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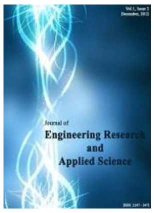

Effects of post material and cement on stress distribution by using finite element analysis and in vitro fracture test

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Abstract
A comparative study on the stress distribution of an endodontically treated maxillary incisor has been carried out by three dimensional stress analyses using the Finite Element Method. The role of post material and cement rigidity on reliability of endodontic restorations is discussed. Methods: A 3D FEM model of a central maxillary incisor with 2 mm surviving dentinal walls was created. The following parameters were studied: 3 loading conditions, 3 different luting cements, 4 post materials when present, and absence of post. The teeth were constructed with 5 different techniques: steel, titanium, glass fiber, zirconium posts with composite cores and composite restoration without post. Three luting cements with different elastic moduli were discussed. The structural efficiency of restorations has been evaluated under 3 different loading conditions (mastication, bruxism and impact). In this study the validity of the FEM model was controlled by an in vitro test. Twenty five recently extracted caries free, human maxillary central incisors with similar root sizes were divided into 5 groups. Endodontic treatment was subsequently performed and post core restorations were prepared and porcelain restorations were fabricated. Fracture strengths and modes of failure were determined by universal testing machine. Results and significance: There were significant differences between post systems, cements. The stresses decreased with the post material in order of steel, zirconium, titanium, glass fiber. Minimum stress values were obtained with the glass fiber post bonded with an adhesive resin cement with low elastic modulus. In functional loading, maximum equivalent stress mostly occurs at the vestibular side of the cement layer. Horizontal loading from the buccal aspect increased and vertical loads decreased the maximum stress. There was correlation between the results of FEM and fracture test results.

Keywords: Dental material, post, finite element analysis, stress.

1. Introduction

Endodontically-treated teeth are affected by a higher risk of biomechanical failure than vital teeth (1-5). The fracture resistance of dowel-restored teeth has been the subject of numerous in vitro and in vivo studies (6-45). Posts are necessary to build up and retain coronal restorations but they do not reinforce dental roots (46). Moreover, some authors asserted that posts may interfere with the mechanical resistance of treated teeth, leading to an increased risk of damage to residual tooth structure (30,47). To date, there is still no agreement regarding which material or technique can be considered ideal for the restoration of endodontically-treated teeth (48).

Many different points of view regarding the best choice of restorative technique can be found in the literature but in vivo studies often cannot control the many variables that are present clinically and result in very high standard deviations in fracture resistance. In addition, static loading used in an in vitro experiment may not be representative of the in vivo situation. Dynamic loading would seem to be more valid but in many studies unrealistically high loads are used to register a fracture. Because of the large variability of the results obtained from in vitro studies, many investigations of dowel-restored teeth are based on finite element (FE) analysis (14,32-34,36,42-44).

A post with biomechanical properties similar to those of dentin could reduce the risk of root fractures of teeth (30). A very stiff post working against the natural function of the tooth creates zones of tension and shear both in the dentine and at the interfaces of the luting cement and the post (39,43,44). Numerous studies have been performed to evaluate the influence of post and luting material on stress distribution in dentin (43,44). Post restorations are complex systems where the stress distribution within the structure is multiaxial, non-uniform and

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depending on the magnitude and direction of the applied external loads (43).

The results of an FE analysis are expressed as stresses distributed in the structures under investigation. These stresses may be tensile, compressive, shear, or a 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. FE analysis can be performed with 2 dimensional (2D) and 3 dimensional (3D) models, and the consensus is that the results obtained with 3D models are more valid but also are more time-consuming and costly than 2D models (6,7).

The aim of this study was to analyse the stress distribution in a 3D FEM model of a central maxillary incisor restored with 3 different luting cements and 4 different post materials under 3 different loading conditions.

