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Original Research

Stress evaluation of maxillary central incisor restored with different Ni Cr and Zirconia post materials: A finite element analysis

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ABSTRACT:
Introduction: For a successful restoration, knowledge,selection and proper use of restorative materials is critical. As far as rehabilitation of compromised tooth structure is concerned, post and coreoffers considerable functional advantage to the patient. Various types of posts have been used by practitioners like cast metal post, gold post, titanium post, carbon and glass fiber post and zirconia post in the recent past. Each of the above mentioned posts have several advantages and disadvantages. The main concern of posts is their difference in modulus of elasticity from dentin which may generate deleterious stresses that affect the long term success of the restoration. **Aim:** The present study was undertaken to evaluate the stress distribution of two most commonly used materials in dental practice i.e. cast metal postand zirconia post. A series of computer programs like MIMICS, Hypermesh version 13.0 and ANSYS 12.1 were used to create a computerized model of a maxillary central incisor which was restored with different post materials. A 3-D finite element analysis was carried out on the tooth and an arbitrary load of 100 N was applied to the model at an angle of 45^0 on the palatal surface to simulate normal masticatory load. Von Mises stress distribution on both the posts was noted on three different parts of the root i.e. cervical third, middle third and apical third. A colour coding was used where red depicted the area of maximum stress and blue depicted the minimum stress and the shades in between showed variation of stresses from maximum to minimum. The data obtained from the study were evaluated to observe the effect of different post materials on the stress they generated on the root and surrounding structures. **Results:** Results showed that maximum stresses were seen on the cervical 1/3rd in each post material indicating that this region is more prone to fracture in tooth restored with posts. Among the three materials tested Ni-Cr post showed maximum stress generation followed by zirconia post.

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INTRODUCTION

Due to considerable amount of tooth structure loss as a result of caries, endodontic treatment, and placement of previous restorations, retention of subsequent restoration of the toothis more challenging and increases the likelihood of fracture during functional loading. In such cases where a substantial amount of coronal structure is missing, a post and core is indicated.The primary function of the post is to retain the core, which subsequently provides a suitable foundation for final restoration placement. It also provides a substructure for anchoring a final restoration to the tooth.[1]The selection of postmaterial is based on its biocompatibility, mechanical properties, ease of fabrication, and availability in market and cost factor. Structurally compromised roots have conventionally been restored with casting posts and cores with the advantages of poststiffness, optimum adaptation, and high retention.[2] Metallic posts include titanium (Ti) and nickel-chromium (Ni-Cr) posts. Newer materials include ceramics and fiber reinforced resin[3,4,5]used for their unique aesthetic properties and other positive features. The key element of tooth preparation, when using post and core is the incorporation of the ferrule. Extension of axial walls of the crown apical to missing tooth structure provides the ferrule. It helps to bind the remaining tooth structure and prevents root fracture during the function.[6,7]In the past, several methods like experimental methods and the finite element method used have been used to analyse the effects of the post-core system on the stress distributions in dentin having their own advantages.

Intraorally, post and core restorations like any other restoration, are subjected to masticatory forces. The stress originated by the masticatory forces in an endodontically treated tooth restored with post and core can cause root fracture. Post and core restorations are multicomponent complex systems wherein the stress distribution within the structure is multi-axial, nonuniform, and depends on the magnitude and direction of the applied external loads. A theoretical well-known method for calculating stress distribution within such a complex structure is the FEM, which allows the investigators to evaluate the influence of model parameter variation, once the basic model has been correctly defined.

The present study analyses and compares the stress distributed by most widely used post materials now days; i.e. Ni-Cr, and Zirconia.

