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Mechanical performance of endodontically treated teeth

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Abstract

This paper aims at evaluating the mechanical performance of endodontically treated teeth. A three-dimensional finite element analysis of teeth is presented. The stress distribution in the teeth restored with a few variants of posts is compared. An improved design of the post is presented. A study on alternative materials for posts has been reported. Conclusions on the ideal shapes and materials of the posts are drawn.

1. Introduction

In the field of endodontics, restoration of an endodontically treated tooth is a challenging task for a restorative dentist. The emphasis on maintenance and preservation of natural dentition has created an unprecedented boom in this area. In cases where there is extensive decay of a tooth or a tooth fracture due to trauma, a conventional filling is inadequate. Under these circumstances *root canal* treatment is initiated (Fig. 1). In this method, the tooth is *killed* replacing its central vital pulp by a soft thermoplastic material called gutta percha. Then removing about 3/4th of this material, a dowel or a post is inserted and a composite core is constructed over it. Finally an artificial crown made of ceramic is placed over it. The success of the method depends heavily on the design of the dowel (post). There are many dowel designs available for the restoration of an endodontically treated tooth. These may vary from the conventional custom-made dowels to the prefabricated ones. Understanding the biomechanical factors that affect the ability of a dowel to retain a restoration and protect the remaining tooth structure is paramount in the successful design of a dowel core system. Parameters such as material, length, diameter, configuration and surface roughness affect

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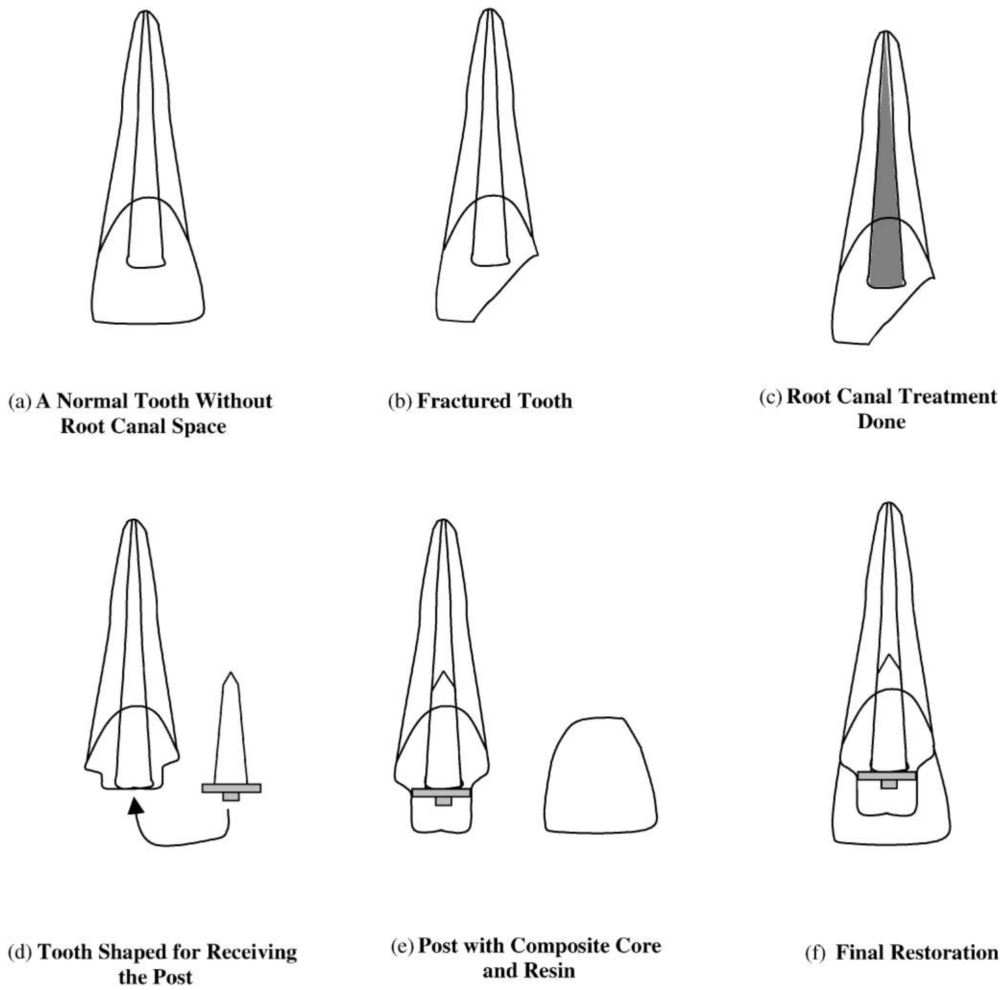


Fig. 1. Root canal treatment and tooth restoration.

its mechanical properties. Several researchers have studied the mechanical aspects of endodontically treated teeth. Pioneering research on prefabricated posts [1–3] has given an insight to the post behavior. It is observed that screw posts generate high stresses during installation and function. Tapered posts exhibit wedging effect and produce shoulder stress concentration. Several studies have been carried out on the effects of cast post and core on stress distribution in the dentin. The effects of post dimensions on the stress distribution have also been studied. These have used either photoelastic methods or two-dimensional finite element analysis [4–6]. Moreover, previous finite element analyses have simplified the problem either by plane stress, plane strain or axisymmetric assumption [4,7–9]. However, neither the tooth structure nor the loads on it follow these assumptions. Some studies have been carried out using three-dimensional finite element analysis [10]. These use the digitized data from computer scanned images for model generation. The analyses have been performed for specific tooth structure, post type and material.

