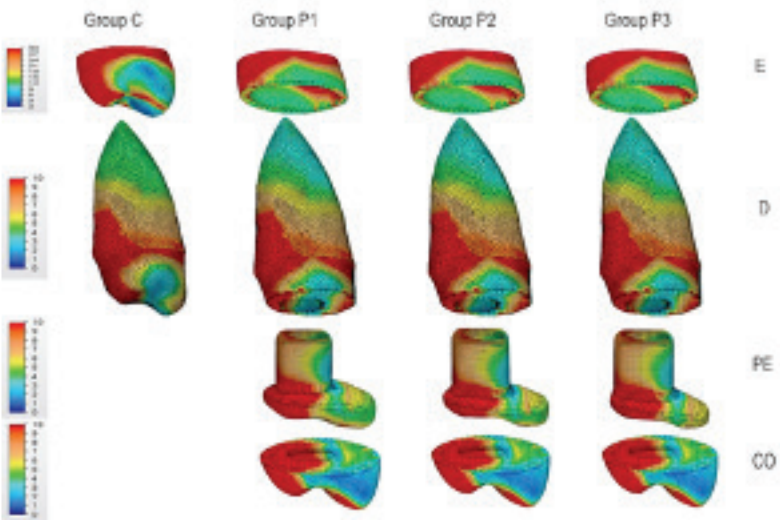

Fig. 4. Von Mises stress distributions in Control Group, Group P1, P2 and P3 under oblique load

Table 4. Maximum values of von Mises stress, maximum principle stress, minimum principle stress in enamel, dentin and restorative material under oblique forces (MPa)

Group	Enamel			Dentine			Restorative Material		
	Von Mises	Maximum principle	Minimum principle	Von Mises	Maximum principle	Minimum principle	Von Mises	Maximum principle	Minimum principle
Control	138.73	33.25	7.41	63.08	12.76	5.45			
P1	141.36	35.14	10.54	67.21	16.13	7.76	PE:37.44	PE:7.29	PE:0.10
							CO:106.69	CO:10.49	CO:0.65
P2	141.36	35.14	10.54	67.21	16.13	7.76	PE:44.32	PE:9.45	PE:0.13
							CO:116.37	CO:12.32	CO:0.74
P3	141.36	35.14	10.54	67.21	16.13	7.76	PE:44.73	PE:10.21	PE:0.19
							CO:117.67	CO:12.65	CO:0.86
*PE: Peek, CO: Composite									

DİSCUSSİON

As a result of the study, the hypothesis was accepted as the thickness of the PEEK and indirect composite material didn't affect the stress distribution and values on endodontically treated teeth's enamel and dentin.

Due to in vivo studies have increased risks, costs and some ethical problems, in vitro studies with mathematical models and 3D analysis are widely using by researchers.[26-29] Stress concentrations on materials are depended on loading conditions, geometry of the material and intrinsic or extrinsic flaws.[29-31] It has been stated that restorative materials' elastic modulus has more effect on stress concentrations than material's thickness.[32] In this study, supportingly to the literature,[32] thicknesses of PEEK and indirect composite resin materials didn't affect stress values and distributions in enamel and dentin.

The stress values in teeth are related to elastic modulus of the restorative materials.[33] In a finite element analysis study, Costa et al.[34] stated that, as the elastic modulus of the composite resin material is lower than the elastic modulus of enamel and dentin, tensile stresses was concentrated and transmited to the tooth structures. In addition, Desai and Das[35] also reported that restorative materials with low elastic modulus, transferred a higher concentration of stress to the tooth structure. Dejak et al.[36] stated that, dentin VMS levels in teeth with an endocrown were smaller than the intact mandibular molar tooth. They also acknowledged that rigid ceramic endocrowns fabricated from leucite-reinforced ceramics with elasticity modulus of 65 GPa rein-force tooth structures. However, in our study, opposing to supportingly to other studies,[34-36] stress levels both in enamel and dentin were higher in intact maxillary premolar tooth than endocrown restored teeth. It is probably due to, elastic modulus of PEEK (3.5 GPa) and indirect composite resin (4.85 GPa) materials that were used in this study were lower than both enamel (84.10 GPa) and dentin (14.60 GPa).

The materials which had higher elasticity modulus have a tendency to transfer stresses to the deeper parts of the root. The materials that transfer higher amount of stress to the tooth structure can cause detrimental effects such as fractures of crown and root.[29-31] In this study, supportingly to other studies,[29-31] stress weren't transfered to deeper parts of root and VMS distributions were concentrated in the coronal 1/3 part of root dentin.

In addition, it was reported that, the clinical performance of premolars restored with endocrowns were is lower than endocrown-restored molars and main reason for failure in endocrown-restored premolar was cohesive failure of bonding.[37] Due to, endocrown-restored premolar teeth showed higher tendency to adhesive failure than molar teeth, premolar tooth was used in this study to investigate border cases.

Due to the knowledge that direction of forces may influence the stress/strain distributions of teeth,[38] and application 200 N was considered as an imitation of physiologic conditions in maxillary premolar area[17,18] 200 N force with different directions (vertical and oblique) were applied in this study.[16] In this study, similar to Zhu et al.[16] VMS values were higher in oblique loads than vertical loads in all groups. It was due to the intensities of oblique and vertical forces were not equal in this study. In vertical loading, 200 N force was decomposed into 2 part and applied to buccal and palatal cusps seperately, while in oblique loading resultant forces of 200 N applied to palatal cusp.[16]

The thickness of the occlusal part of the ceramic endocrowns is generally 3-7 mm. It was showed in an in vitro study that the fracture resistance of ceramic crowns increases when occlusal thickness of material increases.[39] On the other hand, when the thickness of endocrown material increases, the less tooth structures preserve during endocrown preparation and it would increase the risk of future catastrophic tooth fracture.[16] Furthermore, in a FEA study, it was stated that, the maxillary premolar teeth that was restored with 3 mm thickness endocrown material had lower von Mises strain values in cement layer than endocrowns with 1 and 2 mm thicknesses. As a consequence, an endocrown with 3 mm occlusal thickness may be more difficultly dislodged.[16] In the present study, an endocrown with 3 mm occlusal thickness was designed to preserve tooth structure and increase retention of endocrown.

There were some limitations in this study. Firstly, FEA can only analyze stress distribution under static loading and static load was analysed in this study. But, teeth are subjected to fatigue loading in chewing system.[16] Secondly, a single type of endocrown material was used in this study. Therefore, further studies under fatigue analysis are recommended and adhesive failure of different endocrown materials should be investigated with mechanical tests. However the results of this study may help clinicians ideal thickness of PEEK or indirect composite materials.

CONCLUSION

Within the limitations of this study, it was concluded that;

1. When vertical/ oblique forces were applied, VMS values in enamel and dentin were higher in study groups than sound teeth.
2. Different thickness of indirect composite resin and PEEK materials didn't affect VMS values and distributions in enamel and dentin.
3. The lowest Von Mises in restorative material were found in a study group with 2 mm PEEK substructure and 1 mm indirect veneering composite resin thickness.
4. VMS values were higher and VMS distributions were different in oblique loads than vertical loads.

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Conflict of Interest

The authors declare that there is no conflict of interest.

*This in vitro study didn't involve any human participant, tissue, biomaterial and personal data. Therefore, ethical committee approval didn't required in this study.

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