AIM AND OBJECTIVES

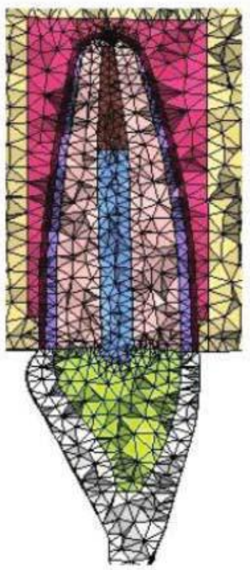
1. To evaluate, through Finite element analysis the stress distribution of custom made posts of different compositions.
2. To evaluate the stress distribution of Cast metal (Nickel-Chromium) posts at three regions.
3. To evaluate the stress distribution of Zirconia posts at three regions.
4. To compare the stress distribution of these two types of posts at three regions.

METHOD

Finite element modelling (FEM) uses the concept of representing the object by an analytic model consisting of a finite number of elements that are interconnected at a finite number of points called nodes. This collection of nodes and elements forms the finite element mesh which are the building blocks of the numerical representation of the model used in the study. Using computer tomography (CT) slice images of the maxillary central incisor at a slice thickness of 1 mm, an analytical model was created. These images were recorded in Dicom format and were converted into to Initial Graphics Exchange Specification (IGES) and Stereolithography (STL) formats using MIMICS software (Materialise Interactive Medical Image Control System Version 8.11). The geometric model was then converted into finite element model by using Hypermesh Version 13.0, which is a general purpose processor. Ansys was the solver used to do the analysis of the present study.

The model was divided into large number of elements and nodes. Total nodes were 13691 and total elements were 64201.

Fig 1



The post model was generated using a Computer Aided Reverse Engineering (CARE), using a laser based range scanner. The posts used were parallel posts having a length of 12 mm and diameter of 1.5 mm. Each point on the post had an x, y and z co-ordinate locating the point in 3-D space. The collection of these points is called a point cloud. The point cloud and the detected features were then used by the CARE system to model the entire geometry of the post.

The material properties assigned were the Young's modulus of elasticity (E) and the Poisson's ratio (*v*). The corresponding elastic properties such as Young's modulus of elasticity (E) and the Poisson's ratio (*v*) of post, dentin, cementum, PDL, core, crown, and cortical and cancellous bone were incorporated.

Table 1. Material Properties Material		
	Elastic modulus (MPa)	**Poisson's ratio (v)**
Dentin	18.6 x 103	0.31
Periodontal ligament	69	0.45
Cortical bone	13.7 x 103	0.30
Spongy bone	1.37 x 103	0.30
Gutta Percha	0.69	0.45
Zirconia post	200 x 103	0.33
Fiber glass post	45 x 103	0.32
Cast metal post	210	0.33

A total of three configurations were evaluated and in each one of them the highest von Mises stress values in the root were recorded after a load of 100 N was applied at angle of 450 at the palatal surface on the cingulum of the tooth.

RESULTS

The following study was conducted with an objective to evaluate the stress distribution of two different post materials on a maxillary central incisor.

With a Ni-Cr post of 8 mm length, the maximum stress value recorded was 10.09 MPa at the cervical 1/3rd of the root. At the middle 1/3rd of the root the maximum stress value recorded was 8.12 MPa and at the apical 1/3rd the maximum stress value recorded was 6.61 MPa (Fig. 2).

The maximum stress recorded on the root with each post material is depicted in table 2.

Table 2: Distribution of stresses generated by different posts Material							
	Maximum stress on dentine (MPa)	**Maximum stress on PDL (MPa)**	**Maximum stress on post (MPa)**	**Maximum stress in core (MPa)**	**Maximum stress in crown (MPa)**	**Maximum stress in cortical bone (MPa)**	**Maximum stress in spongy bone (MPa)**
Ni-Cr	4.29	0.38	10.09	8.1	48.14	36.09	2.18
Zirconia	4.06	0.38	9.58	8.1	48.55	39.10	2.18

With a Ni-Cr post of 8 mm length, the maximum stress value recorded was 11.04 MPa at the cervical 1/3rd of the root. At the middle 1/3rd of the root the maximum stress value recorded was 9.92 MPa and at the apical 1/3rd the maximum stress value recorded was 7.68 MPa (Fig. 9).

