The stress distribution within dentin upon the use of different restoration materials

Mohammed Bakhit, BDS, Daizo Okada, DDS, PhD, Siyang Luo, DDS, PhD, Chiharu Shin, DDS, PhD, Reiko Ogura, DDS, PhD, Wataru Komada, DDS, PhD, and Hiroyuki Miura, DDS, PhD

Fixed Prosthodontics, Department of Restorative Science, Graduate School, Tokyo Medical and Dental University, Tokyo, Japan

Purpose: High flexibility makes polyetheretherketone (PEEK) attractive for use as a restoration material. The aim of this study was to evaluate the stress distribution within a root for five types of restoration materials.
Materials and Methods: A three-dimensional root canal-treated premolar finite element model was fabricated, and the model was reconstructed with five restoration materials. A 100-N occlusal force was loaded 45° to the long axis, and the stress was calculated.
Results: The magnitudes of the stress surrounding the cervical area for the palladium-silver-gold alloy, hybrid resin composite, zirconia, all ceramic, and PEEK materials were 22.7, 21.0, 22.2, 22.2, and 18.4 MPa, respectively. The magnitudes of the stress surrounding the base of the posts were 6.5, 8.8, 5.9, 6.4, and 14.6 MPa, respectively.
Conclusion: The restoration fabricated using PEEK prevented stress from occurring at the marginal area of the dentin; however, PEEK increased the stress at the base of the post to a greater degree than the other restoration materials.

(Asian Pac J Dent 2017; 17: 41-47.)
Key Words: stress distribution, von Mises stress, Young's modulus

Introduction

Various materials are used as restorations to restore decayed teeth. Metals or porcelain fused with metals are example of materials used in restorations. Full metal restorations have often been used in the premolar and molar regions due to their good strength, reliability, and adaptability; however, full metal restorations are not esthetically pleasing. Therefore, porcelain fused to metal restorations or hybrid resin composites are used instead of full metal restorations to satisfy aesthetic demands in the premolar and molar regions. Porcelain fused to metal restorations exhibit good mechanical strength, are abrasion resistant, and have good biocompatibility; however, the equipment needed is expensive, and these restorations requires much skill to fabricate. Hybrid resin composites are easier to fabricate than porcelain fused to metal restorations, but they are less abrasion resistant and have poorer mechanical strength. The Young's modulus of most of these materials is the same or higher than that of dentin. The differences between the value of a material and dentin may influence the stress distribution around the marginal area of a restoration, which can lead to secondary caries. Wedge-shaped defects are often found at the cervical area of natural teeth and restorations; this defect may also be caused by the concentration of stress at the cervical area of dentin. Secondary caries often cause restoration dislocations and may be related to the concentration of stress around the marginal area, the adaptability of a restoration and the elution of a luting agent.

Polyetheretherketone (PEEK), which is derived from polyaryletherketone, has both good chemical stability and biocompatibility. PEEK was developed three decades ago and is used in medicine, dentistry, and other industries [1-10]. PEEK is a crystalline thermoplastic polymer and an aromatic polyether that displays very good biological and mechanical properties. Thus, PEEK is a good candidate for the clasps used in removable partial dentures, abutments, and implants because it exhibits high strength and fatigue tolerance and is impact resistant. In addition, PEEK also has good thermostability and creep behavior, and it more naturally resembles normal tooth colors than do other restoration materials. In addition, PEEK can be used for patients suffering from metal allergies because it releases less metallic ions than other materials [2,4,5,7-12].

Moreover, PEEK is more flexible than other materials, and restorations made from PEEK may prevent stress from occurring in the marginal areas of dentin; however, PEEK restorations may also enhance the stress at the other part of root because of its higher flexibility [12]. The aim of this study was to evaluate the stress distribution within a root induced by five different types of restoration materials, including PEEK.