This paper presents a three-dimensional finite element analysis of endodontically treated teeth to study the efficacy of the treatment. A comparison of generic posts viz. cast post and core, parallel post and hollow post is presented. An improved post design is also demonstrated. A previous study of this post design with reference to its retentive properties has shown promising results [11,12]. The new design has several advantages. It has better retentive properties as compared to parallel posts. The design also gives better vertical support, venting and torsional resistance. Stress concentration, especially at the interface of the dentin and the post, is a critical factor for durability. The stress distribution in the dentin in presence of these endodontic posts and the behavior of the posts themselves under masticatory loads has been studied in detail in the present paper. Other factors such as post material and the effect of the presence of a crown on the stress distribution have also been studied. This study recommends the ideal material and geometry of the endodontic post.

2. Materials and method

Fig. 2 shows the details of the tooth structure. Several researchers have employed two-dimensional finite element technique for stress analysis of tooth. However, it has been observed that the two-dimensional plane strain models exaggerate the effects of post placement in teeth. In this work a three-dimensional finite element analysis is employed for stress analysis of tooth structure. Three-dimensional brick and tetrahedral elements are used to generate the tooth model. The master model comprises of dentin, gutta percha, endodontic post, core, crown, periodontal ligament and cortical bone. Four such master models have been generated that incorporate different post designs viz. cast post and core, solid parallel post, hollow parallel post and the present post. The details of teeth with different posts are shown in Figs. 3a–d. Except for the model

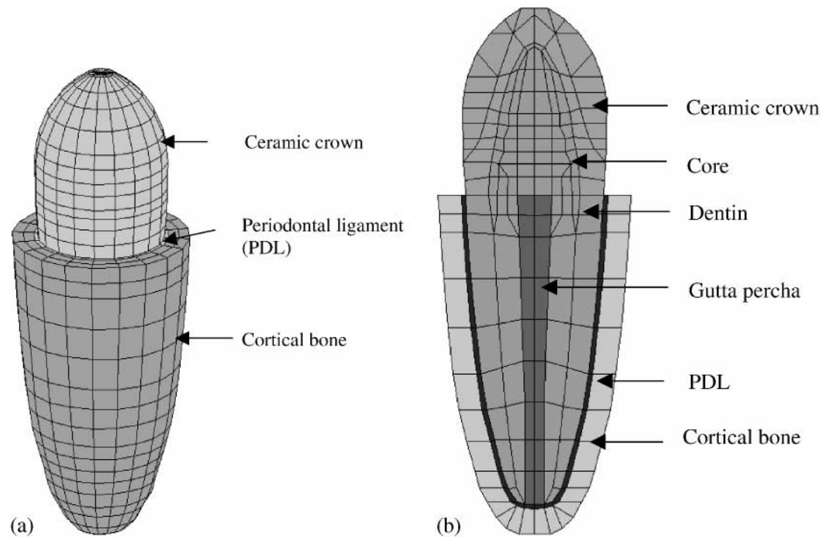


Fig. 2. (a) Three dimensional model of a tooth (b) Sectional view of endodontically treated tooth without post.

