Original Article

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Dentistry Section

A Comparative Evaluation of Effect of Different Ferrule Heights on Stress Distribution in Endodontically Treated Teeth Restored with Zirconia Post and Core System using 3D-Finite Element Analysis

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ABSTRACT

Introduction: Customised Zirconia postcore exhibits high strength, toughness and superior aesthetics. The stress distribution in the root of endodontically treated teeth has been found to improve with use of ferrule.

Aim: To evaluate the effect of different ferrule heights on stress distribution in endodontically treated maxillary central incisor restored with zirconia postcore system using three-dimensional (3D) finite element analysis.

Materials and Methods: The in-vitro experimental study was conducted at Maharashtra Institute of Dental Sciences and Research, Latur, Maharashtra, India, from December 2014 to July 2016. The external shape of the right maxillary central incisor was obtained by the micro computed tomography scan of previously extracted maxillary central incisor. The scanned profiles were then assembled and a 3D-finite element model of five dentin ferrule heights was designed with customised zirconia postcore (1.2 mm diameter) and all ceramic crown. Total five models of different ferrule heights (0 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm) were made. Von mises stress was determined by applying a load of 100 N at 45° and at a distance of 2 mm from the incisal edge on the palatal surface of crown. Descriptive statistical methods and Pearson correlation test were used to analyse the data.

Results: The maximum von Mises stress at the postdentin interface decreased from 2.808 MPa to 0.512 MPa and that of zirconia post reduced from 57.163 MPa to 48.29 MPa when the ferrule height increased from 0 to 2 mm. The maximum von Mises stress in the radicular dentin decreased from 15.219 MPa to 11.321 MPa.

Conclusion: There was association between increased height of ferrule and reduced von Mises stress in the zirconia post, postdentin interface and in remaining radicular dentin. Also, with increase in height of ferrule there was an evident shift of von mises stress to the cervical end of root from midroot and apical end of root.

Keywords: Aesthetic post, Finite element method, Maxillary central incisor, Stress analysis

INTRODUCTION

The challenging task for clinicians for more than 100 years is the restoration of endodontically treated teeth [1]. Endodontically treated teeth are weaker and more susceptible to fracture than vital teeth due the change in the biomechanical behaviour and premature loss of moisture supplied by a vital pulp [2].

The choice of an appropriate restoration for endodontically treated anterior teeth is guided by strength and aesthetics [3]. Materials used for post and core can be metal or non metal. Metal posts cause blackish discolouration of all ceramic crowns and gingiva. Other disadvantages of metal posts include corrosion reaction, metallic taste, oral burning, sensitisation and allergic reaction [4]. Zirconia postsystems have been introduced for better aesthetics. The use of ceramic postcore materials helps in maintaining translucency of all ceramic crown. Zirconia posts have excellent physical properties, biocompatibility and superior aesthetics [5].

The quality of postcore system to survive chewing forces and remain retained to the tooth is essential for the long-term durability of a restoration [5]. Resistance to fracture is directly related to the amount of remaining tooth structure [6]. For restoration of an endodontically treated tooth, one important design consideration is the “ferrule” [7]. Dental ferrule is an encircling band around the coronal surface of the teeth. Ferrule is provided by parallel walls of dentin extending coronal to the shoulder of the preparation, which after being encircled by a crown produces a protective effect called ferrule effect, thereby reducing stresses within a tooth [2]. Ferrule increases the retention and resistance of restoration; also reduces incidence of tooth fracture. It reduces the wedging of tapered posts or bending forces during postinsertion and helps to improve the marginal integrity [8].

The effectiveness of the ferrule has been evaluated by a variety of methods like fracture testing, impact testing, fatigue testing, photo-elastic analysis and finite element analysis [9]. The only method that eliminates operator factors and uses materials under ideal conditions is finite element method. It is a numerical tool, which is popularly used to analyse very complex and irregular structures. It has proved to be the most adaptable, accurate, easy and less time-consuming process as compared to the other experimental analysis. The finite element method includes the two dimensional and three-dimensional methods. A 3D finite element model is more accurate and realistic way to analyse the stress in the tooth [10].

Successful rehabilitation of endodontically treated anterior tooth has been a major concerns for the prosthodontist. The major indication of customised zirconia postcore is for wide, blunderbuss or extremely tapered canals where cylindrical prefabricated posts may not achieve adequate adaptation to the canal. They are also indicated in grossly destructed tooth, areas with heavy occlusal forces, in high lip line and thin gingival tissues for better aesthetics [3].

