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Effect of Post Material, Cement and Amount of Coronal Destruction on Stress Distribution: 3D FEA Study

SUMMARY

Introduction: *The aim of this study was to asses the stress distribution of an endodontically treated maxillary incisor by 3-dimensional stress analyses using the Finite Element Analysis (FEA). The role of the post material and cement rigidity on reliability of endodontic restorations is discussed.*

Material and methods: *A 3D FEA model of a central maxillary incisor was created. The following parameters were studied: 2 levels of coronal destruction (total loss of coronal dentin, and partial loss of coronal dentin with 2 mm surviving dentinal walls); 3 loading conditions (mastication, bruxism and impact); 3 different luting cements (Zinc polycarboxylate cement; resin cement with low modulus of elasticity; resin cement with high modulus of elasticity); 4 post materials (steel, titanium, glass fibre, zirconium posts with composite cores) and composite restoration without post.*

***Results** and **Discussion:** There were significant differences between post systems and cements. The stresses decreased with the post material in order of steel, zirconium, titanium, glass fibre. The presence of 2 mm coronal dentin decreased the maximum stress values in all the models. Minimum stress values were obtained with 2 mm coronal dentin with the glass fibre post and adhesive resin cement.*

Keywords: Glass Fibre Post; Post Material; Finite Element Analysis

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Introduction

Special care is indicated when selecting the most efficient way to restore endodontically treated teeth because they have a higher risk of biomechanical failure than vital teeth[1]. The fracture resistance of post-restored teeth has been the subject of numerous *in vitro* and *in vivo* studies[2-6]. A theoretical method for calculating stress distribution within complex structures is the finite element analysis (FEA), which allows the investigator to evaluate the influence of model parameter variation once the basic model have been correctly defined[7].

In the case of incisors, when loaded transversely, the flexural behaviour of posts should be carefully considered[8]. The magnitude and the angle of incisal load greatly influence the long term success of restorative systems involving central incisors. A post with biomechanical properties similar to those of dentin could reduce the risk of tooth root fractures[9]. A very stiff post working against the natural function of the tooth creates zones of tension and shear, both in the dentin and at the interfaces of the luting cement and the post. Some studies have been performed to evaluate the influence of post and luting material on stress distribution in dentin[7,10].

When a restorative system is loaded, it is able to absorb the applied forces, generating peculiar stress and strain distributions. The evaluation of such patterns, for example using the FEA, could be a reliable predictive parameter to forecast areas under risk of possible mechanical failures[11]. It is possible to mechanically characterize not only enamel and dentin but also bone tissues, periodontal ligament and adhesive interfaces. Different loading conditions can be evaluated with FEA in order to evaluate stress distributions within the restorations and hypothesize predictive areas under risk of clinical failure. Recently, many studies were related to biomechanical analyses with different post-and-core systems[10-15]. FEA 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[7,12].

The **aim** of this study was to analyse the stress distribution in a 3D FEA model of a central maxillary incisor with 2 levels of coronal destruction, restored with 3 different luting cements and 4 post materials, under 3 different loading conditions.