Materials and Methods

A three-dimensional finite element model was fabricated on a personal computer using finite element structural analysis software (MSC Marc Mentat 2003, MSC Software Corp., Santa Ana, CA, USA), as per previous reports [13-15]. The model was assumed to contain endodontically treated premolar teeth. The teeth in our model were 18 mm long, and the cervical area was 6 mm in diameter. The root of this model was 12 mm long and was surrounded by periodontal ligaments and lamina dura, whose thicknesses were 0.2 and 0.3 mm, respectively. The coronal part of this finite element model was assumed to be 6 mm tall. The finite tooth model was surrounded by two types of bone: cortical bone and cancellous bone Fig. 1.

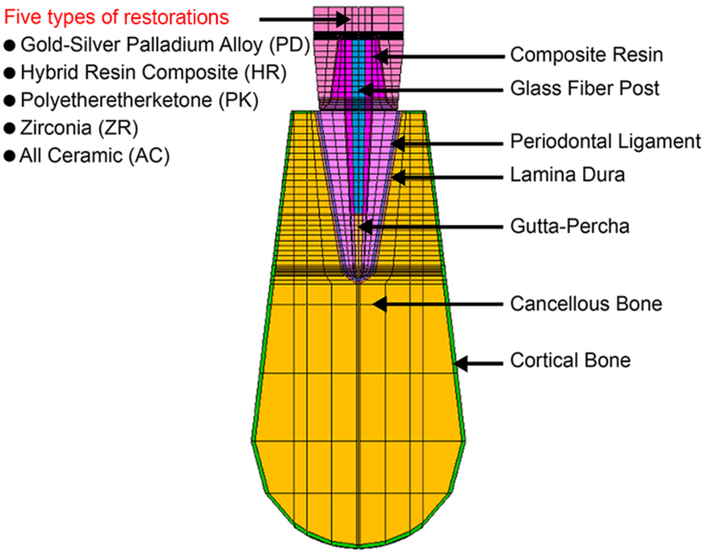

Fig. 1 Finite element model

Table 1 Mechanical properties of the materials

	Young's modulus (MPa)	Poisson's ratio	Reference
Dentin	15,000	0.31	[15,16]
Periodontal ligament	10	0.49	[17]
Lamina dura	13,700	0.30	[15,18]
Cancellous bone	345	0.31	[15,16]
Cortical bone	13,700	0.30	[15,18]
Gutta-percha	0.69	0.45	[15,19]
Composite resin core	12,000	0.33	[15,20]
Glass fiber post	29,200	0.30	[15,21]
Luting agent	8,000	0.33	[22]
Palladium-silver-gold alloy	86,000	0.33	[23]
Hybrid resin composite	21,000	0.27	[17]
Polyetheretherketone	4,100	0.40	[24]
Zirconia	205,000	0.19	[22]
Ceramics	95,000	0.24	[25]

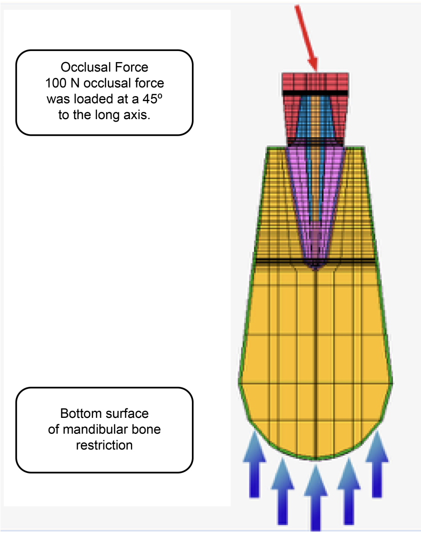

Fig. 2 Three-dimensional occlusal force with bottom surface of mandibular restriction