To our knowledge, no study till date has been conducted to evaluate the effect of different ferrule heights on stress distribution in endodontically

treated anterior teeth restored with customised zirconia postcore. Hence, the aim of the present study was comparative evaluation of the effect of different ferrule heights on stress distribution in endodontically treated maxillary central restored with zirconia post and core system using 3D finite element analysis. The null hypothesis was that stress distribution does not vary as a function of ferrule configuration.

MATERIALS AND METHODS

The in-vitro experimental study was carried out at Maharashtra Institute of Dental Sciences and Research, Latur, Maharashtra, India, from December 2014 to July 2016. It was approved by the Institutional Ethical Committee board of MIDSR Dental College, Latur, under protocol number MIDSR/STU/PG/56/001/2014.

Inclusion criteria: A extracted sound maxillary right central incisor with single canal was included in the study.

Exclusion criteria: Extracted tooth with caries, restorations, previous endodontic therapy, fractures, pulp stones and root resorption was excluded from the study.

Study Procedure

The external shape of the tooth was obtained by the Micro Computed Tomography of previously extracted maxillary central incisor. The scanned profiles were then assembled in a 3D wire frame structure using 3D image software. A 3D finite element model was fabricated to represent an endodontically treated maxillary central incisor restored customised zirconia postcore using ANSYS R 14.5 software (Solid works 2014). Total five models of different ferrule heights (0 mm; 0.5 mm; 1 mm; 1.5 mm; 2 mm) were made.

Description of Model

In this study model of postcore restored endodontically treated tooth has seven components: the cortical bone supporting the tooth, Periodontal Ligament (PDL), dentin, post and core, crown and gutta percha. To simplify the development of finite element model, some assumptions have been made regarding the material properties of each part [3,11,12].

- All the materials are assumed to be homogenous, isotropic, linearly elastic and axi-symmetric along the vertical centreline.
- Maxillary central incisor with single root, single canal with dimensionally regularity of the canal anatomy with circular cross sections.
- Cement (luting agent) layer between the materials and tooth structure is very thin, the cement layer is regarded as a part of dentin.
- Cementum covering the surface of the root is very thin hence considered as part of dentin.
- All components are assumed to be perfectly bonded, since no gap exists between the components.
- Zero displacement seen as outside surface of bone is fixed.
- A force of magnitude 100 N with 45° angulation at a distance of 2 mm from the incisal edge was applied on the palatal surface of crown.

Material Properties

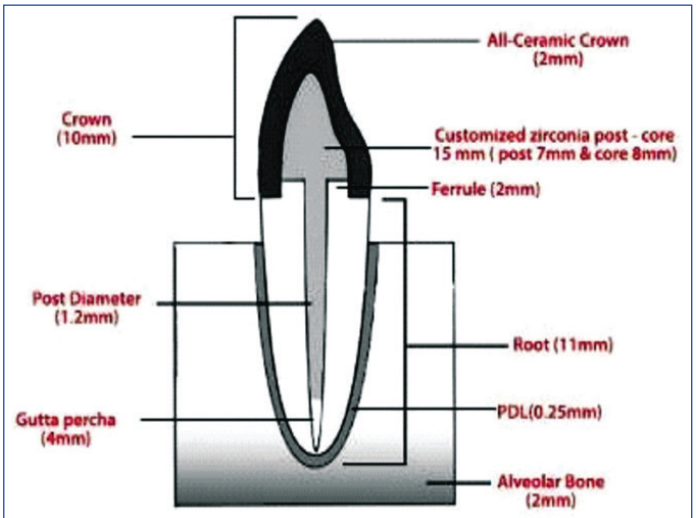
The corresponding elastic properties such as Young's modulus (E) and Poisson ratio (μ) were determined from the literature and are summarised in [Table/Fig-1] [13,14].

