Influence of type of cement and their thickness on stress distribution at dentin-cement interface of computer-aided designed glass fiber post: A three-dimensional finite element analysis

Sonali Taneja, Pragya Kumar, Nitin Gupta, Rabab Khan
Department of Conservative Dentistry and Endodontics, I.T.S Centre for Dental Studies and Research, Ghaziabad, Uttar Pradesh, India

Abstract

Aim: This study aims to evaluate the effect of type of cement, and their thickness on stress distribution at dentin-cement interface of computer-aided designed glass fiber post using three-dimensional finite element analysis.

Materials and Methods: Nine 3D models of endodontically treated maxillary second premolar were divided into three groups according to the adhesive cement used PermaCem (Group I), Variolink II (Group II), and ParaCore (Group III). Each group was further divided into subgroup a, b, and c on the basis of the thickness of the adhesive cement 50 μm, 200 μm, and 300 μm, respectively. All the models were simulated to be cemented with computer-aided designed glass fiber post and core followed by zirconia crown. The load of 200N at 45° at lingual and central fossa was applied. Maximum von Mises stresses distribution was calculated.

Results: Maximum and minimum stresses in dentin were seen in the Ic and IIIa, respectively. Maximum and minimum stresses in cement were seen in IIIc and Ia, respectively.

Conclusion: The von Mises stresses in dentin can be minimized by keeping the cement thickness minimum and selecting the cement whose modulus of elasticity is closest to that of dentin.

Keywords: Cement thickness; finite element analysis; glass fiber post; modulus of elasticity

INTRODUCTION

The restoration of endodontically treated teeth still presents a challenging task for clinicians. Unless the tooth is not restored functionally, the endodontic treatment is incomplete. The task is complicated by the substantial loss of coronal tooth structure and the ability to predict long-term restorative success. Endodontically treated teeth, with a large amount of coronal tooth structure loss, frequently require the placement of a post inside the root canal, to retain a core for definitive restoration. The fundamental function of endodontic post is to retain core, which subsequently provides a suitable foundation for final restoration placement. It also serves as a substructure for anchoring a definite restoration to the tooth. Although restorative methods affect the fracture resistance and fracture mode of postrestored teeth at a certain extent, preserving intact coronal tooth structure and maintaining cervical tissue are still considered to be more crucial to optimize the biomechanical behavior of the endodontically treated teeth.

Prefabricated glass fiber post-having modulus of elasticity close to dentin have been widely used for restoration of...
root canal treated grossly decayed tooth. Such posts are retained in the root canal with the help of luting cement. However, due to the difference between the diameter of root canal and post, the achievement of close fit becomes difficult thus, a thick layer of cement will be created.\(^6\)

Loss in retention is the most common failure seen in prefabricated post. The concentration of stresses has been seen in the cement layer which causes the debonding of post.

Therefore, to achieve long-term success in endodontic treatment with fiber post, it is necessary is to establish a quantitative understanding on how cement thickness will influence the adhesive property of fiber post.

Variolink II is a dual-cure (light as well as self-curing) luting composite system for luting the ceramic as well as composite restorations. Its advantages include high radiopacity, it releases fluoride, and it is very less sensitive to light.

PermaCem is a light curable, zero-expansion permanent cement. It is an automix delivery system, thus ensures predictable, accurate, consistent, and homogeneous mix every time. It is fluoride releasing thus reduces secondary caries. It does not expand so it is safe for all restorations, including ceramic crowns.

ParaCore is a dual-cured glass-reinforced composite, which is radiopaque and available in three shades, dentin, white, and translucent. ParaCore simplifies the post and core restorative technique with its ability to be used as a 3-in-1 material for postcementation, core build-ups and crown, and bridge cementation. ParaCore also helps in cementation of inlays and onlays.

The finite element analysis has become an important tool in stress analysis and has been used in dental biomechanics from the past two decades. Finite element method (FEM) is a numerical modeling tool, which provides a versatile method of analyzing stresses in any complex system. The advantages of this method are that it more closely simulates the natural conditions, reduces experimentation cost, avoids destructive experimentation, has good reproducibility, and accuracy of the results and saves time.\(^7\)

No study till date has been conducted to evaluate the effect of cement type and thickness on stress distribution at dentin-cement interface of cemented computer-aided designed (CAD) glass fiber postinterface. Therefore, the aim of the study was to evaluate the effect of type of cement and their thickness on stress distribution at dentin-cement interface of cemented computer-aided designed glass fiber postinterface through three-dimensional finite element analysis the null hypothesis tested was there would be no effect of the type of cement and its thickness on stress distribution along dentin-cement fiber postinterface.