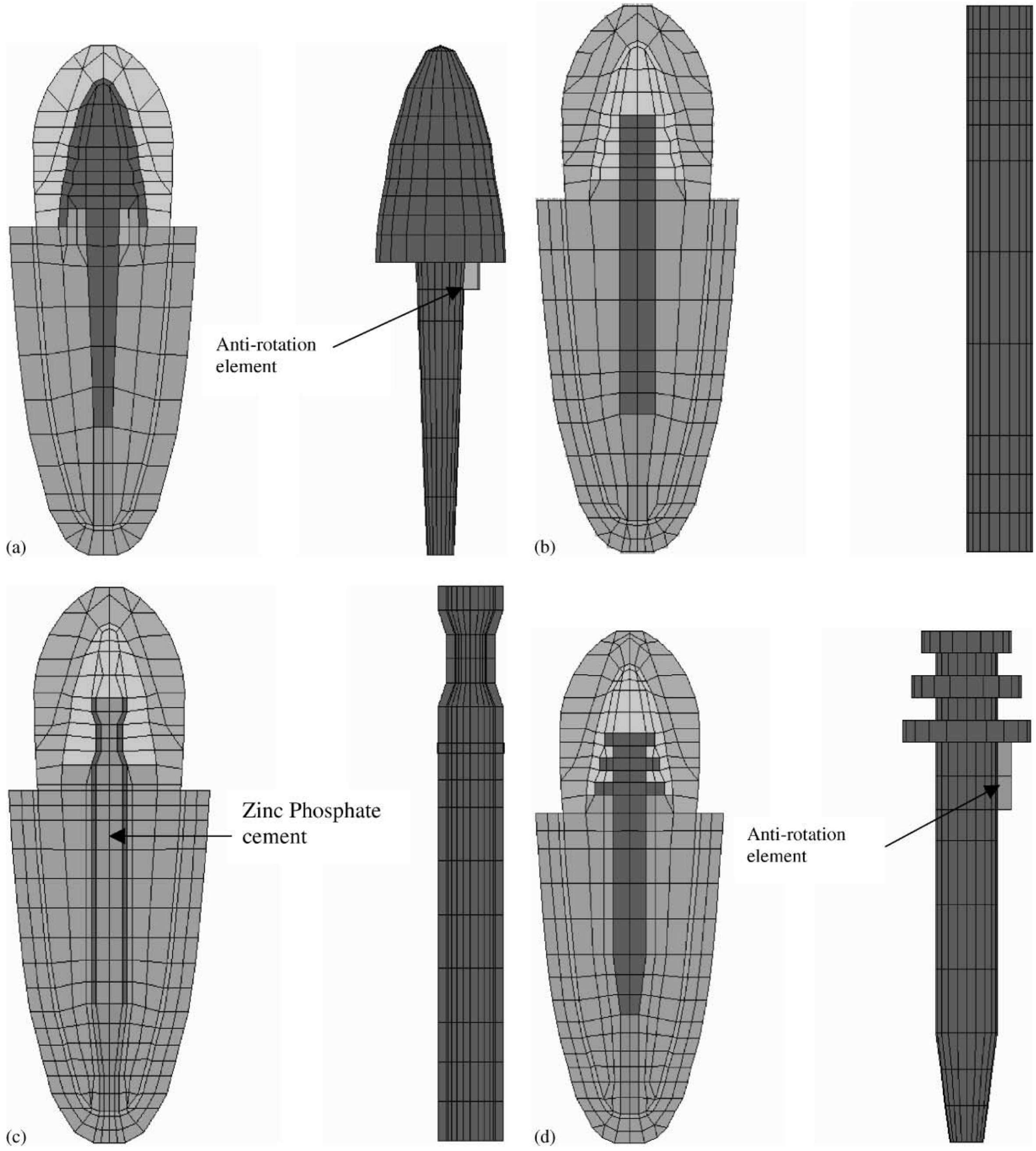


Fig. 3. (a) Sectional view of tooth restored with cast post and core. (b) Sectional view of tooth restored with parallel post. (c) Sectional view of tooth restored with hollow post. (d) Sectional view of tooth restored with parallel post.

Table 1
Models for study

Sr. no.	Crown	Post type	Post material			
			Stainless steel	Titanium	Ceramic	CFRC
1	✓	×				
2	✓	Cast post and core	✓ (Base metal)	×	×	×
3	✓	Parallel	✓	×	×	×
4	✓	Hollow	✓	×	×	×
5	✓	Present	✓	✓	✓	✓
6	×	Cast post and core	✓ (Base metal)	×	×	×
7	×	Parallel	✓	×	×	×
8	×	Hollow	✓	×	×	×
9	×	Present	✓	×	×	×

with cast post that has a core material of the same cast alloy all other models have a core made of composite resin. The crown in all models is made of porcelain. In every model, the margins of the crown have been placed beyond the core on sound tooth structure. The cast posts and core are made of base metal alloy while the remaining post designs are made of stainless steel. The present post and the cast post have an anti-rotation element in the cervical third. The cast post and core has been modeled with a ferrule of metal encompassing a vertical portion of the tooth and having a margin on second tooth structure. The hollow post has been modeled with its central hollow portion filled with zinc phosphate cement. Several models have been created for studying the behavior of the tooth as given in Table 1.

The dimensions of the tooth have been adopted from Wheeler [13] and Rosenstiel [14] and they represent data for a maxillary central incisor. The properties of the constituent materials are given in Table 2. The loads applied on each model are,

1. Oblique pressure giving a net force of 100 N at 45°.
2. Vertical pressure giving a net force of 100 N.
3. Horizontal pressure giving a net force of 100 N.

The stresses under these loads are inspected using von Mises criteria.

3. Observations

From the viewpoint of structural mechanics an endodontically treated tooth restored with an endodontic post, a core and a crown can be treated as a multi-component engineering structure made of complex geometry. Stress distribution in such a system is dependent on the geometry, rigidity and material of the post, rigidity of the supporting structures, material of the core, crown and the direction and magnitude of occlusal forces. In order to have a greater longevity of the restoration, the nature of stresses in terms of their magnitude and direction must be understood.

Table 2
Material properties

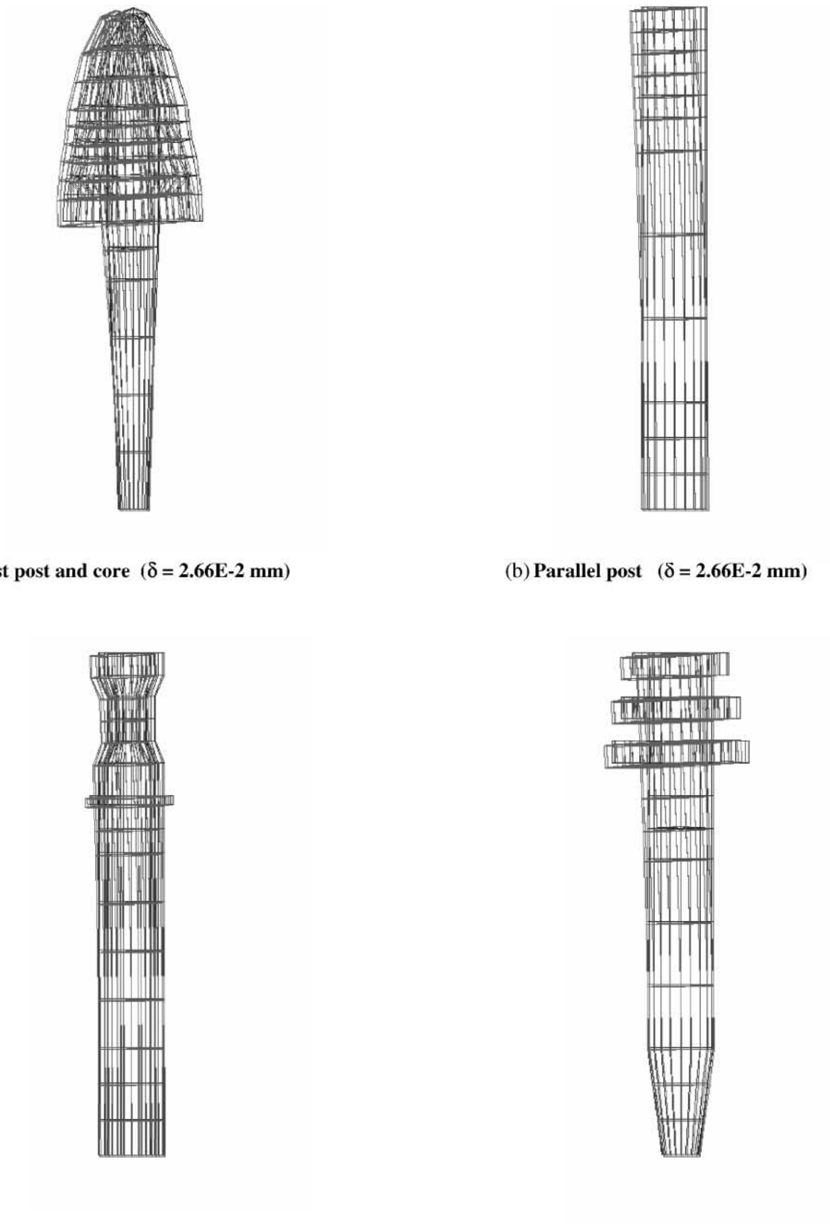
Sr. no.	Material	Young's Modulus (GPa)	Poisson's ratio
1	Dentin	18.6	0.30
2	Periodontal Ligament	68.9E-3	0.40
3	Cortical Bone	13.70	0.30
4	Gutta Percha	0.96E-3	0.40
5	Stainless Steel	200.00	0.30
6	Base Metal Alloy	200.00	0.30
7	Composite Resin	16.60	0.24
8	Ceramic	69.00	0.28
9	Titanium	120.00	0.30
10	Fiber Reinforced Composite	15.00	0.28
11	Zinc Phosphate Cement	22.4	0.25