Fig 2

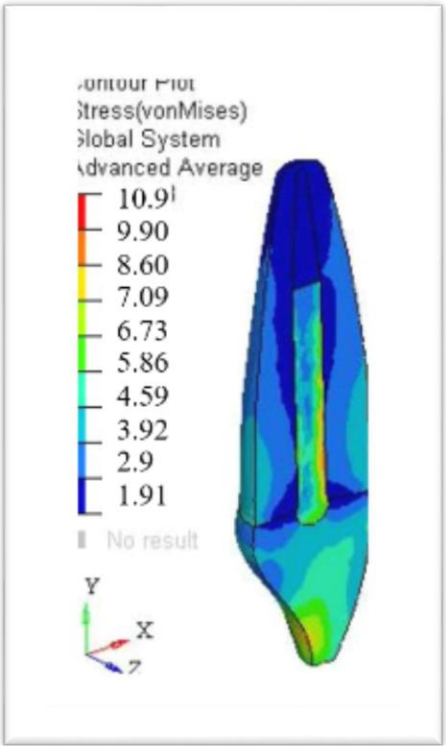
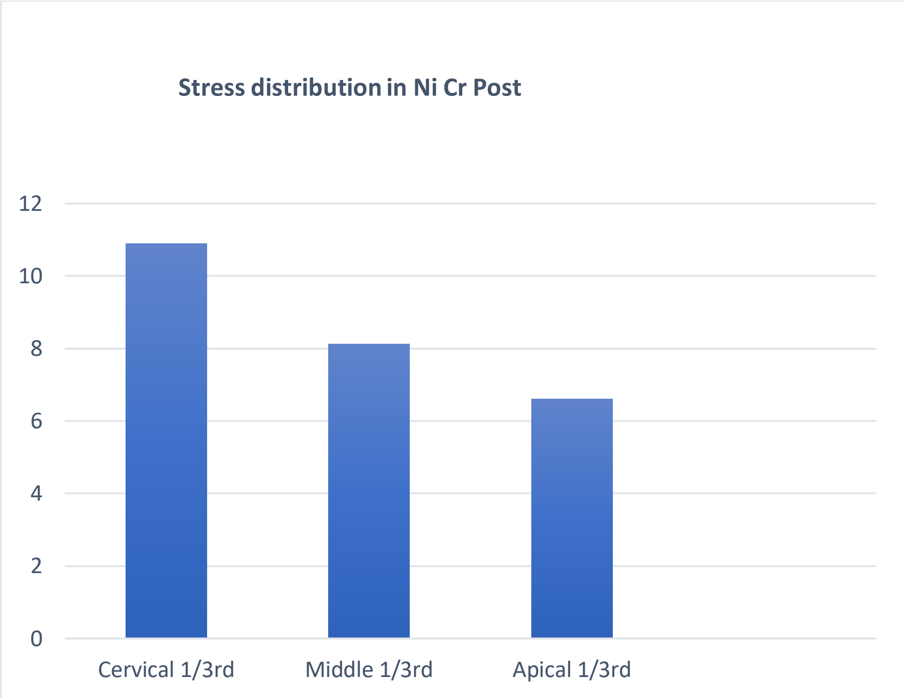


Fig 3



In configuration II, with a Zirconia post of 8 mm length, the maximum stress value recorded was 10.58 MPa at the cervical 1/3rd of the root. At the middle 1/3rd the maximum stress value recorded was 9.5 and the maximum stress value recorded at the apical 1/3rd was 6.2 MPa (Fig.4).