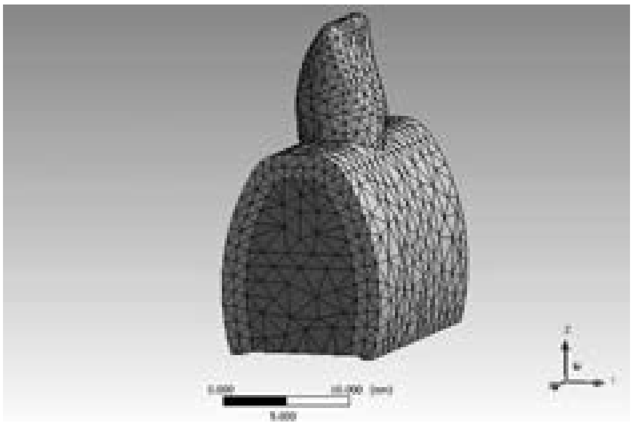

Figure 1a. 3D model of maxillary central incisor

Material and Methods

The solid model was generated using literature data and the dimensions of the tooth were modelled according to the ideal shape of a central incisor. A 3D FEA 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 3D FEA model with 85326 elements and 148787 nodes (Fig. 1a). All the nodes on the external surface of the root were constrained in all directions. Accuracy of the model was checked by convergence tests. Particular attention was devoted to the refinement of the mesh resulting from the convergence tests at the cement layer interfaces. Different material properties were coupled with the elements and geometries according to the volume material defined in fig. 1a (enamel, dentin, restored crown, core, cement, post, periodontal ligament, cortical bone, spongious bone). 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. Mechanical properties of each component used in this study were summarized in table 1.

2 levels of coronal destruction were modelled: (1) Total loss of coronal dentin; and (2) Partial loss of coronal dentin with 2 mm surviving dentinal walls. The teeth were constructed with 5 different techniques: Group 1: Steel post with composite core; Group 2: Titanium post with composite core; Group 3: Glass fibre post with composite core; Group 4: Zirconium post with composite core; Group 5: Composite restoration without post. 3 luting cements with different elastic modules were discussed: (1) Zinc polycarboxylate cement; (2) Resin cement with low modulus of elasticity; (3) Resin cement with high modulus of elasticity.

Table 1. Mechanical properties used in this study

Material	Elastic modulus (Gpa)	Poisson ratio
Enamel	41	0,30
Pulp	0,002	0,45
Dentin	18,6	0,31
Periodontal Ligament	0,0689	0,45
Cortical bone	13,7	0,30
Spongious bone	1,37	0,30
Gingiva	0,003	0,45
Gutta-percha	0,00069	0,45
Porcelain crown	120	0,28
Composite core	12,0	0,30
Titanium post	112	0,33
Glass fibre post	40	0,26
Zirconium post	200	0,33
Steel post	210	0,30
Zinc phosphate cement	22,0	0,35
Resin cement (low modulus)	7,0	0,28
Resin cement (high modulus)	18,6	0,28

The structural efficiency of restorations have been evaluated under 3 different loading conditions: (1) 100N force inclined at 135º with respect to the tooth axis, 2 mm below the incisal edge in order to simulate mastication loads; (2) 100N vertical pressure in order to simulate axial loads; (3) 100N horizontal force to simulate an accidental impact force.

In order to identify areas of strain and stress concentration where possible fatigue failures are more expected to occur, the choice of the pertinent stress representation criterion was based on the evaluation of failure predictive potential of the analysis performed. Von Mises (equivalent stresses) energetic criterion was then chosen.

To standardize the results of the analysis, 22 different points were defined on the model and their analytical positions were determined (Fig. 1b)[10].

