RESEARCH

Stress distribution in endodontically treated maxillary central incisor restored with different post and crown materials

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Farklı post ve kron materyalleri ile restore edilmiş endodontik tedavili maksiller santral kesici dişlerde stres dağılımı

Amaç: Yapılarında meydana gelebilecek kırılmalardan dolayı endodontik olarak tedavi görmüş dişlerin restorasyonu restoratif diş hekimliğinde yaygın bir problemdir. Oklüzal kuvvetlere dayanabilecek uygun post ve kron materyalinin seçilmesi gereklidir. Bu çalışmanın amacı sonlu elemanlar stres analiz yöntemi kullanarak farklı post ve kron materyallerinin diş restorasyon kompleksindeki stres dağılımını incelemektir.

Gereç ve Yöntemler: 2 farklı post materyali (everStick ve cosmopost) ve 2 farklı kron materyali (IPS Empress e.max ve Cercon) içeren endodontik olarak tedavi edilmiş maksiler santral kesici dişi simüle eden 3-boyutlu sonlu elemanlar modelleri hazırlanmıştır. Sonlu elemanlar modellerinde kök yüzeyindeki tüm noktalar sınır koşulları olarak sabit kabul edilmiştir. 300N'luk statik oklüzal yük kronun palatal yüzeyine 135°'lik bir açıyla uygulanmıştır. Modellerin stres transfer karakteristiklerindeki farklılıklar analiz edilmiştir.

Bulgular: Bütün modellerde maksimum stres kuvvet uygulanan alanlarda konsantre olmuştur (10MPa). Cosmopost'ta gözlenen maksimum stresler (2.5MPa) everStick'de gözlenenlerden (1.6 MPa) daha yüksek bulunmuştur. Cercon ve e.max kronların her ikisi için de maksimum stresler kronun bukkal ve lingual marjinlerinde yoğunlaşmıştır (5.8 MPa, 5.0 MPa). Fakat e.max'deki stres değer ve dağılımları Cercon kronla karşılaştırıldığında daha homojen ve daha düşük bulunmuştur.

Sonuç: Bu çalışmanın sonuçlarına göre endodontik tedavili bir dişe everStick post uygulanarak e.max seramik ile restore edildiğinde restorasyon-diş kompleksindeki von Mises stresleri azalmaktadır.

KEY WORDS

Post-kor, sonlu elemanlar stres analizi, dental kron

Restoration of maxillary anterior teeth presents a great challenge in everyday practice of dental practice of dental clinicians. Despite many developments in materials and techniques patients' demand for improved aesthetics, function and longevity of such restoration drives researchers and practitioners to make further developments. This challenge is even greater in cases where there is massive tooth damage, due to caries or trauma, because a damaged tooth possesses less resistance to fracture due to a reduction in the number of cross-linked collagen fibres and a loss of moisture within the tooth (Gutmann 1992). In such cases, there is often a need to compensate for the lack of tooth substance by additional restoration, which is achieved by placing a post and core in a root canal of the tooth (Morgano 1996).

A dental post is useful for building up and thereby retaining coronal restoration, but the post does not reinforce the root of the tooth (Caputo and Standlee 1976). Moreover,

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some authors assert that posts may interfere with the mechanical resistance of a root-treated tooth, leading to an increased risk of damage to the remaining tooth structure (Sornkul and Stannard 1992, Akkayan and Gülmez 2002). To date, there is no consensus about the ideal material or technique for restoring root-treated teeth (Hudis and Goldstein 1986, Creugers et al. 1993, Ortega et al. 2004).

Posts can be divided into two categories: custom-made posts and cores and pre fabricated posts, primarily with composite core. Prefabricated posts are divided into two groups: metallic, such as titanium alloy posts, and non-metallic, such as zirconia ceramic, glass fiber-reinforced composite and glass-ceramic posts (Toksavul et al. 2006).

The prefabricated post and core system is one of the most popular systems, because it is less time consuming (Shilllingburg et al. 1997b). In this system, the root canal is prepared by using drills that have the same diameter as posts. Thus, the perfect fit of the post t the root canal achieved. This increases the fracture resistance of endodontically treated teeth (Sorensen and Engelman 1990a). In addition, it was reported that cast posts showed lower fracture resistance compared to prefabricated posts due to weakening of the posts during the casting process (Heydecke et al. 2002).