Development of Finite Element Model

Finite element model of maxillary central incisor was developed with length of 21 mm; of which 11 mm is root length and 10 mm is crown length. The diameter of coronal surface was 9 mm. It was assumed to be axi-symmetric along the vertical centre line. The dentin component was connected to post, core, crown, Periodontal Ligament (PDL) and gutta-percha. Gutta-percha fills the previously prepared root canal and seals the apex. In the model, the canal was assumed to be axi-symmetric along the longitudinal axis. When post was inserted all the gutta-percha was removed except the apical 4 mm. The customised zirconia post and core of 15 mm length (post-7 mm and core-8 mm) was placed into the canal. The diameter of the zirconia post was 1.2 mm. The ferrule height was considered to be 2 mm in this model. The thickness of PDL was 0.25 mm. The cortical layer of bone was 2 mm thick. All ceramic crown of thickness 2 mm was placed above the customised zirconia post and core [Table/Fig-2]. In this study, the design parameters include 5 ferrule heights (0 mm ferrule, 0.5 mm ferrule, 1 mm ferrule, 1.5 mm ferrule and 2 mm ferrule). Total 15 models were made of 5 different ferrule heights to analyse the Von mises stress at postdentin interface, radicular dentin and customised zirconia postcore assembly.

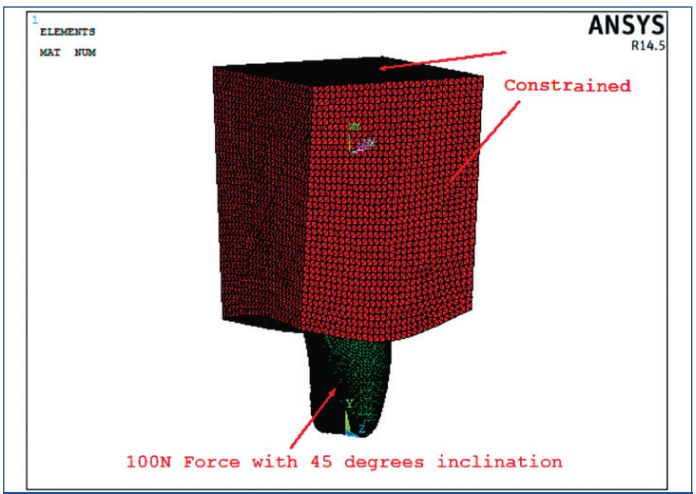
Material	Young's modulus (GPa)	Poisson's ratio (v)
Dentin	18.6	0.31
Periodontal Ligament (PDL)	0.0689	0.45
Cortical bone	13.7	0.30
Gutta percha	0.00069	0.45
CAD/CAM zirconia postcore	205	0.31
Zirconia crown	210.	0.33

[Table/Fig-1]: Material properties of components.
Computer-aided design and Computer-aided manufacturing (CAD/CAM)



[Table/Fig-2]: Schematic diagram of the finite element model of endodontically treated maxillary central incisor restored with zirconia post and core.

Loading and boundary condition: An average static load of 100 N at 45° and at a distance of 2 mm from the incisal edge was applied on the palatal surface of crown [Table/Fig-3]. The external load of 100 N was used in this study because it simulates the maximum load in the oral cavity during normal mastication [3,10].



[Table/Fig-3]: Mesh model of maxillary central incisor with cortical bone with loading and boundary conditions.

The output data from ANSYS software (version14.5) was given as Von Mises stress. The unit of measurement used was Newton per millimetre square (N/mm^2). Von Mises criterion is a formula combining three principal stresses (tensile, shear, compressive). Maximum value of Von Mises stress is denoted by red colour. Minimum value of Von Mises stress is denoted by dark blue colour [15].

STATISTICAL ANALYSIS

The above data was compiled using Microsoft Excel and compared using Statistical Package for the Social Sciences (SPSS) software. Result was presented using descriptive statistical methods (Pearson correlation test).

RESULTS

In the present study, the distribution of maximum von Mises stress in the radicular dentin, zirconia post and at the postdentin interface in 5 models of differing ferrule heights was determined under load 100 N at 45° on palatal surface.

The maximum von Mises stress at the postdentin interface (2.808 MPa) was seen with 0 ferrule height, whereas increase in the ferrule height (2mm) decreases the von Mises stress at the postdentin interface (0.512 MPa). The maximum von Mises stress in the zirconia post at the dentin ferrule height of 2mm was 48.29 MPa which was significantly (p-value=0.001) lower than that at the ferrule height of 0 mm (57.163 MPa). Examination of maximum von Mises stress within the radicular dentin showed that as the ferrule height increases from 0 mm to 2 mm the stress value decreased from 15.219 MPa to 11.321 MPa [Table/Fig-4].