Fig 4

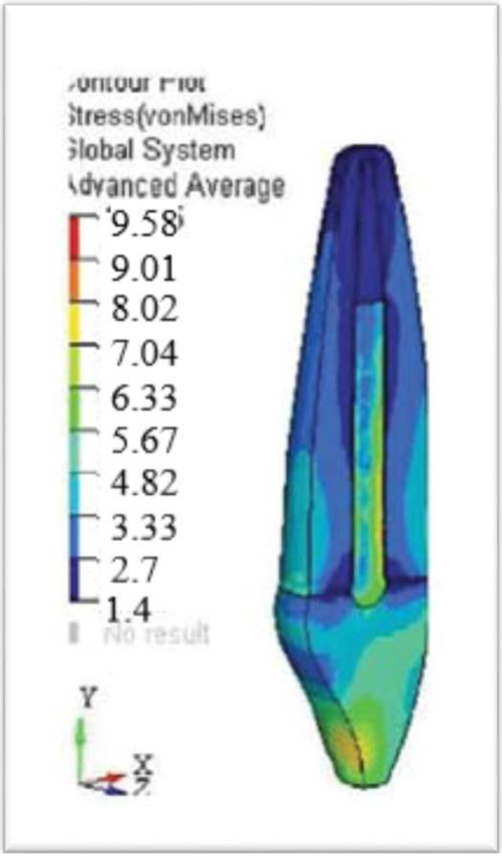


Fig 5

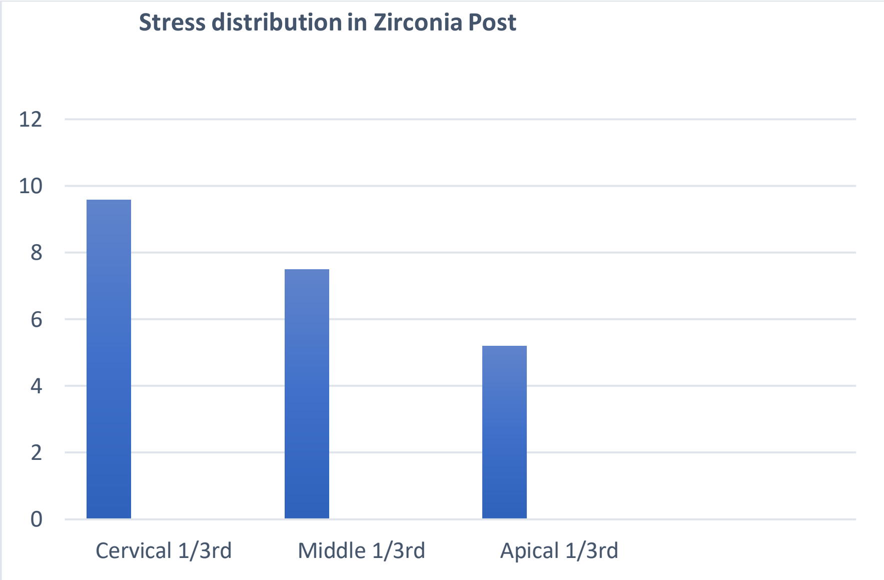
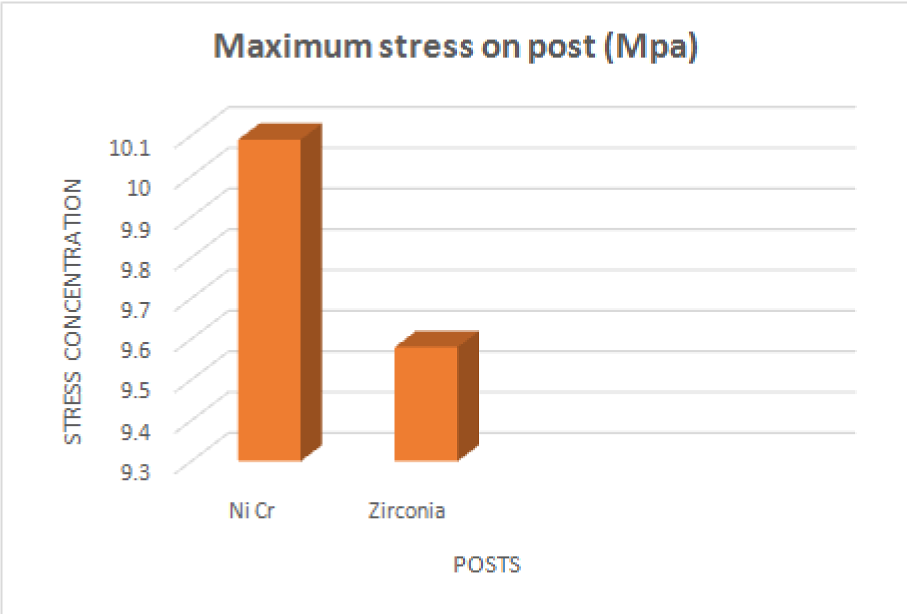