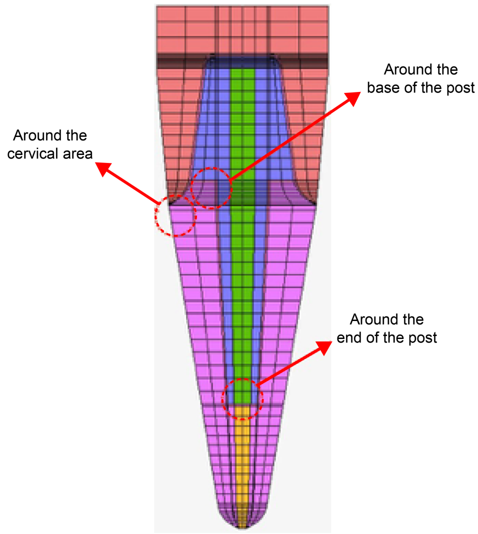

Fig. 3 The three dentin analysis points

The post and core system was assumed to be that of a composite resin composed of a glass fiber post, which was 8 mm long. The height of the ferule was assumed to be 2 mm, and five restoration materials (palladium-silver-gold alloy (PD), hybrid resin composite (HR), zirconia (ZR), all ceramic (AC), and PEEK (PK)) were applied to each model. The material properties of each element are shown in Table 1 [15-25].

In all models, an occlusal force of 100 N was applied at the center of the occlusal surface, and the direction of this force was 45° to the long axis. The bottom of the mandibular bone was restricted, as shown in Fig. 2. In this study, three different analysis points were used, as shown in Fig. 3: the cervical area of the dentin, the base of the post, and the end of the post. Following this analysis, the magnitude of the von Mises stress distribution was calculated.

Results

Figures 4, 5, and 6 show the stress distribution from the mesiodistal direction and under the loading force of 100 N at the center of the occlusal surface, while Table 2 presents the magnitude of the stress distribution for each material at each analysis point. The magnitude of the stress concentration at the cervical area of the dentin was calculated for each analysis point. PD had the highest stress concentration, whereas PK showed the lowest stress concentration. However, at the base of the post, PK had the highest stress concentration, whereas ZR had the lowest stress concentration.

Meanwhile, at the end of the post, there were no differences in the magnitude of stress, suggesting that the type of restoration material did not affect the magnitude of the stress concentration at the dentin around the end of the post. Table 2 shows that the Young's modulus of PK is much lower than that of the other restoration materials, which means that PK is highly flexible and can readily deform during use.

Discussion

Various experimental methods are used in dentistry to analyze stress distribution in teeth. One of these methods is finite element analysis, the application of which has grown considerably among clinicians, technicians, and other medical professionals [13,26]. Finite element analysis has many advantages over the conventional experimental methods, such as the tooth fracture test or photo elastic method. The advantages of this technique include the following; a) ability to observe any cross-sectional plane, b) ability to evaluate the magnitude of stress at any analysis point, and c) ability to observe or analyze the inside of the root. Additional advantages of this approach over conventional experimental methods include time, cost, possibility for modification, and repetition [13,19,25-30].

In this study, a 3-dimensional finite element analysis of endodontically treated premolar teeth was fabricated to evaluate the stress distribution within the dentin, particularly in the cervical area of the dentin. Secondary caries can be caused by inadequate adaptation of the restoration, thickness of the luting agent, and dissolution of the luting agent. Related to secondary caries is the stress in the marginal area, where the teeth perform several functions. The occurrence of wedge-shaped defects, which can be observed in the cervical area of natural teeth or restoration, is also related to the stress in the cervical area of the dentin. Therefore, this study focuses on stress concentrations.