Dentin ferrule height (mm)	Maximum Von Mises stress at postdentin interface (MPa)	Maximum Von Mises stress in zirconia post (MPa)	Maximum Von Mises stress at radicular dentin (MPa)
0	2.808	57.163	15.219
0.5	2.202	54.2658	14.825
1	1.521	52.2931	13.235
1.5	1.031	50.729	12.315
2	0.512	48.29	11.321

[Table/Fig-4]: Maximum Von mises stress at postdentin interface, zirconia post, radicular dentin with different ferrule heights.

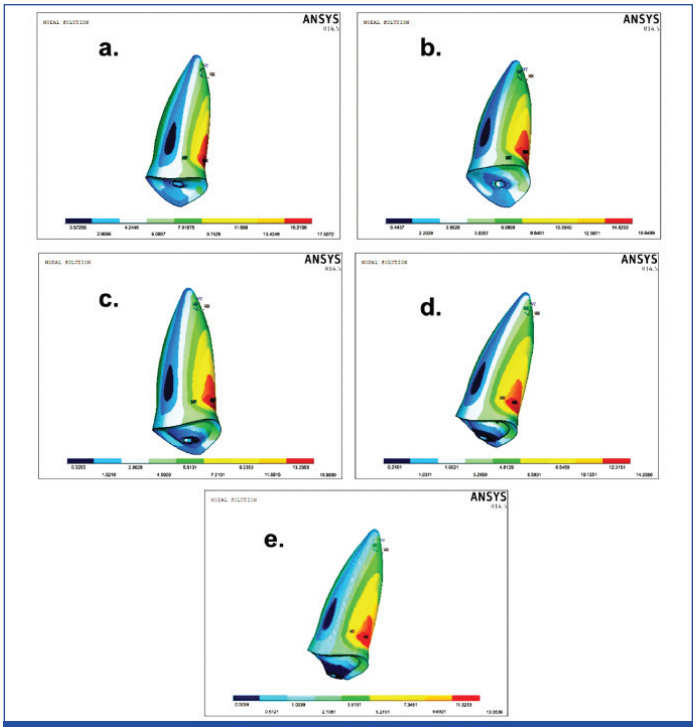
These findings indicate that increased ferrule height is associated with reduced von Mises stress at the postdentin interface, in the zirconia post and within the Radicular dentin. (Cervical end of root, mid-root, apical end of root).

Also, [Table/Fig-5] clearly indicates that with each ferrule height, cervical area of root has maximum stress which goes on decreasing from mid-root to the apex of root. With dentin ferrule height of 0 mm there was maximum Von mises stress (15.2196 Mpa) at cervical area of root and minimum Von mises stress (1.0039 Mpa) at apical end of root with 2 mm ferrule height [Table/Fig-6,7].

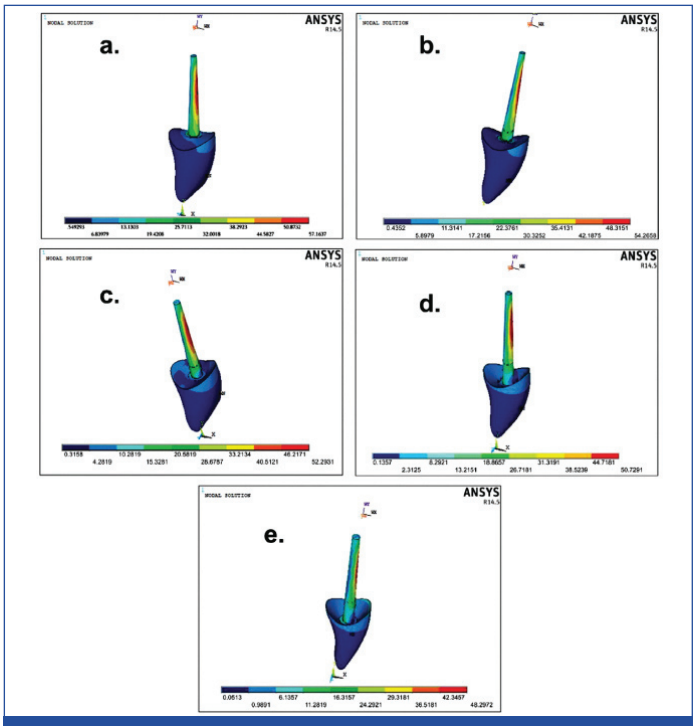
The Pearson correlation test were then applied which clearly indicated that dentin ferrule height is strongly inversely correlated with each variable [Table/Fig-8].