2. Materials and methods:

A 3D FEM model of a central maxillary incisor with 2 mm surviving dentinal walls was created The solid model was generated using literature data and the dimensions of the tooth were modeled according to ideal shape of a central incisor (53). A 3D FEM model of a central maxillary incisor and surrounding structures was generated by ANSYS software (Ansys, Inc. Houston) using IGES format. The volumes were redefined in the new environment and meshed with 8 nodes brick with 3 degree of freedom per node, finally resulting in a model with 85326 elements, 148787 nodes (Fig. 1). Accuracy of the model has been checked by convergence tests. Particular attention has been devoted to the refinement of the mesh resulting from the convergence tests at the cement layer interfaces.

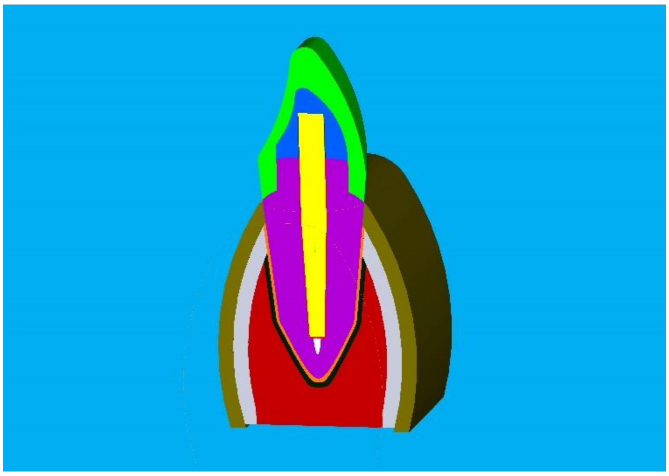

Figure 1: 3D model of maxillary central incisor.

Mechanical properties of each component used in this study were summarized in Table 1. Due to the comparative aim of the structural evaluations, the given arbitrary commercially available post geometry has been used: 6% conicity; tip diameter 1.0 mm; 10 mm insertion depth (about 2/3 of the root length). All the nodes on the external surface of the root were constrained in all directions. Complete bonding between post and cement was considered.

The following models with different materials configuration were considered:

Model 1a (M1a): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with steel post cemented with zinc phosphate cement. A composite core and a feldspathic crown were considered.

Model 1b (M1b): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with steel post cemented with a low modulus dual-cure resin cement. A composite core and a feldspathic crown were considered.

Model 1c (M1c): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with steel post cemented with a high modulus dual-cure resin cement. A composite core and a feldspathic crown were considered. Model 2a (M2a): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with titanium post cemented with zinc phosphate cement. A composite core and a feldspathic crown were considered.

Table 1: Mechanical properties used in this study.

Material	**Elastic modulus**		
(Gpa)	Poisson ratio	Reference	
Enamel	41	0,30	6
Pulp	0,002	0,45	6
Dentin	18,6	0,31	6,7
Periodontal Ligament	0,0689	0,45	7
Cortical bone	13,7	0,30	6,7
Spongiose bone	1,37	0,30	6,7
Gingiva	0,003	0,45	7
Gutta percha	0,00069	0,45	6
Porselain crown	120	0,28	33
Composite core	12,0	0,30	31,42
Material	Elastic modulus		
(Gpa)	Poisson ratio	Reference	
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Cortical bone	13,7	0,30	6,7
Porselain crown	120	0,28	33
Composite core	12,0	0,30	31,42

Model 2b (M2b): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with titanium post cemented with a low modulus dual-cure resin cement. A composite core and a feldspathic crown were considered.

Model 2c (M2c): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with titanium post cemented with a high modulus dual-cure resin cement. A composite core and a feldspathic crown were considered.

Model 3a (M3a): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with glass fiber post cemented with zinc phosphate cement. A composite core and a feldspathic crown were considered.

Model 3b (M3b): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with glass fiber post cemented with a low modulus dual-cure resin cement. A composite core and a feldspathic crown were considered.

Model 3c (M3c): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with glass fiber post cemented with a high modulus dual-cure resin cement. A composite core and a feldspathic crown were considered.

Model 4a (M4a): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with zirconium post cemented with zinc phosphate cement. A composite core and a feldspathic crown were considered.

Model 4b (M4b): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with zirconium post cemented with a low modulus dual-cure resin cement. A composite core and a feldspathic crown were considered.