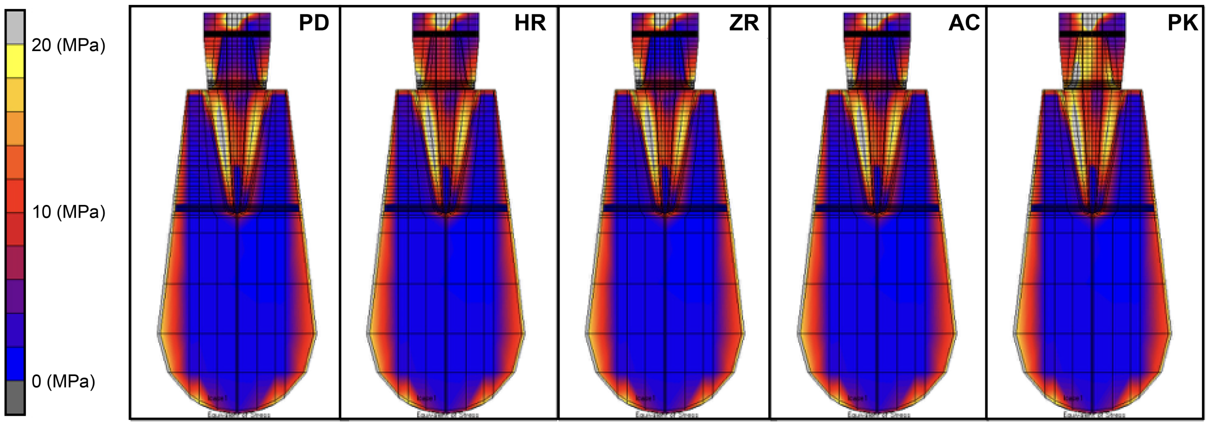

Fig. 4 The stress distribution (frontal plane)

Table 2 Magnitude of von Mises stresses for each material at each analysis point by finite element analysis (MPa)

	PD	HR	ZR	AC	PK
Cervical area	22.7	21.0	22.2	22.2	18.4
Base of the post	6.5	8.8	5.9	6.4	14.6
End of the post	6.8	6.8	6.8	6.8	6.8

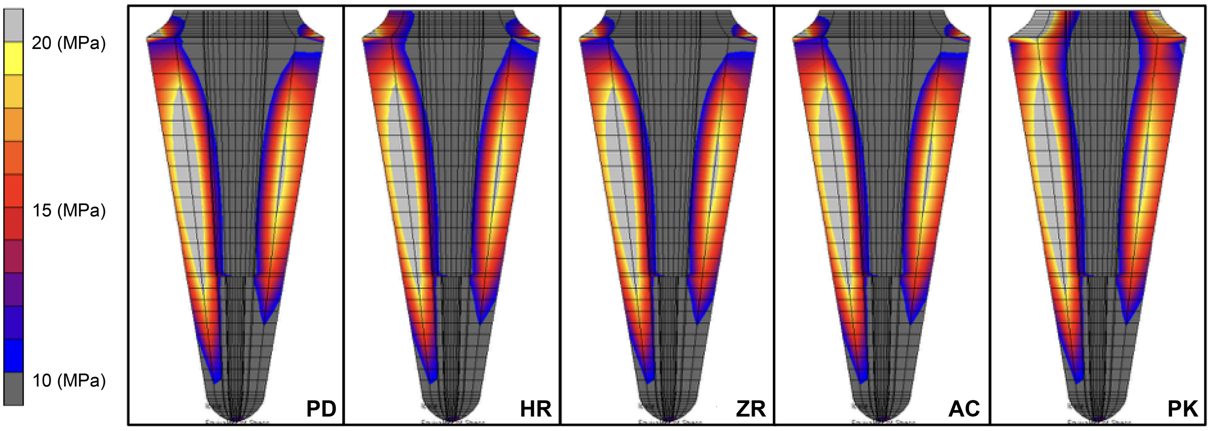

Fig. 5 The stress distribution within the dentin root (frontal plane)