Dentin ferrule height (mm)	Cervical end of root (MPa)	Mid root (MPa)	Apical end of root (MPa)
0	15.2196	7.9167	4.2446
0.5	14.8253	6.9808	3.8626
1	13.2353	5.5131	2.8628
1.5	12.3151	4.8129	1.9021
2	11.3213	3.5191	1.0039

[Table/Fig-5]: Maximum Von Mises stress within the radicular dentin with different ferrule heights.



[Table/Fig-6]: Maximum von mises stress at postdentin interface(values in light blue colour) and radicular dentin (values in red colour) {a= 0 mm ferrule; b=0.5 mm ferrule; c=1 mm ferrule; d=1.5 mm ferrule; e=2 mm ferrule}.



[Table/Fig-7]: Maximum von mises stress zirconia post (values in red colour) {a=0 mm ferrule; b=0.5 mm ferrule; c=1 mm ferrule; d=1.5 mm ferrule; e=2 mm ferrule}.

Pair	r value	p-value
Dentine ferrule height vs Maximum Von Stress Cervical end of root (MPa)	-0.989	0.001*
Dentine ferrule height vs Maximum Von Stress Mid root (MPa)	-0.996	0.001*
Dentine ferrule height vs Maximum Von Stress Apical end of root (MPa)	-0.992	0.001*
Dentine ferrule height vs Maximum von mises stress at postdentin interface (MPa)	-0.998	0.001*
Dentine ferrule height vs Maximum von mises stress in zirconia post (Mpa)	-0.995	0.001*
Dentine ferrule height vs Maximum von mises stress at radicular dentin (Mpa)	-0.989	0.001*

[Table/Fig-8]: Correlation between ferrule height and various parameters. Pearson correlation test; negative r-value indicates negative correlation; *indicates level of significance at p≤0.05;. Dentin ferrule height is strongly negatively correlated with each variable

DISCUSSION

The above 3-dimensional study confirmed that ferrule height had an influence on stress distribution in endodontically treated teeth, which rejected the null hypothesis. Endodontically treated teeth are different than the natural tooth in the following manner- moisture loss, collagen alteration, dentin toughness and architectural changes [16]. A 3D finite element method is a more accurate and realistic way to analyse the stress in a tooth as it allows the investigation of a single variable in a complex structure [10]. In the present study, ANSYS 14.5; USA based software is used as it provides advanced surface meshing capabilities that reduce pre-processing and solving time [17]. Von Mises stress is a formula for calculating whether the stress combination at a given point will cause failure. The Von Mises criterion is a formula for combining three principal stresses (tensile, compressive and shear) into an equivalent stress. In the present study, the values of Von Mises stress distribution due to different ferrule heights in the endodontically treated maxillary central incisor are calculated. Maxillary central incisor was used as the model tooth in the present study. The maximum masticatory force on the maxillary central incisor is 100 N. To simulate the biological conditions, 100 N force at 45° and at a distance of 2 mm from the incisal edge was applied on the palatal surface of maxillary central incisor. This angle simulated the average angle of function for angle class I occlusion [3,11,12].

Custom made zirconia post and cores are indicated for wide, non circular (blunderbuss) or extremely tapered canals, in retreatment cases due to failure of cast post or fibre post in the anterior aesthetic region [18]. Assif D and Gorfill C, reported that, if the modulus of elasticity differs between materials, there is potential for separation of the core from the post [19]. Also, if the modulus of elasticity of post and core material is similar, a more uniform stress distribution within the entire postcore restoration and within the dentin is achieved [11,12]. Custom made post and core (one piece zirconia postcore) is thus more reliable as compared to prefabricated post. Zirconia posts have a high elastic modulus of 200 MPa which causes stress to be transferred to the less rigid dentin [20].

A dentin ferrule increases the fracture resistance, providing a protective effect by reducing the stress concentration on the tooth [2]. Ferrule is coronal dentinal extension of the tooth structure occlusal to the shoulder preparation [4]. Libman WJ and Nicholls JI stated that the marginal area of a crown should extend onto the tooth structure 1.5-2 mm beyond the core material to produce an adequate ferrule [21].

Morgano SM et al., suggested that when the ferrule effect was absent, occlusal forces would become concentrated at the junction of the dowel and core with potential for dowel fracture [22]. In the present study, stress distribution in the endodontically treated maxillary central incisor restored with zirconia post and core with five different ferrule heights (0 mm, 0.5 mm, 1 mm, 1.5 mm, 2 mm) is evaluated using three-dimensional finite element analysis.