Model 4c (M4c): Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored with zirconium post cemented with a high modulus dual-cure resin cement. A composite core and a feldspathic crown were considered.

Model 5: Endodontically treated maxillary central incisor with 2 mm surviving dentinal walls, restored a composite core without post. A feldspathic crown was considered.

The structural efficiency of restorations have been evaluated under 3 different loading conditions: 100 N force inclined at 135 º with respect to the tooth axis 2 mm below the incisal edge in order to simulate mastication loads; 100N vertical pressure in order to simulate axial loads; 100N horizontal force to simulate an accidental impact force

Validation of the finite element model: Two main problems in the FE method are accuracy and validity. Accuracy of the model can be checked by convergence tests or by laboratory tests or clinical observations. In particular, it is important that the distribution of stresses predicted by the finite element model shows a good correlation with fracture probability. Failure is expected to start where the equivalent stress reaches a critical value. In this study the validity of the FEM model is controlled by an in vitro test.

Twenty five recently extracted caries free, human maxillary central incisors with similar root sizes were divided into 5 groups. Root lengths were measured from the cementoenamel junction on the facial surface and mesiodistal widths were measured from the proximal surfaces. Coronal portions of teeth have been removed 2 mm coronal to the most incisal point of the approximal CEJ and perpendicular to the long axis of the tooth with a high-speed diamond bur under water cooling. Endodontic treatment was subsequently performed. All roots were filed with a rotary instrument (Anthogyr NiTi Control, Anthogyr, Sallanches, France). After intermittent rinsing with 5% sodium hypochlorite, all roots were obturated with laterally condensed gutta-percha (Spident, Inchon, Korea, Lot no: G4140) and sealer (Endomethasone, Septodont, France. Batch no: P3 U22). After endodontic treatment the specimens were embedded into self polymerizing acrylic resin (Meliodent Denture Material, Heraeus Kulzer, Berkshire, USA) cylinders 1 mm above the CEJ with the guidance of a dental surveyor (Kavo EWL, Typ 990, Kavo Elektrotechnisches Werk GmbH, Leutkirch im Allgau, Germany).

The roots were randomly assigned to groups of 5 samples each. Gutta percha was removed from the root canals with peaso reamer, leaving 3 mm of filling at the apical portion. Root canals were enlarged to receive endodontic posts.

Group 1 (G1): Endodontically treated maxillary central incisor restored with glass fiber post (Postec, Vivadent, Schaan, Liechtenstein) and resin cement (Variolink II, Vivadent, Schaan, Liechtenstein) according to manufacturer’s instructions.

Group 2 (G2): Endodontically treated maxillary central incisor restored with zirconium post (Cosmopost, Vivadent, Schaan, Liechtenstein) and resin cement (Variolink II Vivadent, Schaan, Liechtenstein) according to manufacturer’s instructions.

Group 3 (G3): Endodontically treated maxillary central incisor restored with stainless steel posts (Obtur. Screws, FKG Dentaire, La Chaux de Fonds, Switzerland. Lot no:2904) applied with zinc phosphate cement (Adhesor, Spofa Dental, Praha, Czech Republic Lot no: 1544813-1).

Group 4 (G4): After endodontic treatment no post was applied in the canal.

Group 5 (G5): Natural teeth without restorations were used as control.

The cores were constructed with light cured composite (Te-Econom, Vivadent, Schaan, Liechtenstein Lot no: G28736). Impressions were taken with polyvinyl siloxane type impression material (Affinis, Coltene Whaledent, Alstatten, Switzerland, Lot no: 0091939) and porcelain fused to metal crowns (VMK-95 Metal Keramik; Vita Zahnfabrik, Bad Sackingen, Germany) were constructed. The restorations were cemented with zinc phosphate cement (Adhesor, Spofa Dental, Praha, Czech Republic. Lot no: 1544813-1). The specimens were tested with universal testing machine (Testometric Micro 500, Testometric Company Ltd., Lancashire, United Kingdom). Each sample was mounted in a custom made device to ensure that the force was applied at the specific angle. The load was applied 2 mm from the incisal edge of the crown on the palatal side at an angle of 90 degrees to the long axis of the tooth with a crosshead speed of 0, 5 mm/min. Failure threshold was defined as the point fracture occurred. The mode of failure was recorded for each specimen.