Observation of the deformed shapes of the posts indicates a cantilever bending action (Fig. 4). The maximum stresses are seen in the middle thirds of the post on the side opposite to that of the load. A study of von Mises stresses in the tooth restored without a post with a ceramic crown only reveals a uniform stress pattern without areas of concentration. Teeth with posts have localized high stressed areas because of the stiffer post material. As a result, under clinical conditions posts behave as stress amplifiers causing localized high stress areas. This is in agreement with the results of previous investigators [2]. Previous studies have stated that posts cause a favorable stress distribution and that they reinforce teeth [10]. However, in the light of the present study, this is not the case. This study indicates that the teeth already weakened due to access opening can further weaken due to presence of posts. The placement of an endodontic post must be considered only when no option for retention of the core exists, bearing in mind that a tooth so treated has a greater likelihood of fracture in the future. Minimum tooth structure must be removed during post insertion.

The effects of shape of the posts, presence of crown and the material of the posts have been elaborated in subsequent sections.

3.1. Shape of posts

The von Mises stresses in the dentin and the post are presented in Tables 3 and 4 respectively. Higher stresses in the dentin are hazardous to the life of the remaining tooth structure, while high stresses in the post may endanger the post. Among the four post designs studied, stresses in the cast post are the least. The cast post has the same material (base metal) for both the post and the core. This leads to a favorable stress distribution. However, the cast post requires more visits to the dentist for implementation. The hollow post design shows high stress concentration and the stresses are about 25% higher than cast post. The hollow post is clearly unsuitable due to high stress concentrations. The present post shows 13.6% and 10% more stresses than the cast post and the parallel post, respectively. This is attributed to the decrease in area in the apical third due to the



(a) **Cast post and core** (**δ = 2.66E-2 mm**)

(b) **Parallel post** (**δ = 2.66E-2 mm**)

(c) **Hollow post** (**δ = 2.93E-2 mm**)

(d) **Present post** (**δ = 2.69E-2 mm**)

Fig. 4. Deformed shapes of various posts under oblique loading.

taper. The stress distributions in the posts under oblique load are shown in Figs. 5–8. The pattern of stress contours is similar for all designs. The cast post has same material for the post and the core. Unlike other cases where the core is made from soft resin, the core also contributes significantly in the distribution of stresses. This leads to least stress concentration. The design also

Table 3
Von-Mises stresses (MPa) in the dentin of endodontically treated teeth

Loading condition		Cast post and core		Parallel post		Hollow post		Present post	
	S.P	Opposite side	Same side	Opposite side	Same side	Opposite side	Same side	Opposite side	Same side
Oblique load[a]	A[a]	20.88	11.96	21.65	9.88	26.57	14.02	25.08	13.43
	B	22.43	13.79	22.70	15.22	32.83	14.15	24.62	14.36
	C	8.76	8.41	18.17	9.33	20.44	14.97	19.78	13.22
Axial load	A	11.20	11.15	13.97	13.90	17.00	17.05	15.04	15.04
	B	11.30	11.31	13.89	13.87	19.70	19.70	16.20	16.15
	C	13.39	13.35	9.75	9.70	13.64	13.69	11.82	11.84
Horizontal load	A	6.04	4.60	20.41	19.46	29.96	16.47	20.88	19.03
	B	14.16	4.71	21.33	18.35	28.47	22.66	22.97	20.90
	C	5.62	4.19	16.04	15.54	20.89	15.69	21.19	17.82

[a]A—Cervical third region; B—Middle third region; C—Aplical third region.