The use of all-ceramic restorations has increased considerably due to rising esthetic demands. The application of an all-ceramic crown after insertion of a metallic post and core compromises the esthetic appearance of the all ceramic crown. In this respect, several tooth colored post and core systems, as mentioned above, have been used. These systems have improved the esthetics of teeth restored with posts and cores. In addition, zirconia ceramic can offer superior strength compared to other post materials. In the zirconia ceramic post system, two different core materials, composite and zirconia enriched glass-ceramic are being used. The use of zirconia ceramic post with composite core simplifies the restorative procedure, because all steps can be completed chairside (Toksavul et al. 2006).

Finite element analysis (FEA) is a popular numerical method in stress analysis. FEA shows the internal stresses and, on that basis, predictions about failure can be made. The effect of post design (Sorensen and Martinoff 1984), post material (Ukon et al. 2000) and core material (Combe et al. 1999) is very important on dentinal stress distribution. Therefore, this study compared the dentinal stress distribution of 3-D finite element (FE) models of maxillary central incisors restored with 2 different post materials (everaStick and cosmopost) and 2 different all-ceramic crown materials (IPS Empress e.max and Cercon). The null hypothesis was that different post and crown materials do not affect the stress distribution within endodontically treated teeth.

MATERIAL AND METHODS

The study was conducted using a three-dimensional FEM and FE structural analysis program (Solid works Corporation, USA). A three-dimensional FE model was fabricated to represent an endodontically treated maxillary central incisor restored with an all-ceramic crown restoration. The geometry used for the tooth model was previously described by Wheeler (Wheeler 2003). On the basis of the root-form geometry of teeth, approximately 3mm gutta-percha apical seal were developed (Tada et al. 2003).

The post systems modeled for analysis were a glass fiber reinforced (everStick; StickTech, Turku, Finland), and a zirconium oxide ceramic (Cosmopost; Ivoclar Vivadent Schaan Liechteinstein) post materials. The core material modeled was composite resin (Biscore; Bisco, Vancouver, Canada). Two different ceramics (IPS e.max Press, Ivoclar Vivadent AG; Cercon, DeguDent GmbH Hanau Wolfgang Germany) were simulated as the final crown material.

An average occlusal force of 300N was determined from the literature (Eskitaşçıoğlu et al. 2004). Static occlusal load was applied from the palatal surface of the crown in a 135° angle to the tooth long axis. The nodes of the root surface in the FE models were fixed in all directions as the boundary condition (Figure 1a).

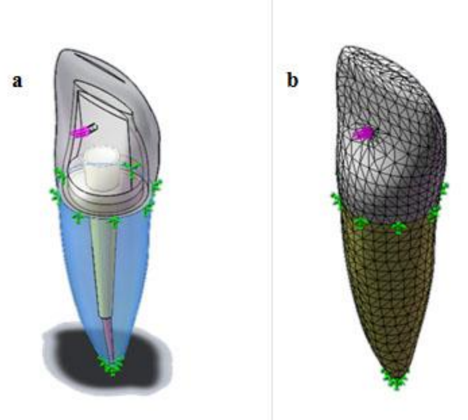

Figure 1.

a Three-dimensional FE model and illustration of materials involved, pink arrows represent the load application, and green arrows and blue area is assumed as fixed as boundary condition. **b** Three dimensional mesh and material arrangement of FE model.

Each mathematical model included approximately 54464 nodes and 39360 tetrahedral solid elements (Figure 1b). Materials used in study were assumed as homogenous and isotropic. The elastic properties of the materials (Young's modulus [E] and Poisson's ratio [ɥ]) were determined from the literature and provided in Table 1 and 2. Results are presented by considering von Mises criteria (Akça and Iplikçioğlu 2001, Beer and J ohnston 1993, Timoshenko and Young 1968, Ugural and Fenster 1995, Yang et al. 2001). A convenient way of reporting the stresses is in the form of a color representation of the stress distributions (Asmussen et al. 2005). Calculated numeric data were transformed into color graphics to better visualize mechanical phenomena in the models.

Table 1.