Failure loads were analyzed with 1 way analysis of variance (ANOVA) and Scheffe multiple comparison with a significance level of $p<.05$.

3. Results

Table 2 shows that the stresses decreased with the post material in order of steel, zirconium, titanium, glass fiber. Horizontal loading from the buccal aspect increased and vertical loads decreased the maximum stress in all models. Minimum stress values were obtained with the glass fiber post bonded with an adhesive resin cement with low elastic modulus in all loading conditions (Figure2).

Table 2: Effect of coronal destruction, post material, cement and loading.

Cement material	Post material	Group	135	Vertical	Horizontal
Zinc Phosphate cement	Metal post	M1a	101,08	51,41	108,69
	Titanium post	M2a	91,07	32,73	91,91
	Glass fiber post	M3a	92,55	33,05	93,41
	Zirconium post	M4a	96,45	49,35	103,78
Adhesive cement low	Metal post	M1b	103,47	52,3	110,47
	Titanium post	M2b	58,5	31,3	63,08
	Glass fiber post	M3b	38,64	26,07	37,24
	Zirconium post	M4b	98,74	50,21	105,48
Adhesive cement high	Metal post	M1c	104,75	59,42	111,21
	Titanium post	M2c	59,22	35,96	63,44
	Glass fiber post	M3c	39,11	26,23	37,68
	Zirconium post	M4c	99,97	56,99	106,19
Adhesive restoration		M5	39,27	26,21	37,56

Model 1: (Figure 2A,3A) Maximum equivalent stress occurs at level of the cervical region on the facial aspect of the tooth under functional loading. The stress reaches a maximum value of 101,08 for the steel post cemented with zinc phosphate cement (M1a) while it reaches a similar value of 103,47 for steel posts cemented with dentine like cements (low elastic modulus) (M1b) (Fig 3A). In vertical loading the maximum stress area is located near the post apex and in horizontal loading from the buccal aspect the area of maximum stress is located at the palatinal surface.

Model 2: (Figure 2B,3B) Maximum equivalent stress occurs at level of the cervical region on the facial aspect of the tooth under functional loading. The stress reaches a maximum value of 91,07 for the titanium post cemented with zinc phosphate cement (M2a) while it reaches a lower value of 58,5 for titanium posts cemented with dentine like cements (low elastic modulus) (M2b) (Fig 3B). Titanium posts exhibited smaller stress values than steel posts.

Model 3: (Figure 2C,3C) Maximum equivalent stress occurs at level of the cervical region on the facial aspect of the tooth under functional loading. The stress reaches a maximum value of 38,64 for the glass fiber post cemented with low modulus adhesive resin cement (dentin like cement) (M3b) (Fig 2C) while it reaches a similar value of 39,11 for glass fiber posts cemented with high modulus adhesive cement (M3c) (Fig 3C). In vertical loading the maximum stress area is located near the post apex and in horizontal loading from the buccal aspect the area of maximum stress is located at the palatinal surface. The values obtained from glass fiber posts were similar to the model without post (M5).

Model 4: (Figure 2D,3D) Maximum equivalent stress occurs at level of the cervical region on the facial aspect of the tooth under functional loading. The stress reaches a maximum value of 98,74 for the zirconium post cemented with low modulus adhesive resin cement (dentin like cement) (M4b) (Fig 2D) while it reaches a value of 99,97 for zirconium posts cemented with high modulus adhesive cement (M4c) (Fig 3D). In vertical loading the maximum stress area is located near the post apex and in horizontal loading from the buccal aspect the area of maximum stress is located at the palatinal surface.

Model 5: Maximum equivalent stress occurs at level of the cervical region on the facial aspect of the tooth under functional loading. The stress reaches a maximum value of 39,27 under functional loading, 26,21 under vertical loading and 37,56 under horizontal loading.