**MATERIALS AND METHODS**

This study was approved by the ethical committee of the institute. Ten sound maxillary second premolar indicated for orthodontic extraction were collected from the department of oral and maxillofacial surgery and were kept in chloramine-T solution for 24 h for disinfection. They were checked for any caries and restorations. IOPAR was taken buccolingually as well as mesiodistally to confirm the absence of any root resorption, pulp stones, and caries and to verify the presence of single canal. Teeth were viewed under dental operating microscope (GLOBAL USA) to verify any crack, and one tooth which met the above criteria was selected for optical scanning.

**Optical scanning of tooth**

A prototype of maxillary second premolar was obtained by scanning the surface of single-rooted maxillary second premolar through CAD machine (3M ESPE LAVATM SCAN ST) which is a 7-axis scanner machine. The obtained file was in Stereolithography format which was converted to IGES format, thus a hollow model was converted to a solid model.

**Generation of models**

The IGES format file was imported to solid works 2014 software. Totally nine models of maxillary second premolar were made in solid works 2014 software and were divided into three groups on the basis of the type of cement used Group I, II, and III. The groups were further divided into three subgroups a, b, and c in which cement thickness was kept 50 $\mu$m, 200 $\mu$m, and 300 $\mu$m, respectively. All the groups were cemented with simulated CAD one-piece fiber post and core (OPFPC) followed by zirconia crown (ICE Zircon Zirkonzahn SRL, Gais, Italy). In Group I, II, and III, OPFPC was cemented with (PermaCem, DMG Inc., Hamburg, Germany), Variolink II composite resin cement (Ivoclar, Vivadent AG, Schaan, Lichtenstein), ParaCore dual-curing resin cement (Switzerland), respectively. The cement thickness in subgroups a, b, and c was kept 50 $\mu$m, 200 $\mu$m, and 300 $\mu$m, respectively.

**Simulation of root canal treatment**

In all the models, endodontic treatment was simulated with apical preparation up to file no. 35. Working length was kept 0.5 mm short of apex and obturation was simulated with gutta percha on the basis of the lateral compaction technique.

**Simulation of postspace**

Postspace was simulated in all the models keeping the 5 mm gutta percha at the apex. Finally, the post was cemented in all the subgroups according to the subgroups formed.
The ferrule of 2 mm in height was maintained at buccal and lingual side of the tooth. Tooth reduction was simulated 1 mm circumferential with 2 mm of cusp reduction. The shoulder was kept as a finish line, and finally, the tooth was simulated to be restored with zirconia crown.

**Analysis in ANSYS 15**

Finally, all the assemblies were imported to finite element analysis software Ansys 15 (Ansys, Inc., Pennsylvania, USA) software and two mechanical properties, modulus of Elasticity and Poisson’s ratio was assigned to the respective domains of the tooth, which were determined from the review of literature [Table 1]. Next, the triangulated elements were idealized for automatic mesh generation using a tetrahedral mesh. Boundary conditions were fixed for all the models. The base of the cortical bone was fixed. All materials were modeled as linearly elastic and isotropic material except the glass fiber post which is considered to be orthotropic material. All the components were assumed to be in contact and bonded with one another. Each model will be subjected to a static load of 200N at the lingual cusp at an angle of 45° and 200N at central fossa. A static finite element analysis was done for stress distribution. The maximum von Mises equivalent stresses at cement-dentin interface were calculated.

**RESULTS**

FEM analysis showed that maximum stress was concentrated at the cervical third of the root in all the groups. In case of cement the minimum stresses were developed in Group I (PermaCem) with the thickness of 50 μm and maximum were seen in Group III (ParaCore) with thickness 300 μm [Figure 1a-c and Table 2]. In case of dentin, minimum stresses were developed in Group III (ParaCore) when the cement thickness was kept 50 μm and maximum were seen in Permacem with thickness of 300 μm [Figure 1d-i and Table 2].

**DISCUSSION**

The FEM is a numerical method used in the analysis of stress because it displays the internal stresses on different elements and on the basis of that, prognosis about failure can be judged.[9]

Among all properties of cement, elastic modulus was the most important factors that affected stress redistribution of restorations. Stress was passed to root dentin by two ways: one was passed directly from tooth crown to root dentin; the other was from post and cement to root dentin. The stress distribution of weakened root restored with different cements was analyzed by FEM. Three representative cements were selected for the study, among which, PermaCem generated highest, and ParaCore generated the lowest stresses in dentin. Thus, the null hypothesis was rejected.