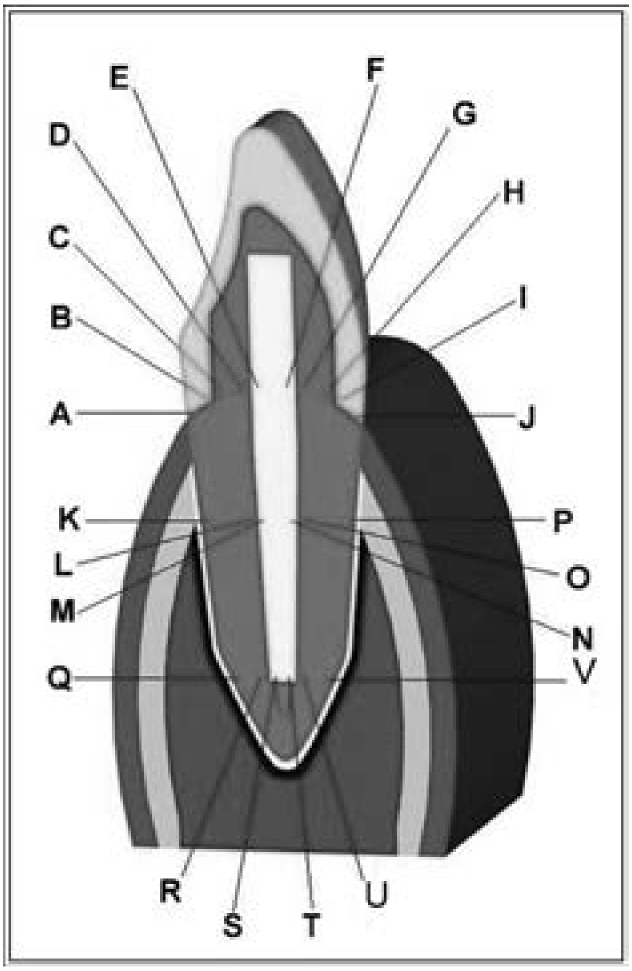

Figure 1b. Schematic presentation of the tooth model and local coordinate system

Results

The effect of coronal destruction, post materials, cements, and loading were shown in table 2. In functional loading, the presence of 2 mm coronal dentin tissue decreased the maximum stress values in all models. 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 fibre post bonded with adhesive resin cement having low elastic modulus in all loading conditions (Figs. 2-5).

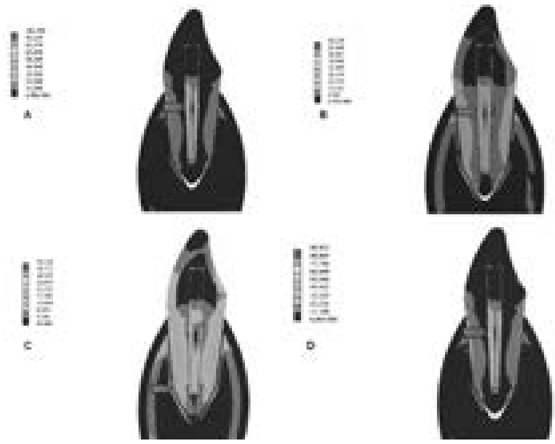

Figure 2. Effect of the post material bonded with adhesive cement (high) under functional loading in the model with 2 mm surviving dentinal walls (A) Steel post, (B) Titanium post, (C) Glass fibre post, (D) Zirconium post

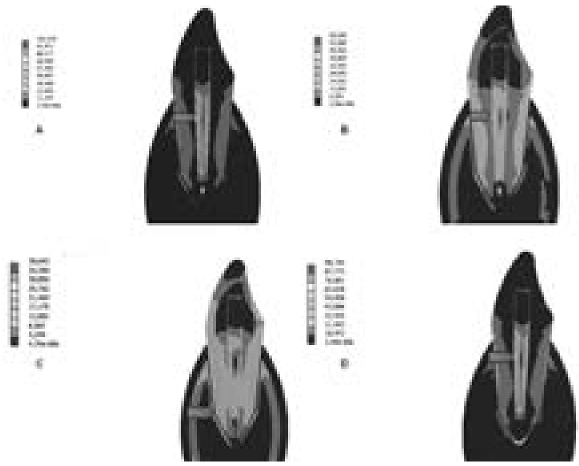

Figure 3. Effect of the post material bonded with adhesive cement (low) under functional loading in the model with 2 mm surviving dentinal walls (A) Steel post, (B) Titanium post, (C) Glass fibre post, (D) Zirconium post

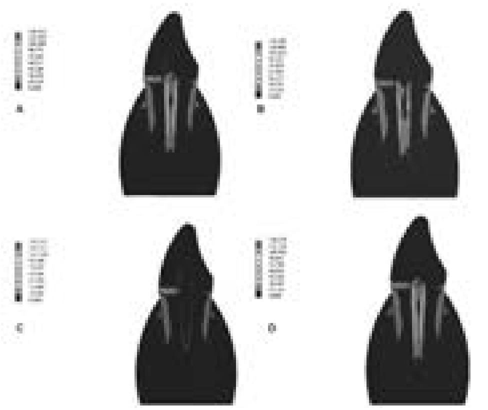

Figure 4. Effect of post material bonded with adhesive cement (high) under functional loading in the model with no surviving dentinal walls (A) Steel post, (B) Titanium post, (C) Glass fibre post, (D) Zirconium post