Mechanical properties of orthotropic material (Lanza et al. 2005)

Properties	Glass Fiber post
Ex (MPa)	37000
Ey (MPa)	9500
Ez (MPa)	9500
Vxy	0,27
Vxz	0,34
Vyz	0,27
Gxy	3100
Gxz	3500
Gyz	3100

The FEM results are presented as stresses distributed in the investigated structures. These stresses may occur as tensile, compressive, shear or a stress combination known as equivalent von Mises stresses. Von Mises stresses depend on the entire stress field and are a widely used indicator of the possibility of damage occurrence (Pegoretti et al. 2002, Pierrisnard et al. 2002). As compressive strength of dentin is considerably higher than tensile strength, calculated tensile and von Mises stresses may be compared with the tensile strength of dentin to assess the risk of fracture (Asmussen et al. 2005). Thus, von Mises stresses were chosen for presentation of results.

Table 2.

Mechanical properties of investigated materials (Reinhardt et al. 1983)

Material	Elastic modulus (*E*; GPa)	Poisson's ratio (ɥ)
IPS e.max core*	95	0.24
IPS e.max veneer*	65	0.24
Cercon*	210	0.3
Zirconium oxide ceramic post (Christel et al. 1989)	200	0.33
Glass fiber-reinforced post (Christel et al. 1989)	42178	0.32
Composite core	12	0.30
(Ausiello et al. 2002)		
Dentin (Reinhardt et al. 1983)	42173	0.31
Gutta-percha	0.00069	0.45

*Acquired from manufacturers

RESULTS

The maximum stress values are presented as color figures. In Cercon models the maximum von Mises stresses were primarily located at the force application areas for both post systems (everStick and cosmopost) (10MPa) (Figure 2). Maximum dentin stress values were observed at buccal cervical preparation margins for both models (5.8MPa) (Figure3). In addition stresses were progressively increased from outer to the inner part of the root for cosmopost.

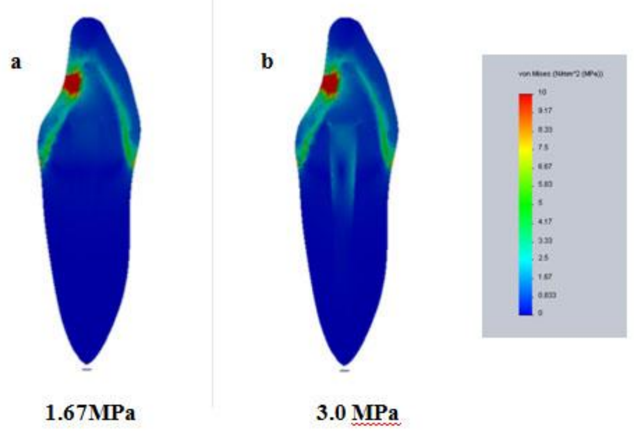

Figure 2.

Distribution of von Mises stresses (MPa) in Cercon models, **a** everStick post, **b** cosmopost.
Dark blue to red colors represent stress values from lower to higher, respectively.

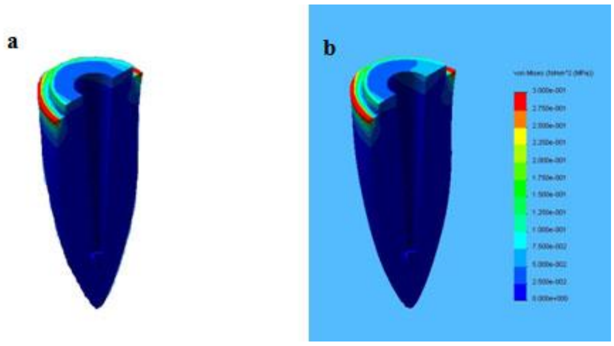

Figure 3.

Distribution of von Mises stresses (MPa) at dentin tissue in bucco-lingual section of Cercon models,
a everStick post, **b** cosmopost.
Dark blue to red colors represent stress values from lower to higher, respectively.

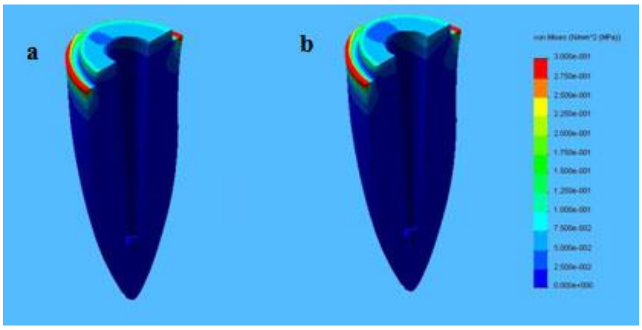

Figure 5.