Table 4
Von-Mises stresses (MPa) in the endodontic posts

Loading condition		Cast post and core		Parallel post		Hollow post		Present post	
	S.P	Opposite side	Same side	Opposite side	Same side	Opposite side	Same side	Opposite side	Same side
Oblique load	A[a]	22.44	12.27	21.71	12.97	27.16	14.99	25.69	20.14
	B	26.12	14.57	26.86	17.73	34.08	24.41	29.18	19.69
	C	9.95	9.91	20.01	9.72	21.44	14.93	20.56	13.97
Axial load	A	11.61	11.61	12.31	12.30	17.10	17.08	15.69	15.71
	B	11.50	11.47	14.67	14.69	19.75	19.78	17.00	16.95
	C	13.90	13.95	11.80	11.79	13.85	13.88	12.20	12.17
Horizontal load	A	11.49	4.97	22.33	19.54	23.67	22.66	24.58	15.47
	B	14.36	14.36	22.04	18.71	25.99	25.70	29.85	21.23
	C	9.77	9.77	18.74	18.58	23.29	18.65	16.99	15.79

[a]A—Cervical third region; B—Middle third region; C—Aplical third region.

incorporates the ferrule effect that has been discussed by previous investigators. [5,6]. The ferrule prevents wedging of tapered posts by having a shoulder of metal resting on sound tooth structure and improves stress distribution by bearing, through direct contact of the post and core with the

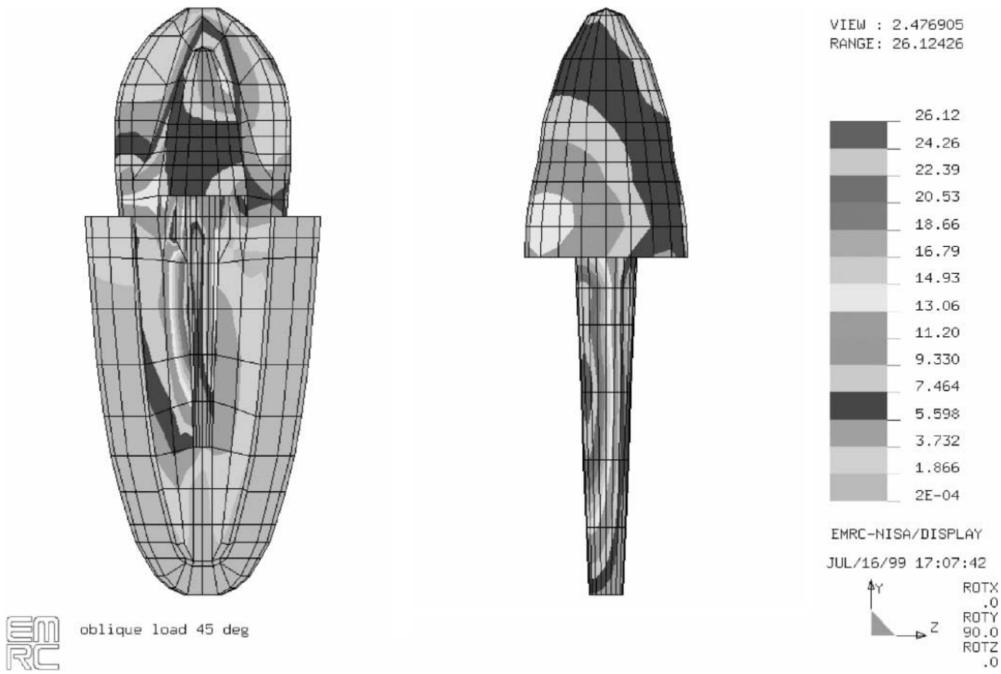


Fig. 5. Von-Mises stresses in tooth with cast-post and core under oblique load.

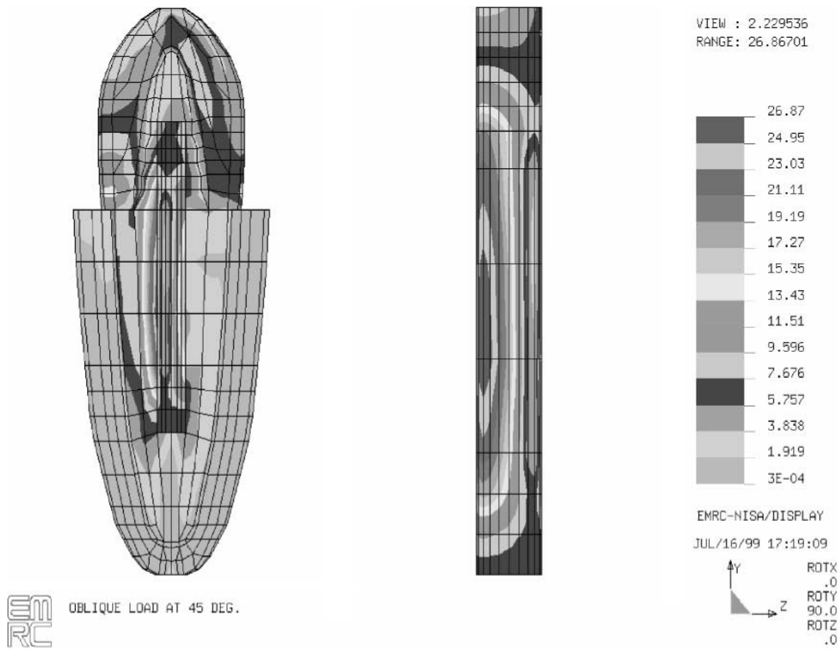


Fig. 6. Von-Mises stresses in tooth with parallel post under oblique load.