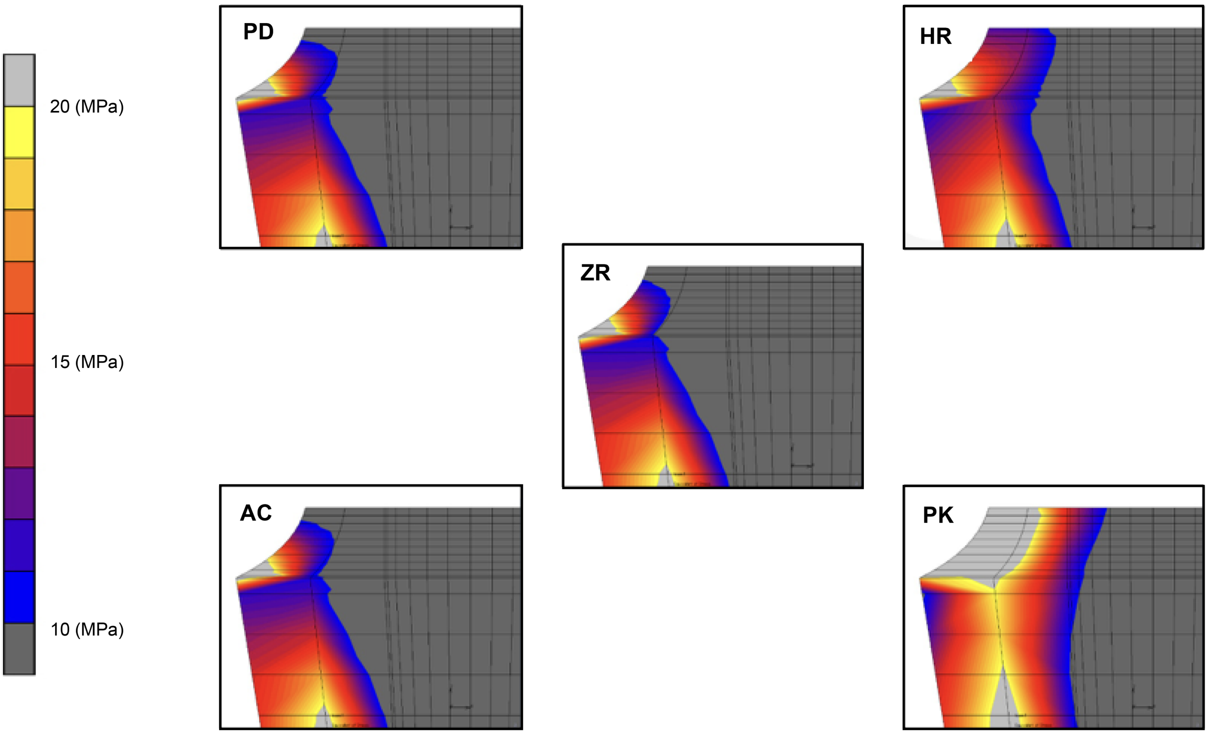

Fig. 6 The stress distribution within the cervical area of the dentin (frontal plane)

During restoration, the post and core system influences the stress concentration in the cervical area of the dentin. When a cast post and core system is applied to the endodontically treated teeth, the stress is concentrated at the end of the post, which can lead to a fatal vertical root fracture. In contrast, the composite resin core with a glass fiber post concentrates less stress at the end of the post. Therefore, the composite resin core with the glass fiber post is applied to all models in the present study because this post and core system prevents the occurrence of fatal vertical root fractures [14,31,32].

In the composite resin core with a glass fiber post, stress occurs in the cervical area of the dentin, causing a horizontal root fracture in the cervical area or secondary caries to decrease the stress at the end of the post [33]. The type of restoration materials may influence the stress in the cervical area of the dentin. If the magnitude of stress depends on the restoration material, the stress may be concentrated on other parts of the dentin to reduce the stress in the cervical area of the restoration. Therefore, we evaluated the stress at the base of the post, the end of the post, and the cervical area of the dentin.

In all models, a 100 N occlusal force was applied at a 45˚ angle to the long axis of the tooth, and the bottom of the mandibular bone was restricted. The stress distribution was calculated at three different analysis points: around the cervical area of the dentin, around the base of the post, and around the end of the post for five different types of restoration material. PD, HR, ZR, and AC showed higher stress in the cervical area in the dentin than PK.

In our study, a restoration material with a high Young's modulus led to a high concentration of stress in the marginal area of the dentin. Therefore, a restoration material with a lower elastic modulus than that of the dentin may largely reduce the stress in the marginal area. Most restoration materials have an elastic modulus either higher or equal to that of dentin [30]; however, PEEK has the least elastic modulus among all traditional restoration materials considered in this study. Thus, PK was more deformed than other restorations under the same loading, and the stress was directly transmitted to the top of the composite resin core.

Meanwhile, PD, ZR, and AC produced lower stress, whereas HR produced moderate stress at the base of the post. PK resulted in the highest concentration of stress at the base of the post. Instead of reducing the stress in the marginal area, PK exhibited the highest concentration of stress. This stress was also transmitted from the top of the restoration because of the deformation of the PK restoration. Therefore, in the case of PK, the composite resin must adhere strongly to the dentin. The composite resin core and glass fiber post must exhibit high fracture strength. If the post and core system in the case of PK exhibits no sufficient adhesive properties or fracture strength, a horizontal root fracture in the cervical area may occur.