Fig 6



Among the two posts tested, Ni-Cr post showed more stress concentration (11.4 MPa) as compared to Zirconia (10.58 MPa).

DISCUSSION

A finite element analysis is a useful tool for investigating biomechanical interactions of various designs. FEA allows investigators to predict stress distribution in the contact area using a mathematical model of the structures. The three dimensional (3D) finite element analysis was chosen for the study because the application of a 3D model simulation with non-symmetric loading by the masticatory force on a dental root results in a more satisfactory modeling of "clinical" reality than can be achieved by a 2D model used in other studies. According to Ho et al[6] while 2D model conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. Three dimensionalmodeling, however, produces more accurate results by sacrificing the ability to run on all but the fastest computers effectively. A major limitation of a 2D model in post and core dentistry is that the stresses generated buccally and lingually cannot be evaluated.

Although there have been numerous studies documenting stress distribution on posts with 3D element models, few researchers have examined the influence of stress distribution by newer materials. The purpose of the present study was to compare and evaluate the effect of different post materials on the stress distribution pattern on the root.

The evaluation of stress distribution patterns among Ni-Cr post, fiber post have been investigated previously but zirconia being a relatively newer material, very few studies have been conducted to evaluate its material properties. Hence zirconia post is a unique feature of the study.

Tooth is a complex living tissue and its simulation in FEA is approximate. The material properties for the 3D finite element analysis as presented in table 1 were taken from the literature by Okamoto et al and Yaman et al.[8,9]

Three configurations were generated by the software, with each configuration simulating a restored maxillary central incisor. In each configuration posts were placed up to two third i.e. 8 mm of the root length with 4mm of gutta percha remaining in the root canal. This simulated the clinical situation to maintain apical seal.

Forces on the prosthesis such as chewing are transferred to the post and lead to stress in the dentin and surrounding tooth structures. Too much stress can lead to fracture of the post, loosening of the post, fracture of the tooth etc. Also, too much stress can lead to resorption of bone. It has been reported that the maximal bite force measured in incisal region is about 250 N though the maximum biting force that can be applied to the teeth varies from individual to individual. In this study a force of 100 N was applied on the palatal surface at the cingulum at an angle of 45^0. These loads represent the average masticatory force recorded, and were in accordance with various studies by Okamoto et al,[9]Amarante et al,[10] Ho et al,[6] Jang et al[11]&Joshiat al.[12]Also, investigators like Cohen et al who have studied restoration of teeth have typically used a 45^0 angled load as the post core combination would have the greatest fractural resistance to a force directed at 45^0angle. The structural integrity and clinical longevity of post-and-core restored teeth are therefore strongly dependent on the state of stress created in their different regions due to occlusal loads.