In the present study, at the postdentin interface the maximum Von Mises stress (2.808 MPa) was observed with minimum (0 mm) ferrule height. The Von Misses stress was least (0.512 MPa) with maximum ferrule height (2 mm). Therefore, it was concluded that, as the ferrule height increases, the stress at the postdentin interface decreases gradually. This result was in accordance with the study by Mezzomo E et al., who reported that 2 mm cervical ferrule improves the fracture resistance of maxillary central incisor restored with cast post and cores [23]. Also, Pereira JR et al., Tan PL et al., studied the effect of crown ferrule height on fracture resistance of maxillary canine restored with prefabricated post and composite core and reported that increased amount of coronal dentin significantly increases the fracture resistance [24,25]. Study by Ma PS et al., concluded that increasing dentin ferrule height uplift the fatigue resistance [26]. Lima AF et al., also concluded that fracture resistance increases on increasing the ferrule height [27].

Assif D and Gorfill C, Zhi-Yue L and Yu-Xing Z investigated the effect of postcore design and ferrule on the fracture resistance of endodontically treated maxillary central incisor and concluded that those teeth with 2 mm dentin ferrule more effectively enhanced the fracture strength of custom made cast postcore [19,28]. The ferrule can improve resistance to dynamic occlusal loading, maintain the integrity of the cement seal of the artificial crown and reduce the stress concentration at the junction of postcore. When the ferrule is absent occlusal forces is exclusively resisted by the post which eventually results in vertical fracture [29].

In this study, the highest Maximum Von Mises stress (57.163 MPa) in the zirconia post in the present study was observed with minimum ferrule height (0 mm). The Maximum Von Mises stress was least (48.29 MPa) with maximum ferrule height (2 mm). Also, the maximum Von Mises stress (15.219 MPa) in the radicular dentin was observed with minimum ferrule height (0 mm). The Von Mises stress was least (11.321 MPa) with maximum ferrule height (2 mm). Hence, it can be concluded that, as the ferrule height increases stress in the radicular dentin and zirconia post decreases. This result was in correlation with Chen D et al., who investigated the stress distribution in endodontically treated maxillary canine with different ferrule heights using finite element analysis and revealed that, increased ferrule height is associated with reduced Von Mises stress in the zirconia post and postdentin interface [30]. Similarly, Akkayan B et al., analysed the effect of different ferrule length of endodontically treated teeth restored with fibre post and zirconia posts and concluded that, fracture resistance were higher with dowel systems with ferrule length of 2 mm [29]. Pierrisnard L et al., reported that ferrule preparation is more effective with zirconia post of high elastic modulus [31]. Comparison of the findings of this study with previous studies have been done in [Table/Fig-9] [2,3,7,30,32-41]. Eraslan O et al., reported that the use of ferrule in endodontically treated teeth restored with an all ceramic post and core reduces the values of Von Mises stresses on tooth restoration complex. In the absence of ferrule, posts with high modulus of elasticity, generated greater cervical stress as compared to carbon fibre post [42].

Author name and year	Topic of study	Place of study	Number of samples	Parameter compared	Conclusion
Gatkal VS et al., (2021) present study	Comparative evaluation of effect of different ferrule heights on stress distribution in endodontically treated teeth restored with zirconia post and core system – 3d-finite element analysis	Latur, Maharashtra, India	Five 3D-FEA models of maxillary central incisor	Effect of five different ferrule heights (0,0.5,1,1.5,2 mm) on stress distribution at postdentin interface, radicular dentin, zirconia postcore in maxillary central incisor at static load 100 N at 45° palataly and distance of 2 mm from incisal edge.	Increase in ferrule height reduces Von Mises stress in zirconia post, radicular dentin and postdentin interface.
Sethuraman R (2011) [32]	The effect of three post and core systems on the stress distribution in endodontically treated teeth using a two-dimensional finite element analysis	Vadodara, Gujarat, India	Four 2D- finite element models of maxillary central incisor.	Model I: no post Model II: cast metal post Model III: titanium post with composite core. Model IV: glass fibre post with composite core. Load of 200 N at 1300 lingually.	The glass fibre post and composite core showed most favourable stress distribution similar to natural tooth structure.