Regions of maximum stress changed for the different loading conditions. In functional loading, maximum equivalent stress mostly occurs at the vestibular side of the cement layer (interface between post and cement). As expected, in the bruxism case, the maximum stress area is located near the post apex. The area of maximum stres is located at the palatinal surface in horizontal loading from the buccal aspect. Horizontal loading from the buccal aspect increased and vertical loads decreased the maximum stress. Only glass fiber with adhesive cements exhibited smaller stress at horizontal loading just like the model without post.

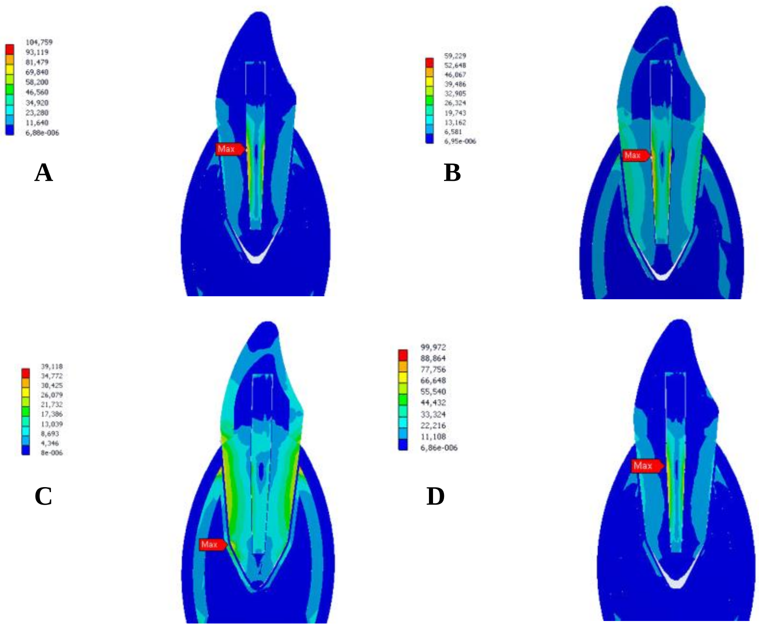

Figure 2: Effect of post material bonded with adhesive cement (high) under functional loading: A: Steel post, B: Titanium post, C: Glass fiber post, D: Zirconium post.

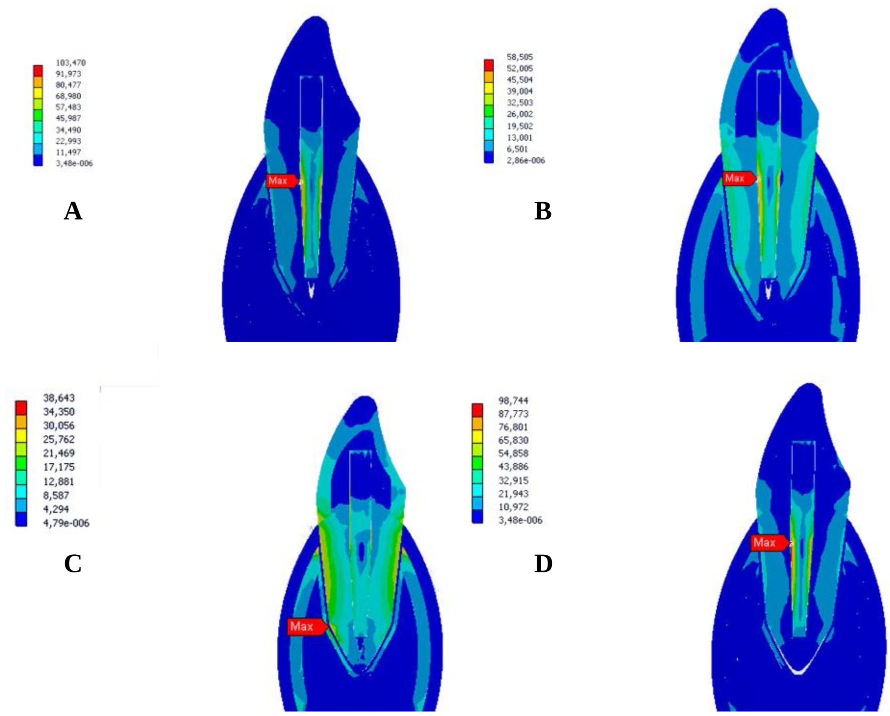

Figure 3: Effect of post material bonded with adhesive cement (low) under functional loading: A: Steel post, B: Titanium post, C: Glass fiber post, D: Zirconium post