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

	No coronal dentin	135	Vertical	Horizontal
Zinc Phosphate cement	Steel post	147,04	58,01	147,93
	Titanium post	181,65	54,43	150,16
	Glass fibre post	154,95	56,66	155,83
	Zirconium post	147,15	55,45	148,05
Adhesive cement low	Steel post	129,9	58,94	132,77
	Titanium post	74,26	34,94	75,8
	Glass fibre post	71,55	25,77	72,3
	Zirconium post	123,52	56,33	126,41
Adhesive cement high	Steel post	136,16	58,12	137,1
	Titanium post	138,38	50,27	139,38
	Glass fibre post	143,11	52,02	144,16
	Zirconium post	136,27	55,56	137,22
Adhesive restoration		40,56	17,28	40,17
	2 mm coronal dentin	135	Vertical	Horizontal
Zinc Phosphate cement	Steel post	101,08	51,41	108,69
	Titanium post	91,07	32,73	91,91
	Glass fibre post	92,55	33,05	93,41
	Zirconium post	96,45	49,35	103,78
Adhesive cement low	Steel post	103,47	52,3	110,47
	Titanium post	58,5	31,3	63,08
	Glass fibre post	38,64	26,07	37,24
	Zirconium post	98,74	50,21	105,48
Adhesive cement high	Steel post	104,75	59,42	111,21
	Titanium post	59,22	35,96	63,44
	Glass fiber post	39,11	26,23	37,68
	Zirconium post	99,97	56,99	106,19
Adhesive restoration		39,27	26,21	37,56

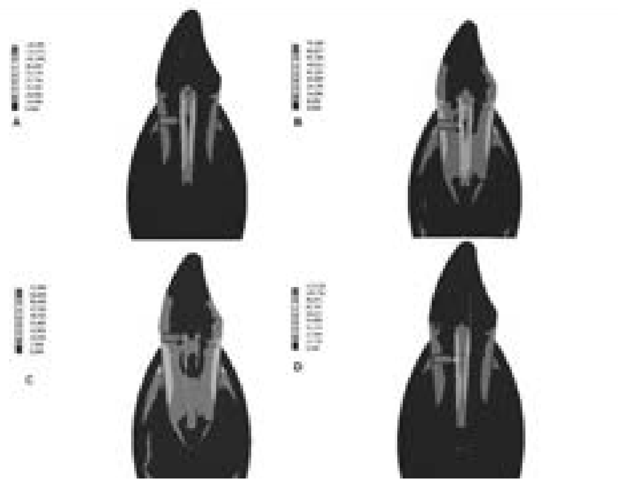

Figure 5. Effect of post material bonded with adhesive cement (low) under functional loading in the model with no surviving dentinal walls (A) Steel post, (B) Titanium post, (C) Glass fibre post, (D) Zirconium post

Regions of maximum stress changed for the different loading conditions. In functional loading, maximum equivalent stress mostly occurred at the vestibular side of the cement layer (interface between post and cement). As expected, in the bruxism case, the maximum stress area was located near the post apex. The area of maximum stress was located at the palatal surface in horizontal loading from the buccal aspect.

Under functional loading in the model without coronal dentinal tissue, the stress reached a maximum value of 181.65N for the titanium post and zinc phosphate cement, while it reached a significantly lower value of 71.55N for glass fibre posts cemented with dentin like cements (low elastic modulus), and 143.11N for glass fibre posts cemented with softer cements (high elastic modulus). There was a significant difference in stress distribution at dentin interfaces for the glass post restored tooth cemented with materials of different rigidity. In the model with 2 mm coronal dentinal tissue, the difference between the stress values of glass fibre posts bonded with different cements was less.

However, even if significantly different load transfer characteristics from post to root occurred in the cases examined, no differences were evident at the level of external root structure either for stress distribution and intensities (Figs. 6-8).