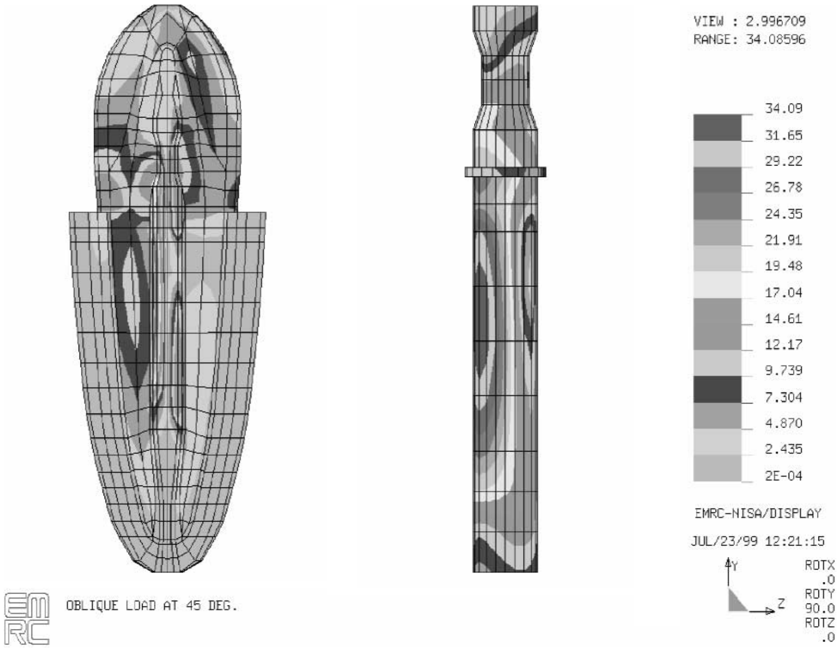


Fig. 7. Von-Mises stressed in tooth with hollow post under oblique load.

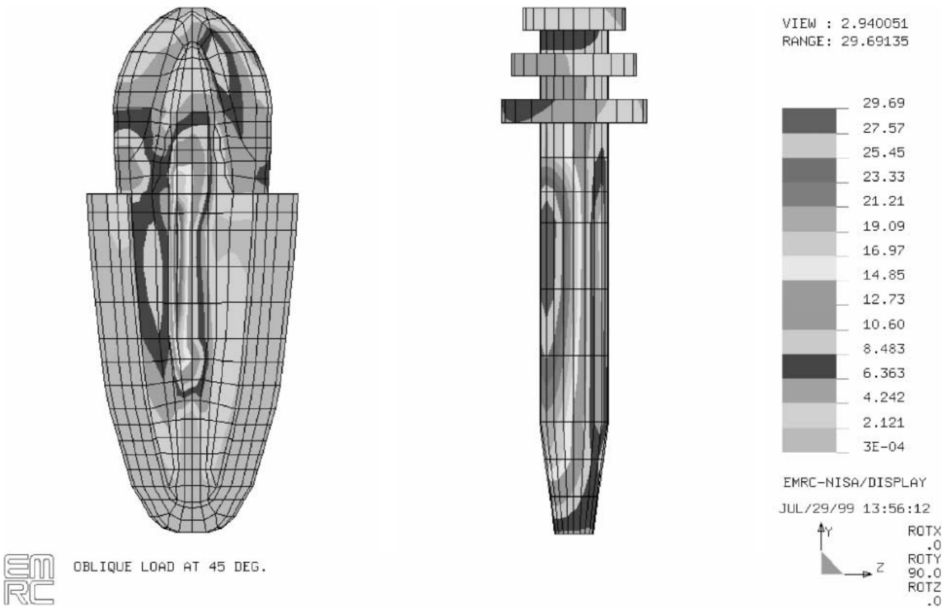
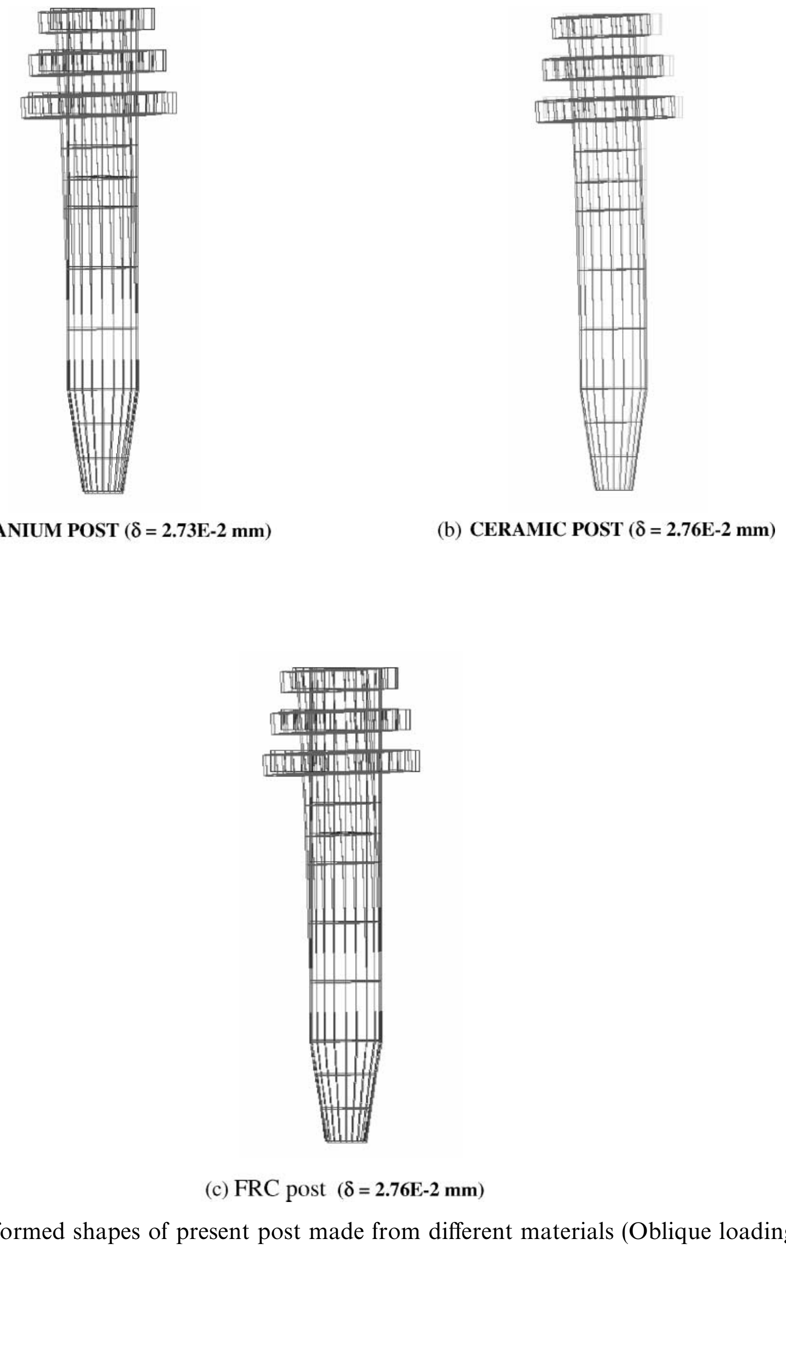