Means and standard deviations of failure loads of the fracture test are listed in Table 3-4. The highest fracture strengths were observed in groups restored with glass fiber posts. The mean failure load for this group was 376,38 ± 13,35 N. The results of the ANOVA and Scheffe multiple comparison are presented in Tables 5 and 6. In the fracture strength test, the specimens from Group 1 (glass fiber post) exhibited significantly ($p \leq 0.05$) higher strengths when compared with Group 2 (zirconium) and Group 5 (control). Group 2 (zirconium) exhibited the lowest strength values (238,98 ± 37,65 N).
Modes of failure are illustrated in Table 3. There were distinct differences in failure patterns between teeth restored with glass fiber posts and those restored with metal and zirconium posts. One of the teeth in Group 1(glass fiber post) fractured in the apical portion of the root and all the other teeth in this group fractured in a horizontal pattern through the facial side at the cervial part of the crown. All the teeth in Group 2 (zirconium) fractured in a horizontal pattern through the facial side at the level of cementoenamel junction. In Group 3 (metal) all the teeth experienced a horizontal fracture at the middle and apical parts of the root and none of the metal posts fractured. In Group 4 (core) all the restorations experienced a bond failure at the junction of the tooth and the composite core.

Table 3: Fracture loads and modes of failure

	Mean	**Std. Deviation**	**Std. Error**	**95% Confidence Interval for Mean**		**Minimum**	**Maximum**
				Lower Bound	Upper Bound		
Fiber	376,3800	13,34942	5,97004	359,8045	392,9555	358,00	392,30
Zirconium	238,9800	37,65152	16,83827	192,2295	285,7305	188,80	284,50
Metal	311,2000	29,24073	13,07685	274,8928	347,5072	267,80	346,50
Adhesive	355,9400	50,49528	22,58217	293,2418	418,6382	277,50	397,70
Control	262,5600	8,92401	3,99094	251,4794	273,6406	250,50	269,90

Table 4: Fracture loads of the groups (means and standard deviations)

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	69038,706	4	17259,677	16,987	,000
Within Groups	20321,100	20	1016,055		
Total	89359,806	24			

4. Discussion:

The 3D FE analysis, showed significant changes in the stresses induced in the tooth-restoration complex when the investigated parameters were varied. It is possible to mechanically characterize not only enamel and dentin but also bone tissues, periodontal ligament and adhesive interfaces using three dimensional solid elements (49) Different loading conditions can be evaluated with FEA in order to evaluate stress and strain distributions within teeth and restorations and hypothesize predictive areas under risk of clinical failure (49).

Adhesive interfaces of bonded restorations transmit and distribute occlusal forces to the remaining tooth structures homogeneously and increasing the resistance to fracture (50). On the other hand, the interfaces of materials with different moduli of elasticity represent the weak point of a restorative system, as the toughness mismatch influences the stress distribution (51). A post with biomechanical properties to those of dentin could be advantageous by reducing the risk of root fractures of teeth. A very stiff post working against the natural function of the tooth creates zones of tension and shear both in the dentine and at the interfaces of the luting cement and the post (43). In this study minimum stress values were obtained with the glass fiber post bonded with an adhesive resin cement with low elastic modulus.

Table 5: ANOVA table for analysis of failure loads.