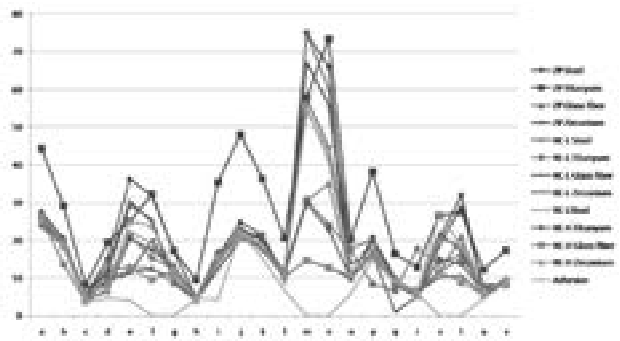

Figure 6a. Effect of post material and cement under functional loading in the model with no surviving dentinal walls

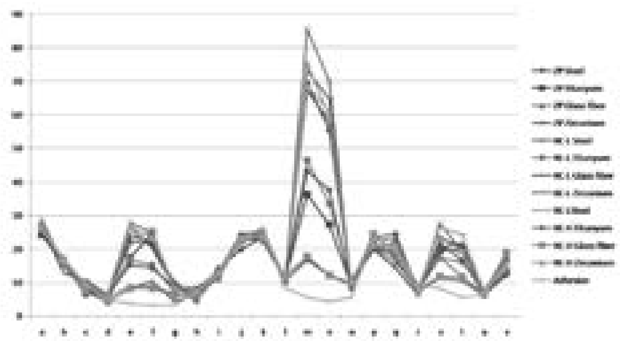

Figure 6b. Effect of post material and cement under functional loading in the model with 2 mm surviving dentinal walls

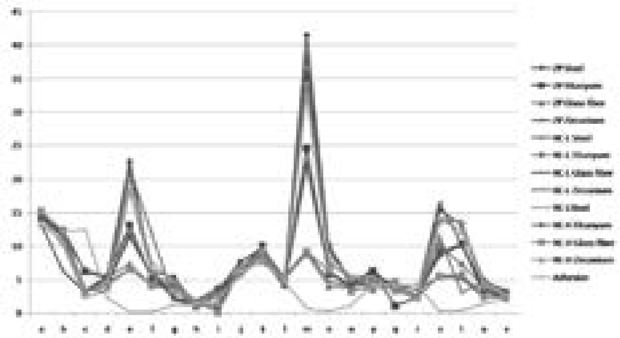

Figure 7a. Effect of post material and cement under vertical loading in the model with no surviving dentinal walls

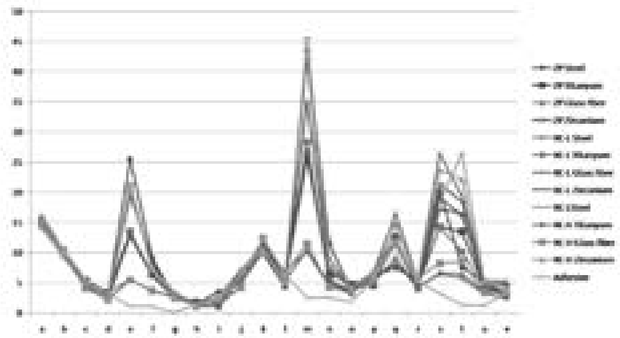

Figure 7b. Effect of post material and cement under vertical loading in the model with 2mm surviving dentinal walls

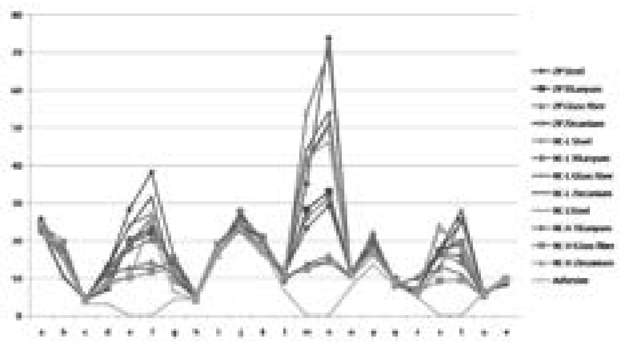

Figure 8a. Effect of post material and cement under horizontal loading in the model with no surviving dentinal walls