In addition to the magnitude and direction of such loads, the stress state at a given point within a restored tooth is also influenced by factors like the design and material of the post and the quantity and quality of the remaining root tissue. As the extensive loss of root dentin increases the risk of radicular fracture, appropriate mechanical behavior of the post is considered, in this case, to be fundamental to the success of rehabilitating restored teeth.[10]

A contentious issue is whether the parallel-sided post shape is more predisposing to a root fracture compared with a tapered shape. One clinical opinion is that the cylindrical post preparation designed to fit the post may result in a post space that does not correspond to the shape of the root, with concomitant risks for fracture sites. It is argued that a tapered post can act as a wedge and fracture the root during function. In vitro tests on this subject have shown various results. Several in vitro studies support the opinion that preservation of tooth structure is one of the most important variables in successful restoration of endodontically treated teeth.[13,14,15] Parallel posts have special drills of specific diameter corresponding to the post size hence more tooth structure may have to be sacrificed. On the other hand tapered post follows the root anatomy. The predominant opinion today is that a post should be used to increase the retention of the core and not for reinforcement.[16]

In order to assess all the eventual variables, the types of materials used for core build-up and crown restoration have to be carefully evaluated. To date, there is still no agreement in the literature about which material or technique can optimally restore endodontically treated teeth. Metal posts made of Ni-Cr alloy are associated with higher risk of root fracture due to the high stiffness and modulus of elasticity of the metal when compared to tooth structure, which might lead to increased stress concentration. Cast posts are advantageous as they are easy to fabricate in the mouth but since their modulus of elasticity differs from the dentin they tend to produce undue stresses.

Zirconia posts have greater strength and are more aesthetic as they do not reflect a blackish hue. They are biocompatible, corrosion resistant and strong, but their cost is a concern. Many researchers have investigated the physical, chemical and bio-medical characteristics of different types of materials and suggested ideal post core build ups by considering their mechanical properties. However the conclusions were diverse. For this study the elastic modulus of dentin was taken as 1.8 x 103 MPa as studied & suggested by Craig.[17]

The placement of the post-core changes the stress distribution patterns within the dentin, which largely correlates with elastic modulus of the post. When oblique forces were applied to the structure the design showed movement in the direction of the force applied. Stress loads were concentrated on the loading area and decreased progressively and radially towards surrounding structures. More stresses were observed on the palatal side of the tooth structure.

In the present study two posts were evaluated for stress distribution when 100 N load was applied at 45^0, which shows stress distribution in Ni-Cr post, indicating that the maximum stress concentration was in the cervical region. Vasconcellos W A et al,[18]Silva N R et al[19] and Dejak B et al[20] also conducted similar studies and found that the maximum stress concentration was at the cervical third.

As shown in fig. 4, upon testing zirconia post for stress distribution, the maximum stress value recorded was 9.58 MPa at the cervical 1/3rd of the root. At the middle 1/3rd the maximum stress value recorded was 7.5 and the maximum stress value recorded at the apical 1/3rd was 5.2 MPa. Amarante et al.[10] also conducted similar studies and recorded the maximum stress in the cervical region which was in accordance with this study. Asmussen et al[22] conducted similar studies and found that with decreasing dowel length the maximum stress concentration was located more apically which was in contrast with this study. The difference could be due to dissimilar study designs used.

While comparing the two materials for the stresses generated it was found that Ni-Cr posts showed highest stresses (10.9 MPa) followed by Zirconia (9.58 MPa); although the region of maximum stress concentration for both the materials were the same that is the cervical 1/3rd of the root. This difference in stresses was due to the difference in elastic modulus of materials. Rigid post materials showed non homogenous stress distribution while materials with elastic modulus similar to dentin showed better stress distribution. Lanza et al[23] concluded that steel posts are most dangerous to the roots potentially leading to its fracture as they do not allow homogenous stress distribution.

The study is significant for clinicians to help decide among the different post materials available and enlists the comparison of stress distribution properties of most commonly used post materials. Also with the advancements in dentistry and the introduction of newer materials studies have to be carried out to test the beneficial potential of newer materials. Further studies need to be done in this regard.

CONCLUSION

The following conclusions were drawn from the present study:

- Zirconia showed less stress concentration as compared to Ni Cr post.
- Stress concentration in the radicular dentin was more at the cervical third.

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