The maxillary second premolar was selected because of its unfavorable crown volume and crown/root ratio, and also are more susceptibility to cusp fracture than any other posterior teeth.[9] The oblique forces concentrate the stress in coronal rather in periodontal tissues, causing more fatigue, and injurious effects in coronal dental tissues. Zirconia crown was selected as they provide the optimal esthetics, biocompatibility, durability and has high flexural strength.

It was also observed that Group III showed less stresses as compared to Group I and II. This might because Group III has the closest modulus of elasticity to dentin. In this manner, optimal combination and mechanical compatibility of the cement and dentin could be achieved, which in turn enhanced the ability to resist external force together. Stress in dentin was reduced because the cement shared the parts of the stress. Cements with elastic modulus close to that of the dentin improve stress distribution in root and also prevents extension of high-stress region which in turn reduces the incidence of root fracture. When restorations were cemented using cements of less elastic modulus than that of the dentin, cements, and adjacent root dentin could not deform at the same time. Under such conditions, von Mises stress in root dentin was greater because root

---

**Table 1: Elastic properties of the materials**

| Materials                | Modulus of elasticity (Gpa) | Poisson’s ratio |
|--------------------------|-----------------------------|-----------------|
| Cortical bone            | 13.7                        | 0.3             |
| Cancellous bone          | 1.37                        | 0.3             |
| Dentin                   | 18.6                        | 0.31            |
| Gutta percha             | 0.14                        | 0.45            |
| Zirconia (ICE Zirkon)    | 210                         | 0.33            |
| Zirkonzahn SRL, Gais, Italy | 17,000 (MPa)                | 0.23            |
| ParaCore                 | 2.8                         | 0.33            |
| PermaCem                 | 8.3                         | 0.35            |
| Variolink II             | X=37                        | XY=0.27         |
| Orthotropic mechanical properties of glass fiber post | Y=9.5 | Xz=0.34 |
|                         | Z=9.5                       | Yz=0.27         |

**Table 2: Von Mises stress in Mpa in dentin and cement**

| Thickness | PermaCem (2.8) I | Variolink II (8.3) II | ParaCore (17) III |
|-----------|------------------|-----------------------|-------------------|
|           | Dentin (Mpa)     | Cement (Mpa)          | Dentin (Mpa)      | Cement (Mpa)   |
| 50 μm (a) | 174              | 11.6                  | 172.8             | 24.1           |
| 200 μm (b) | 135.9           | 13.5                  | 180.8             | 25.4           |
| 300 μm (c) | 258.9           | 19.4                  | 256.2             | 54.7           |

MOE: Modulus of elasticity
The results of our study are in accordance with the study by Li et al.\textsuperscript{10} who stated that cement with elastic modulus similar to that of dentin could reinforce weakened root and reduce the stress in dentin. However, resin cement with a high elastic modulus had a considerable increase in stress in the cement layer, thus increasing the risk of debonding. It was also seen that on increasing the thickness from 200 to 300 $\mu$m the stresses increase drastically in dentin.

In the present study, regardless of the clinical situations simulated, the highest von Mises stress concentration was observed in the subgroup c in which the cement thickness was kept 300 $\mu$m.

A main concern about the thick adhesive layer was its high polymerization shrinkage, which might cause high compressive stress on the fiber post and cause an adverse effect on bond strength.\textsuperscript{11,12} However, some researchers stated that a thick cement layer was able to provide a relatively flexible, stress-absorbing layer between the restoration material and the dentin, thus, resulting in a low interfacial stress.\textsuperscript{13,14}

The decrease in fracture resistance or bond strength was seen on increasing the cement thickness as thicker cement layer closely relates to its higher polymerization shrinkage stress. Polymerization shrinkage is the inherent feature of polymeric adhesives, and in clinical scenario, thicker cement layer would generate higher polymerization shrinkage stress.\textsuperscript{15,16}

Boschian Pest et al.\textsuperscript{6} compared bond strengths between postspace dentin and a resin luting agent, and between a resin luting agent and fiber posts, and reported significantly lower strength values for bonds between postspace dentin and resin luting agent.

Grandini et al. evaluated the resin cement thickness after luting anatomic posts and standardized fiber posts into root\textsuperscript{17} canal preparations. The authors suggested that, if a post does not fit well, especially at the coronal level, the resultant cement layer is too thick, and bubbles are

Figure 1: (a-c) Stresses in cement with thickness 50 $\mu$m, 200 $\mu$m, 300 $\mu$m, respectively. (d-f) Stresses in dentin (external view) with cement thickness 50 $\mu$m, 200 $\mu$m, 300 $\mu$m, respectively. (g-i) Stresses in dentin (internal view) with cement thickness 50 $\mu$m, 200 $\mu$m, 300 $\mu$m, respectively.
likely to be present within it, predisposing the post to debond. Bubbles or voids in cement layer, illustrating the areas of weakness within the material are less likely to form in a uniform and thin layer of cement. Moreover, they stated that the polymerization stress, developing within a relatively thin film of cement, would be minimal.