All five restoration materials displayed the same stress distribution value of 6.8 MPa at the end of the post. This finding suggests that the restoration material does not influence the stress distribution around the end of the post, which sometimes leads to a vertical root fracture. These results indicate that PD results in the highest concentration of stress in the marginal area, whereas PK exhibits the least stress among all restoration materials examined in this study. As a restoration material, PK may prevent or reduce the stress that leads to secondary caries. PK can potentially reduce secondary caries when this material is applied to the restoration.

However, in the case of PK, we have to pay attention to the adhesion strength between the dentin, composite resin, and the glass fiber post, considering the fracture strength of these materials at the base of the post. The following conclusions were drawn; 1) The restoration fabricated by PEEK prevents stress in the marginal area of dentin, and 2) PEEK enhances stress at the base of the post compared with other restoration materials, including metal, composite resin, and ceramics.

References

1. Toth JM, Wang M, Estes BT, Scifert JL, Seim 3rd HB, Turner AS. Polyetheretherketone as a biomaterial for spinal applications. Biomaterials 2006; 27: 324-34.
2. Kurtz SM, Devine JN. PEEK biomaterials in trauma, orthopedic, and spinal implants. Biomaterials 2007; 28: 4845-69.
3. Tetelman ED, Babbush CA. A new transitional abutment for immediate aesthetics and function. Implant Dent 2008; 17: 51-8.
4. Schmidlin PR, Stawarczyk B, Wieland M, Attin T, Hämmerle CH, Fischer J. Effect of different surface pre-treatments and luting materials on shear bond strength to PEEK. Dent Mater 2010; 26: 553-9.
5. Bayer S, Komor N, Kramer A, Albrecht D, Mericske-Stern R, Enkling N. Retention force of plastic clips on implant bars: a randomized controlled trial. Clin Oral Implants Res 2012; 23: 1377-84.
6. Tannous F, Steiner M, Shahin R, Kern M. Retentive forces and fatigue resistance of thermoplastic resin clasps. Dent Mater 2012; 28: 273-8.
7. Stawarczyk B, Beuer F, Wimmer T, Jahn D, Sener B, Roos M, et al. Polyetheretherketone - a suitable material for fixed dental prostheses? J Biomed Mater Res B Appl Biomater 2013; 101: 1209-16.
8. Stawarczyk B, Keul C, Beuer F, Roos M, Schmidlin PR. Tensile bond strength of veneering resins to PEEK: impact of different adhesives. Dent Mater J 2013; 32: 441-8.
9. Stawarczyk B, Eichberger M, Uhrenbacher J, Wimmer T, Edelhoff D, Schmidlin PR. Three-unit reinforced polyetheretherketone composite FDPs: influence of fabrication method on load-bearing capacity and failure types. Dent Mater J 2015; 34: 7-12.
10. Sturz CR, Faber FJ, Scheer M, Rothamel D, Neugebauer J. Effects of various chair-side surface treatment methods on dental restorative materials with respect to contact angles and surface roughness. Dent Mater J 2015; 34: 796-813.
11. Santing HJ, Meijer HJ, Raghoebar GM, Özcan M. Fracture strength and failure mode of maxillary implant-supported provisional single crowns: a comparison of composite resin crowns fabricated directly over PEEK abutments and solid titanium abutments. Clin Implant Dent Relat Res 2012; 14: 882-9.
12. Maekawa M, Kanno Z, Wada T, Hongo T, Doi H, Hanawa T, et al. Mechanical properties of orthodontic wires made of super engineering plastic. Dent Mater J 2015; 34: 114-9.
13. Wada M, Sugawara T, Hanawa T, Ohkawa S, Kondo S, Ota M. Computer simulation of cyclic creep. Dent Mater J 1984; 3: 163-9.
14. Okada D, Miura H, Suzuki C, Komada W, Shin C, Yamamoto M, et al. Stress distribution in roots restored with different types of post systems with composite resin. Dent Mater J 2008; 27: 605-11.
15. Luo S, Okada D, Bakhit M, Matsukawa K, Shin C, Ogura R, et al. Stress distribution in luting agents with different post and core systems. Asian Pac J Dent 2017; 17: 15-22.
16. Rees JS, Jacobsen PH. Elastic modulus of the periodontal ligament. Biomaterials 1997; 18: 995-9.
17. Nakamura T, Ohyama T, Waki T, Kinuta S, Wakabayashi K, Takano N, et al. Finite element analysis of fiber-reinforced fixed partial dentures. Dent Mater J 2005; 24: 275-9.
18. Borchers L, Reichart P. Three-dimensional stress distribution around a dental implant at different stages of interface development. J Dent Res 1983; 62: 155-9.
19. Asmussen E, Peutzfeldt A, Sahafi A. Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 2005; 94: 321-9.