Post		F	Mode of failure
Glass fiber	1	392,3	Cervical, bond failure,
	2	358,0	Root apical
	3	382,9	Cervical, bond failure
	4	368,4	Cervical, bond failure
	5	380,3	Cervical
Zirconium	1	188,8	Cervical horizontal
	2	265,3	Cervical horizontal
	3	284,5	Cervical horizontal
	4	219,4	Cervical horizontal
	5	236,9	Cervical horizontal
Metal	1	267,8	Root middle
	2	303,7	Root middle
	3	311,5	Root middle
	4	346,5	Root middle
	5	326,5	Root middle
Adhesive	1	379,9	Bond failure, core-dentin
	2	391,0	Bond failure, core-dentin
	3	277,5	Cervical
	4	333,6	Bond failure, core-dentin
	5	397,7	Bond failure, core-dentin
Control	1	268,4	Cervical
	2	269,9	Root apex
	3	250,5	Root apex
	4	268,5	Cervical
	5	255,5	Cervical

Scheffe * The mean difference is significant at the .05 level

Glass and carbon posts exhibit high fatigue and tensile strength, and they have a Young's modulus comparable to dentin's (31). Moreover, these posts can be bonded in root canal with adhesive resin cement. Bonding agents transmit stress between the post and the root structure, reducing stress concentration and preventing fracture (26,42). Bonding between the post and the cement and between the cement and the dentin appears an important parameter to achieve optimal behavior of endodontical restorations. On the contrary steel post and traditional cements does not allow a homogeneous stress distribution. In this study increased elastic modulus of the dowel was found to cause decreased dentin stress. This result is in agreement with the earlier in vitro investigations (32,42-44). The FE study of Pegoretti et al (33) concludes that glass fiber dowel resulted in lower stresses inside the root than did the carbon and metal dowel. Isidor and Brondum (12) and Isidor et al (23) found that teeth restored with a carbon fiber dowel were more resistant to fracture than teeth restored with a titanium dowel. Several in vitro studies have determined the resistance to fracture of post restored teeth under static loading and found smaller (18,20) the same (27,38) or higher (30) strength of teeth restored with fiber dowels than teeth restored with metal dowels.

The maximum shear stresses were found to be primarily located at post, cement, dentin interface. Dentin-bonding systems will provide bond strengths, generally in the range of 15 to 30 Mpa (26,43), and posts luted with zinc-phosphate cement have been reported to lose retention at a stress level of approximately 5 to 25 MPa. Cohen et al (15) reported that micromovement of a cemented dowel results in disintegration of the cement and the concentration of stress at the apical end of the dowel over time. The fracture strength of dental cements is less than that of dentin or dowel material. Thus, failure of the system usually occurs cohesively within the cement or at its interface with dentin. Critical areas of high stress concentration were the restoration-cement-dentin interface both in the root canal and on the buccal and lingual aspects of the tooth-restoration interface.

There was a significant difference in the stress distribution at dentin interfaces for the post restored tooth cemented with materials of different rigidity. The results lead to the conclusion that the more flexible the posts are, the less rigidity of the cementing medium is relevant. In this study there was difference between the stress values of posts bonded with different cements. Clinically both carbon and glass posts are subjected to debonding/loosening phenomena (43). Tough cement systems could improve the restoration reliability by opposing to mechanical progression of failure and crack growth.

Table 6: Statistical analysis.

(I) groups	(J) groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	137,40000(*)	20,15991	,000	69,1405	205,6595
	3,00	65,18000	20,15991	,066	-3,0795	133,4395
	4,00	20,44000	20,15991	,902	-47,8195	88,6995
	5,00	113,82000(*)	20,15991	,001	45,5605	182,0795
2,00	1,00	-137,40000(*)	20,15991	,000	-205,6595	-69,1405
	3,00	-72,22000(*)	20,15991	,035	-140,4795	-3,9605
	4,00	-116,96000(*)	20,15991	,000	-185,2195	-48,7005
	5,00	-23,58000	20,15991	,846	-91,8395	44,6795
3,00	1,00	-65,18000	20,15991	,066	-133,4395	3,0795
	2,00	72,22000(*)	20,15991	,035	3,9605	140,4795
	4,00	-44,74000	20,15991	,329	-112,9995	23,5195
	5,00	48,64000	20,15991	,253	-19,6195	116,8995
4,00	1,00	-20,44000	20,15991	,902	-88,6995	47,8195
	2,00	116,96000(*)	20,15991	,000	48,7005	185,2195
	3,00	44,74000	20,15991	,329	-23,5195	112,9995
	5,00	93,38000(*)	20,15991	,004	25,1205	161,6395
5,00	1,00	-113,82000(*)	20,15991	,001	-182,0795	-45,5605
	2,00	23,58000	20,15991	,846	-44,6795	91,8395
	3,00	-48,64000	20,15991	,253	-116,8995	19,6195
	4,00	-93,38000(*)	20,15991	,004	-161,6395	-25,1205