Valandro et al. indicated that polymerization stress is an important factor in the process of failure between an adhesive system and crown and root dentin and reported that the thinner the cement layer, the less will be the microporosities as well as polymerization shrinkage.

**CONCLUSION**

1. On increasing the modulus of elasticity, the von Mises stresses generated on all groups increased. Cement whose modulus of elasticity is closer to that of dentin showed least von Mises stresses in dentin and maximum stress in cement

2. On decreasing the thickness of cement, the von Mises stresses generated on cement increased, and the stresses generated in dentin decreased.

**Financial support and sponsorship**

Nil.

**Conflicts of interest**

There are no conflicts of interest.

**REFERENCES**

1. Toksavul S, Zor M, Toman M, Gündüz MA, Nergiz I, Artuç N. Analysis of dentinal stress distribution of maxillary central incisors subjected to various post-and-core applications. Oper Dent 2006;31:89-96.

2. Mosharraf R, Haerian A. Push-out bond strength of a fiber post system with two resin cements. Dent Res J (Isfahan) 2011;8:588-93.

3. Cohen BI, Condous S, Musilkan BL, Deutsch AS. Retention properties of a split-shaft threaded post: Cut at different apical lengths. J Prosthet Dent 1992;68:894-8.

4. Dietrich D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: A systematic review of the literature – Part 1. Composition and micro- and macrostructure alterations. Quintessence Int 2007;38:733-43.

5. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: A literature review. J Endod 2004;30:289-301.

6. Boschian Pest L, Cavalli G, Bertani P, Gagliani M. Adhesive post-endodontic restorations with fiber posts: Push-out tests and SEM observations. Dent Mater 2002;18:596-602.

7. Tirupathi RC, Ashok DB. Introduction to Finite Elements in Engineering. 2nd ed. New Delhi: Prentice Hall of India Private Limited; 1997. p. 1-20.

8. Verdonschot N, Fennis WM, Stolk J, Creuleen CM, Creugers NH. Generation of 3-D finite element models of restored human teeth using micro-CT techniques. Int J Prosthodont 2001;14:310-5.

9. Zicari F, Van Meerbeek B, Scotti R, Naert I. Effect of ferrule and post placement on frictional resistance of endodontically treated teeth after fatigue loading. J Dent 2013;41:207-15.

10. Li LL, Wang ZY, Bai ZC, Mao Y, Gao B, Xin HT, et al. Three-dimensional finite element analysis of weakened roots restored with different cements in combination with titanium alloy posts. Chin Med J (Engl) 2006;119:305-11.

11. Gomes GM, Rezende EC, Gomes OM, Gomes JC, Loguercio AD, Reis A, et al. Influence of the resin cement thickness on bond strength and gap formation of fiber posts bonded to root dentin. J Adhes Dent 2014;16:71-3.

12. Özcan E, Çetin AR, Tunçdemir AR, Uker M. The effect of luting cement thicknesses on the push-out bond strength of the fiber posts. Acta Odontol Scand 2013;71:703-9.

13. Alonso RC, Sinhoreti MA, Correr Sobrinho L, Consani S, Goes MF. Effect of resin liners on the microleakage of class V dental composite restorations. J Appl Oral Sci 2004;12:56-61.

14. Kemp-Scholte CM, Davidson CL. Complete marginal seal of class V resin composite restorations effected by increased flexibility. J Dent Res 1990;69:1240-3.

15. Ferrari M, Cagidiaco MC, Goracci C, Vichi A, Mason PN, Radovic I, et al. Long-term retrospective study of the clinical performance of fiber posts. Am J Dent 2007;20:287-91.

16. Jongsmia LA, Ir Nde J, Kleverlaan CJ, Felizer AJ. Reduced contraction stress formation obtained by a two-step cementation procedure for fiber posts. Dent Mater 2011;27:670-6.

17. Grandini S, Goracci C, Monticelli F, Borracchini A, Ferrari M. SEM evaluation of the cement layer thickness after luting two different posts. J Adhes Dent 2005;7:235-40.

18. Valandro LF, Filho OD, Valera MC, de Araujo MA. The effect of adhesive systems on the pullout strength of a fiberglass-reinforced composite post system in bovine teeth. J Adhes Dent 2005;7:331-6.