Distribution of von Mises stresses (MPa) at dentin tissue in bucco-lingual section of e.max models,
a everStick post, **b** cosmopost.
Dark blue to red colors represent stress values from lower to higher, respectively.

In e.max models, maximum stress was concentrated on force application areas for both post systems (everStick and cosmopost) as cercon models (10MPa) (Figure 4,5). The stress values observed with cosmopost (2.5MPa) were higher than that of everstick (1.6MPa) for both e.max and cercon models. The stress values and distribution in e.max were more homogeneous and lower than Cercon crown (5.0MPa) . Both stress values and its localization were different between the two evaluated types of post systems. Furthermore, when the zirconium oxide ceramic and glass fiber-reinforced post system were compared, von Mises stresses at the dentin tissue were smaller for the glass fiber-reinforced post system.

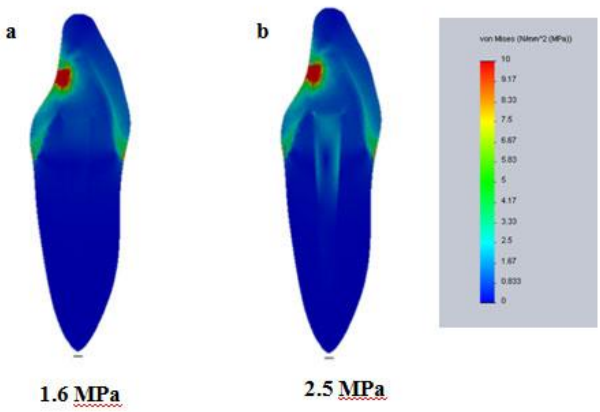

Figure 4.

Distribution of von Mises stresses (MPa) in e.max models,
a everStick post, **b** cosmopost.
Dark blue to red colors represent stress values from lower to higher, respectively.

DISCUSSION

According to the results of the present study, the level of stress and concentration areas influenced both the mechanical properties of crown and post materials.. Based on these results, the null hypothesis that different post and crown materials do not affect the stress distribution within endodontically treated teeth was rejected.

Because of the vast degree of variance in human tooth sizes, a maxillary central incisor believed to represent an avarage size was adapted from Wheeler (1962). The maxillary central incisor was selected because of its likehood of being subjected to oblique occlusal stresses. The principal stresses are, in fact, normal stresses that act on principal planes on which the shearing stresses are zero. The reason for selecting the von Mises criteria, which apparently results in a tensile type normal stress, lies in fact that brittle materials, of which the tooth is a member, fail primarily due to tensile-type normal stresses.

FEM is a basic research tool that is widely being used in dentistry. When FE modeling is compared with laboratory testing, it offers several advantages. The variables can be changed easily, simulation can be performed without the need for human material and it offers maximum standardization (Toksavul et al. 2006). On the other hand, FEM has several limitations. The structures in the model were all assumed to be homogeneous and isotropic and to possess linear elasticity. The properties of the materials modeled in this study, particularly the living tissues, however, are different (Eskitaşçıoğlu et al. 2004). In addition, the stress distribution patterns simulated may be different depending on the materials and properties assigned to each layer of the model and the model used in the experiments. Thus, the inherent limitations in this study should be considered. Clinical experience indicates that most fractures in prosthodontic restorations occur after several years (Kishen 2006). Generally, such failures are unrelated to episodes of acute overload, but result from fatigue failure (Kishen 2006). The absence of fatigue loading is another limitation of the study.

The fracture resistance of post and core restored teeth has been subject of numerous in vitro and in vivo studies (Asmussen et al. 2005, Zhi-Yue and Yu-Xing 2003). Because of the lage variability of the results obtained in vitro studies, an increasing number of invetigations of post and core restored teeth are based on FE analysis (Asmussen et al.2005). The FEM has been used in several previous investigations of the stresses generated in endodontically treated, post and core restored teeth and has been shown to be a useful tool when investigating complex systems that are difficult to standardize in vitro and in vivo (Asmussen et al 2005, Assif et al. 1989,Eskitaşçıoğlu et al. 2002, Kishen 2006, Pegoretti et al. 2002). In addition, the FEM does not result in variability of the results and is restricted by the number of nodules and elements used in the model and the elastic constants attributed to the elements (Asmussen et al. 2005).