Fig. 8. Von-Mises stresses in tooth with present post under oblique load.

dentin. This post design also shows a better resistance to torsional forces by means of the anti-rotation element.

3.2. Effect of crown

In this section we assess stress patterns due to post placement only in absence of the crown. Although this situation has no clinical parallel, it has been studied to evaluate the post designs. An



(a) **TITANIUM POST (δ = 2.73E-2 mm)** (b) **CERAMIC POST (δ = 2.76E-2 mm)**

(c) FRC post **(δ = 2.76E-2 mm)**

Fig. 9. Deformed shapes of present post made from different materials (Oblique loading).

oblique load of 100 N was applied on the tip of the post. The results indicate that although in the presence of crowns stress contours in the posts and surrounding dentin are quite similar, in absence of the crown they are markedly different in magnitude and distribution. This suggests that when crown is placed on sound tooth structure with a ferrule effect the underlying post geometry is of lesser significance. Cast post shows least stresses. The present post shows about 15% higher stresses than cast post. The stresses in the parallel post and the hollow post are about 35% higher than the cast post.

3.3. Effect of post material

Post material has a significant effect on the stress concentration. The performance of present post made of titanium, ceramic and fiber reinforced composite (FRC) has been evaluated. The stresses depend on the elastic modulii of the material. Stainless steel has the highest elastic modulus followed by titanium, ceramic and FRC (Table 2). The FRC has high strength but low elastic modulus. The deformations in these posts vary marginally but the stresses are markedly different (Fig. 9). The FRC posts show least stresses with most favorable distribution, approaching that of a tooth without a post (Fig. 10). Ceramic posts show 20% higher stresses while titanium posts show 25% higher stresses than ceramic posts. Overall, these posts show better stress distribution than stainless steel posts. The stress distribution in present posts made from stainless steel and FRC are compared in Figs. 11 and 12. The FRC allows *stiffness tailoring* where the modulus and strength of the composite can be controlled. Therefore, it is possible to design the posts with a modulus close to

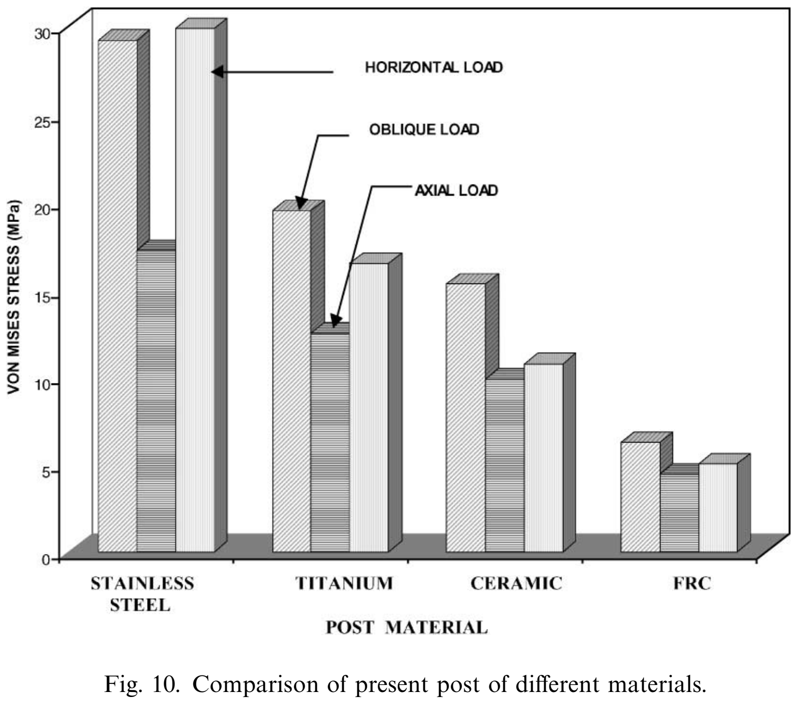


Fig. 10. Comparison of present post of different materials.