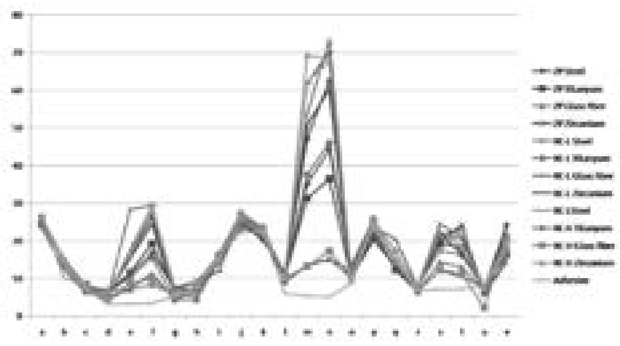

Figure 8b. Effect of post material and cement under horizontal loading in the model with 2 mm surviving dentinal walls

In particular, the investigation on central incisor tooth showed differences in load transfer capability of cast post when different cements were used. The stress was found to be 123.52 for zirconium posts cemented with dentine like cements (low elastic modulus) and 136.27 for glass fibre posts cemented with softer cements having high elastic modulus (Tab. 2, Fig. 5). Glass fibre posts exhibited the lowest stress values in the cervical part (Point f), middle part (Points m and n) and apical part of the post (Points s and t) in all loading conditions (Figs. 6-8). Steel posts exhibited higher stress values at the middle part of the root than glass fibre and titanium posts with all types of cements and under all loading conditions (Figs. 6-8).

The stresses decreased in order of steel, zirconium, titanium, glass fibre, with low modulus adhesive cement. The stresses decreased in order of glass fibre, titanium, zirconium, steel, with high modulus adhesive cement. Minimum stress values were obtained with the glass fibre post bonded with adhesive resin cement with low elastic modulus in all loading conditions (Tab. 2; Figs. 3c and 5c). The placement of an endodontic post created higher stress areas than adhesive restorations without posts.

Figures 6-8 show the stress patterns for the various post restorations considered here. The figures are grouped for each loading condition. Glass fibre restored system ensured enough uniformity of stress level (Figs. 6-8). It can be seen that the stress values in the post become less uniform as the stiffness of the post increased. The stress value at the middle of the steel post was 5 times as large as the stress at the glass fibre post. Steel posts and traditional cements, being no adhesive and also more rigid than fibre posts and resin cements, did not allow a homogeneous stress distribution (Figs. 6-8).

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. Regions of maximum stress changed for the different loading conditions. In functional loading, maximum equivalent stress mostly occurred at the vestibular side of the cement layer - interface between post and cement (Figs. 2-5, 6a and 6b). As expected, in the bruxism case, the stress near the post apex was higher than the other loading conditions (Figs. 7a and 7b). The stress values on the buccal aspect were higher in the horizontal loading (Figs. 8a and 8b).

Discussion

The 3D FEA showed significant changes in the stresses induced in the tooth-restoration complex when the investigated parameters varied. A post with biomechanical properties similar to those of dentin could be advantageous by reducing the risk of tooth root fractures. A very stiff post, working against the natural function of the tooth, creates zones of tension and shear both in the dentin and at the interfaces of the luting cement and the post[7,10]. Glass and carbon posts exhibit high fatigue and tensile strength, and they have a Young's modulus comparable to dentin[2]. 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[3,13]. Bonding between the post and the cement and between the cement and the dentin appears as an important parameter to achieve optimal behaviour of endodontic restorations. On the contrary, steel posts and traditional cements do not allow a homogeneous stress distribution. In this study, increased elastic modulus of the post was found to cause decreased dentin stress. This result is in agreement with the earlier *in vitro* investigations[3,11,13]. The FEA study of Pegoretti et al[14] concluded that glass fibre post resulted in lower stresses inside the root than did the carbon and metal post. Isidor et al[4] found that teeth restored with a carbon fibre post were more resistant to fracture than teeth restored with a titanium post. Several *in vitro* studies have determined the resistance to fracture of post restored teeth under static loading and found smaller, the same or higher strength of teeth restored with fibre posts than those restored with metal posts[6,9].