Boschian et al. (2006) emphasized the effect of elastic modulus of the post material on stresses transferred to tooth structures as another factor. They reported that post materials that have higher elastic modulus than dentin are capable of causing dangerous and non-homogenous stresses in root dentin. That study concluded that the configuration that best preserves the integrity of the root, post, and core unit is when fiber posts are used for restoration (Boschian et al. 2006). Current study confirmed them with lower stress values at dentin structure by use of fiber post. Zirconium oxide ceramic posts that have a greater elastic modulus than glass fiber-reinforced post system produced slightly higher dentin stress values. This was pronounced at the dentin surface adjacent to the post. The higher elastic modulus of zirconium oxide ceramic post than other tooth structures could be the reason of higher stress values. Furthermore, high stress values were observed at the post material with the zirconium oxide ceramic post system. It is known that, when force is applied to composite or layered materials, stresses tend to maximize within the material with the highest elastic modulus (Eskitaşçıoğlu et al. 2002). Therefore, the stresses were more concentrated in the zirconium oxide ceramic post model, as it has a higher elastic modulus than other structures. This finding was in agreement with the study by Eskitaşçıoğlu et al. (2002). The authors reported that stresses accumulated along the cast post and core system that has a high elastic modulus, and with the fiber post-core system (relatively low elastic modulus), stress accumulated along the cervical region of the tooth and the buccal bone. In addition, stresses located at the dentin may influence the risk of root fracture, and stresses located at post/dentin interface may influence the risk of loss of post retention. Thus, every effort should be to reduce these stresses. Again, in agreement with Eskitaşçıoğlu et al. (2002), using restorative materials of elastic modulus close to dentin rather than materials of high elastic modulus may create a mechanically homogenous unit.

The FE model created for this study was a multilayered complex structure involving an all-ceramic crown, a post and core restored, endodontically treated maxillary central incisor. It is important to note that the stress after loading may be influenced greatly by the materials and properties assigned to each material.

As with many in vitro studies, it is difficult to extrapolate the results of this study directly to a clinical situation. Further studies that beter simulate the oral environment and including fatigue loading and different post and porcelain systems are reccommended. Also, the effect of cement layer was neglected in this study. However, a previously reported study revealed that the cement with elastic modulus similar to dentin could reinforce weakened root and reduce the stress in dentin (Li et al. 2006). This was one of the limitations of this study that thin cement layer was not designed.

Conclusions

Within the limitations of this theoretical study, the following conclusions were drawn:

1. Glass fiber reinforced post (everstick) revealed more less and balanced stress distribution than zirconium oxide ceramic post (cosmopost).

2. The physical properties of posts were important on stress distributions in post and crown applications.

3. Both Cercon and e-max crown models maximum stress were localized at the force application areas for both post systems (everstick and cosmopost).

Stress distribution in endodontically treated maxillary central incisor restored with different post and crown materials

Background: Restoration of endodontically treated teeth is a common problem in restorative dentistry, related to the fractures occurring in such teeth. It is necessary to obtain appropriate post and crown material to withstand occlusal forces. The aim of this study was to evaluate the influence of different post and crown materials on the stress distribution of the restoration tooth complex, using Finite Element Analysis (FEM).

Methods: 3-D finite element (FE) models simulating an endodontically treated maxillary central incisor restored with 2 different post materials (everstick and cosmopost) and two different all-ceramic crown materials (IPS Empress e.max and Cercon) were prepared. The nodes of the root surfacein the FE models were fixed in all directions as the boundary conditions. A 300 N static load was applied to the palatal surface of the crown with a 135°angle to the long axis of the tooth. The differences in stress transfer characteristics of the models were analyzed.

Results: Maximum stress was concentrated on force application areas for all models (10 MPa). The stress values observed with cosmopost (2.5 MPa) were higher than that of everstick (1.6 MPa). Maximum stresses were observed at buccal and lingual cervical margins of crown for both Cercon and e.max crowns (5.8 MPa, 5.0 MPa). But the stress values and distribution in e.max were more homogeneous and lower than Cercon crown.

Conclusion: The result of this study demonstrated that use of an everstick post in endodontically treated teeth restored with e.max ceramic reduces the values of von Mises stresses on tooth-restoration complex.

KEYWORDS

Dental crown, finite element analysis, post-core

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