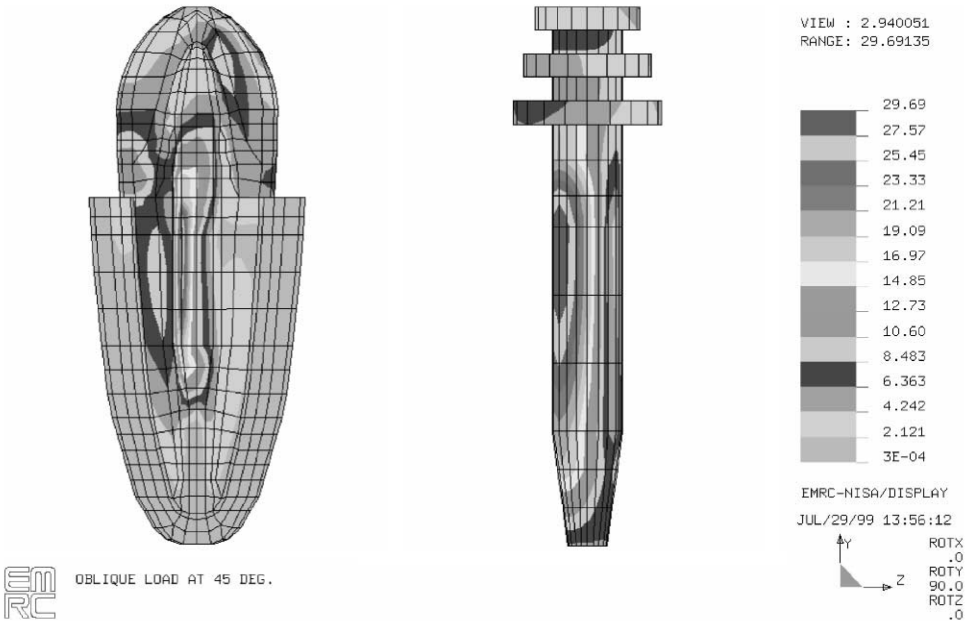


Fig. 11. Von-Mises stresses in stainless steel post under oblique loading.

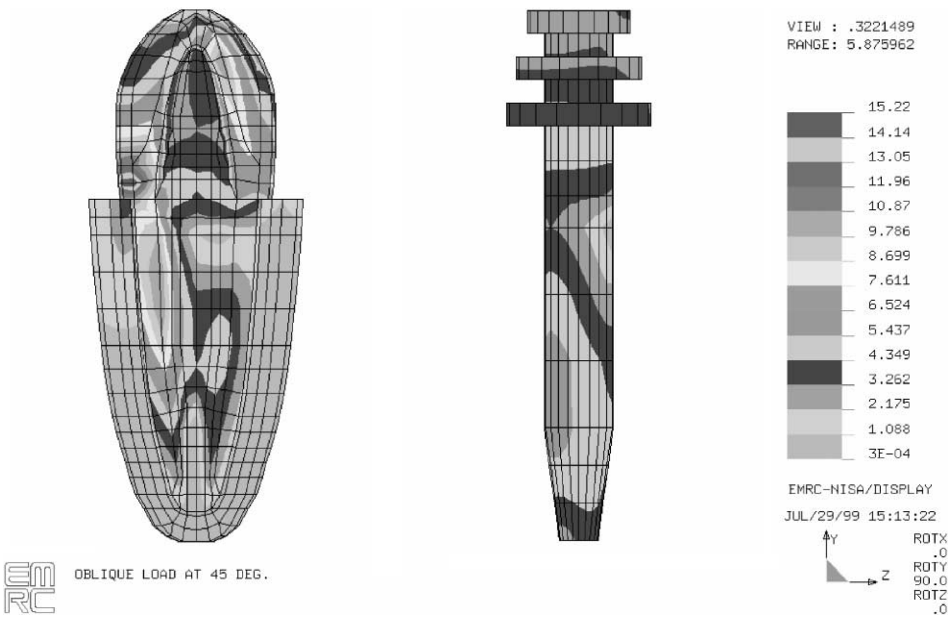


Fig. 12. Von-Mises in FRC post under oblique loading.

that of the existing tooth structure. This would avoid stress concentration. The failure in the FRC post is *gradual* as debonding occurs between individual fibers and the matrix before fracture. Also, the post can be designed to fail before the tooth fractures. This is a great advantage as fracture in the tooth structure generally necessitates extraction of the tooth. Ceramics may also prove to be a better alternative to steel as its mechanical properties are closer to that of the dentin, but their brittleness may be a critical factor.

4. Conclusions

1. For endodontic treatment of tooth the post design that conserves the maximum tooth structure and provides best retention to the core must be used.
2. Among the post designs studied, the cast post shows the least stresses with most favorable distribution, while the hollow post shows the largest stresses with highest stress concentration. The present post shows marginally higher stresses than the cast post and the parallel post.
3. Among the materials studied, stainless steel posts show the highest stress followed by titanium, ceramic and FRC posts.
4. Posts fabricated from conventional materials do not reinforce teeth. Rather they cause areas of stress concentration that may make endodontically treated teeth susceptible to fracture. FRC posts bonded to the dentin have the best potential to reinforce teeth.

To sum up, a clinical examination must be carried out to determine the necessity of an endodontic post. If the post must be placed, the shape of the post must be chosen keeping in mind that maximum coronal dentin must be preserved. The ideal post material should have stiffness properties close to that of the dentin. Moreover, the post material should be tailored to prevent fracture in the existing tooth structure. The failure in the post should also be gradual. The only class of materials that can possess all these properties are composites. In this paper we report an efficient geometry of the post along with a comparison of a few existing materials. Development of a *tailored* post will be reported in future.

5. Uncited references

[15,16]

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