When the post restored maxillary incisors were evaluated (28,29), the load has been always applied on the palatal aspect in an area ranging from 2 to 3 mm from the incisal margin. This was due to the gnatologic role of incisors, designed to bear non axial loads rather than axial forces. The area of load application coincides with the area of incisor guidance during stomatognatic functions. In this study load was applied 2mm below the incisal margin at the palatinal surface.

Maximum biting forces of 100–200N were measured for incisor teeth (52) and occlusal forces occurring in mastication are considerably lower than maximum bite forces. Maximum axial loads between 70 and 150N were recorded during chewing and swallowing a variety of foods. Axial loads may arise also from bruxism. (44)

Recently, several papers supported the use of a direct restoration without placing any post for restoring endodontically treated teeth (54-56). Krejci et al. (57) showed no significant differences between teeth restored with and without posts at fracture strength and fracture patterns. Moreover, some studies pointed out that mechanical resistance to fracture of endodontically treated teeth could be affected by the presence of posts and the risk of damage could increase (30,40,58). In endodontically treated teeth, occlusal loads could be transferred intraradicularly by post restorations, increasing the occurrence of vertical root fractures. On the contrary, other authors noticed that fiber posts reduced the risk of root fractures (25). Actual consensus in restorative dentistry indicates that decementation or failure of posts is preferable than fracture of residual tooth structure(40, 59,60). In this study failures in glass fiber post restored teeth were restorable. The less residual tooth structure the more important the physical properties of post-and-core systems (61).

This study confirmed that the reconstructed tooth is subject to most stress in the cervical region under a functional load. Pierrisnard et al. (32) mentioned that the absence of a cervical ferrule was a negative factor giving rise to considerably higher stress levels. They also concluded that the cervical area of a root canal treated and restored teeth was the area most subject to stress under a simulated occlusal load. The magnitude of deflection and peak stress generated in the reconstructed tooth with horizontal loading was greater than that with vertical loading. Load direction has a greater effect than dowel material on maximum stress and displacement.

Several studies have been performed to assess the mechanical resistance to fracture of post restored teeth (6-45). Most studies have tried to identify the best technique and materials to be used to increase the strength of the toothrestoration complex (60,61). The use of static forces permits to simplify the study realization (30,41) and requires universal testing machines easier to use and less expensive than fatigue and thermomechanical cycling test workstations (28,29,41,57). In this study static loading is also chosen to valididate the FEM results. Different loading jigs were described in the literature in shape and material (28-30,41). In this study rounded tip with a diameter of 5 mm have been chosen to homogeneously apply loads (29-30). Due to the large number of secondary variables involved (i.e. tooth type and condition, restorative procedures and materials), it is hard to compare experimental data extrapolated by different in vitro studies (41) but the results obtained from this fracture test were comparable with earlier reports (18,20).

5. Conclusion

FE analysis is a powerful tool in calculating stress distributions in complex structures. As stated earlier, the method provides results without variation. The validity of the study, however, depends on the extent to which the model approaches reality. In functional loading, maximum equivalent stress mostly occurs at the vestibular side of the cement layer. Horizontal loading from the buccal aspect increased and vertical loads decreased the maximum stress. Minimum stress values were obtained with the glass fiber post bonded with an adhesive resin cement with low elastic modulus. The stress decreased with the post material in order of steel, zirconium, titanium, glass fiber.

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