20. Lanza A, Aversa R, Rengo S, Apicella D, Apicella A. 3D FEA of cemented steel, glass and carbon posts in a maxillary incisor. Dent Mater 2005; 21: 709-15.
21. Komada W, Miura H, Okada D, Yoshida K. Study on the fracture strength of root reconstructed with post and core: alveolar bone resorbed case. Dent Mater J 2006; 25: 177-82.
22. Rekow ED, Harsono M, Janal M, Thompson VP, Zhang G. Factorial analysis of variables influencing stress in all-ceramic crowns. Dent Mater 2006; 22: 125-32.
23. Matsuo S, Watari F, Ohata N. Fabrication of a functionally graded dental composite resin post and core by laser lithography and finite element analysis of its stress relaxation effect on tooth root. Dent Mater J 2001; 20: 257-74.
24. Schwitalla AD, Abou-Emara M, Spintig T, Lackmann J, Müller WD. Finite element analysis of the biomechanical effects of PEEK dental implants on the peri-implant bone. J Biomech 2015; 48: 1-7.
25. Belli S, Eraslan O, Eskitascioglu G, Karbhari V. Monoblocks in root canals: a finite elemental stress analysis study. Int Endod J 2011; 44: 817-26.
26. Eskitaşcioğlu G, Belli S, Kalkan M. Evaluation of two post core systems using two different methods (fracture strength test and a finite elemental stress analysis). J Endod 2002; 28: 629-33.
27. Coelho CS, Biffi JC, Silva GR, Abrahão A, Campos RE, Soares CJ. Finite element analysis of weakened roots restored with composite resin and posts. Dent Mater J 2009; 28: 671-8.
28. Chatvanitkul C, Lertchirakarn V. Stress distribution with different restorations in teeth with curved roots: a finite element analysis study. J Endod 2010; 36: 115-8.
29. Ausiello P, Franciosa P, Martorelli M, Watts DC. Mechanical behavior of post-restored upper canine teeth: a 3D FE analysis. Dent Mater 2011; 27: 1285-94.
30. Chiba A, Hatayama T, Kainose K, Nakajima M, Pashley DH, Wakabayashi N, et al. The influence of elastic moduli of core materials on shear stress distributions at the adhesive interface in resin built-up teeth. Dent Mater J 2017; 36: 95-102.
31. Ma J, Miura H, Okada D, Yusa K. Photoelastic stress analysis of endodontically treated teeth restored with different post systems: normal and alveolar bone resorption cases. Dent Mater J 2011; 30: 806-13.
32. Oshima F, Okada D, Ogura R, Shin C, Ueda Y, Inagaki T, et al. A finite element analysis of stress distribution in roots with different types of post systems. Asian Pac J Dent 2016; 16: 1-7.
33. Suzuki C, Miura H, Okada D, Komada W. Investigation of stress distribution in roots restored with different crown materials and luting agents. Dent Mater J 2008; 27: 229-36.

Correspondence to:

Dr. Daizo Okada
Fixed Prosthodontics, Department of Restorative Sciences,
Graduate School, Tokyo Medical and Dental University,
1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8549, Japan
Fax: +81-3-5803-0201 E-mail: d.okada.fpro@tmd.ac.jp

Accepted July 7, 2017.

 Online ISSN 2185-3487, Print ISSN 2185-3479