The maximum shear stresses were found to be primarily located at post cement/dentin interface. Cohen et al[15] reported that micro-movement of a cemented post results in disintegration of the cement and the concentration of stress at the apical end of the post over time. The fracture strength of dental cements is less than that of dentin or post material. Thus, failure of the system usually occurs cohesively within the cement or at its interface with dentin.

There was a significant difference in 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 the model with 2 mm coronal dentinal tissue, the difference between stresses values of posts bonded with different cements was less. Clinically, both carbon and glass posts are subjected to de-bonding/loosening phenomena[16]. Tough cement systems could improve the restoration reliability by opposing to mechanical progression of failure and crack growth.

Recently, several papers supported the use of a direct restoration without placing any post for restoring endodontically treated teeth[17]. Krejci et al[5] 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[3,9,18]. In endodontically treated teeth, occlusal loads could be transferred intra-radicularly by post restorations, increasing the occurrence of vertical root fractures. On the contrary, other authors noticed that fibre posts reduced the risk of root fractures[19]. Actual consensus in restorative dentistry indicates that de-cementation or failure of posts is preferable than fracture of residual tooth structure[2]. In this study, the stress values and location of maximum stress in glass fibre post restored teeth were less. The less residual tooth structure the more important the physical properties of post-and-core systems.

This study confirmed that the reconstructed tooth is subject to most stress in the cervical region under a functional load. Pierrisnard et al[18] 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 of 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 post material on maximum stress and displacement.

It clearly appears that the oblique load is more critical than the vertical one, both for restoration structures and residual dentin. Moreover, the results' analysis shows a deeply different behaviour between post-core restorations and adhesive restoration without post. As far as residual dentin is concerned, a significant reduction of the mean stress level is obtained at the middle/cervical root zone, whereas high peaks of the average stress are induced at the root apex. Furthermore, high stress concentrations at the post-dentin interface appear.

Finally, the choice of the posts' material and type of cement appears very important when the stress values and dentin-interfaces were considered. A post with biomechanical properties to those of dentin could be advantageous by reducing the risk of tooth root fractures. The ideal root canal post must be sufficiently elastic to accompany the natural flexural movements of the structure of the tooth, something that a very rigid metal post cannot do.

Conclusions

FEA 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.

Within the limitations of this FEA study, the fallowing conclusions were drawn:

- The placement of an endodontic post creates an unnatural restored structure since it fills the root canal space with a material that has a defined stiffness unlike the pulp. Hence it is not possible to recreate the original stress distribution of the tooth. Steel posts are the most dangerous for the root, potentially leading to its fracture. Even working on the cement layer, stress absorbing capability by using less rigid cements cannot possibly improve the stress arising in the system because of the high rigidity of the steel post. Using a fibre post reconstruction, the elastic modulus of the cement layer strongly influences the stress absorbing capability of the system;
- In functional loading, maximum equivalent stress mostly occurs at the vestibular side of the cement layer;
- The presence of 2 mm coronal dentin tissue decreased the maximum stress values in all models;
- Horizontal loading from the buccal aspect increased and vertical loading decreased the maximum stress in all models;
- Minimum stress values were obtained with the glass fibre post bonded with adhesive resin cement with low elastic modulus;
- The stress decreased with the post material in order of steel, zirconium, titanium, glass fibre;
- The ideal root canal post must be sufficiently elastic to accompany the natural flexural movements of the tooth structure, something that a very rigid metal post cannot do;
- Bonding between the post and the cement and between the cement and the dentin appears an important parameter to achieve optimal behaviour of endodontic restorations.

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