Garhnayak L et al., (2011) [7]	The stress distribution in different endodontic post-retained teeth with and without ferrule design using finite element analysis.	Rajasthan, India	12 finite element models	12 models with metal ceramic crown were created based on the combination of three types of postcore systems (titanium post - composite resin core, nickel-chromium postcore, and fibre reinforced composite resin post-composite resin core), two varieties of posts (tapered, parallel) and with or without ferrule. 100 N load was applied in three directions	Incorporation of ferrule offered some degree of stress reduction in nonmetal post, and it increased the stresses within cervical dentin.
Watanabe MU et al., (2012) [33]	3-dimensional finite element (FE) analysis to evaluate the mechanical behaviour of a maxillary central incisor with three types of dowels with variable heights of the remaining crown structure, namely 0, 1, and 2 mm	North Paulista	Nine FEM models of a maxillary central incisor.	Nine models of maxillary central incisor with three ferrule heights (0, 1, and 2 mm) and three types of dowels (glass fibre = GFD; nickel-chromium = NiCr; gold alloy = Au. A 180 N distributed load was applied to the lingual aspect of the tooth, at 45 degree to the tooth long axis	The maximum stress was found for the NiCr dowel, followed by the Au dowel and glass fibre dowels; teeth without ferrule are more susceptible to the occurrence of fractures in the apical root third.
Marghalani TY et al., (2012) [34]	Three-dimensional finite element analysis to study the stress distribution in endodontically treated maxillary extracted canine restored with either custom-made zirconia or cast gold dowel and core.	Jeddah, Saudi Arabia	Two FEM models of maxillary canine.	A concentrated force of 100 N applied at the mid-lingual area. Analyses were made for three load angulations, vertical, buccolingual horizontal, and an in-between oblique force at 45°. The two restored canines with zirconia and gold were compared in terms of the resulting maximum tensile, compressive, and Von Mises stresses.	CAD/CAM zirconia can be used for a custom-made dowel and core in an aesthetically demanding zone as a replacement for a metal cast dowel and core.
Shetty P et al., (2013) [3]	Conducted a finite element analysis to evaluate stress distribution in the dentin and alveolar bone created by load application using two aesthetic posts.	Dharwad, Karnataka, India	2 finite element models were made. Model I glass fibre post Model II Zirconia post.	Von mises stress in dentin and alveolar bone was compared.	Glass fibre post had homogenous distribution of stress whereas in zirconia post the stress was concentrated in the post. Thus, glass fibre post should be used in well conserved radicular tooth structure and Zirconia post is indicated in weakened and grossly destructed tooth structure.
Zhou TF et al., (2014) [35]	Compared the fracture resistance of endodontically-treated teeth restored with prefabricated zirconia posts or one-piece computer aided design and computer aided manufacture (CAD/CAM) zirconia posts and cores, and unrestored endodontically-treated teeth.	Beijing, China	36 samples of maxillary central incisor (n=12 each). Group 1 (n=12each)-prefabricated zirconia posts (Cosmopost) and hot-pressed ceramic cores; Group 2 restored with one piece CAD/CAM zirconia posts and cores; Group 3 not restored.	The teeth were fixed in a universal load-testing machine; a compressive load was applied at 1350 to the long axis of each tooth at a crosshead speed of 1 mm/min until fracture. One-way analysis of variance was used to determine the significance of the differences in failure load between the groups.	Root canal treated teeth restored with One piece zirconia postcore had a higher failure resistance than tooth restored with prefabricated zirconia post.
Chen D et al., (2014) [30]	Conducted a 3-dimensional finite element analysis of the restoration of the maxillary canine with a complex zirconia postsystem.	China	A finite element model of four dentin ferrule heights (0 mm, 1 mm, 2 mm, 3 mm) was designed with zirconia posts and heat-pressed glass ceramics for a complete crown restoration.	Von Mises stresses were determined by applying a 300 N static load to the middle of the lingual surface of the crown.	Increased ferrule height is associated with reduced Von mises stress in zirconia post and postdentin interface, with apparent shift of Von Mises stress to the root cervical area from the midroot and apex
Juloski J et al., (2014) [2]	Evaluated via finite element analysis the effect of different ferrule heights on stress distribution within each part of a maxillary first premolar restored with adhesively luted glass fibre-reinforced resin posts and a ceramic crown.	Italy	Four models were created representing (0 mm, 1 mm, 2 mm and 3 mm of ferrule height).	A 200 N force was applied on the buccal cusp directed at 45° to the longitudinal axis of the tooth. Principal stresses valsues and distribution were recorded within root, abutment, posts, crown and related adhesive interfaces.	Higher ferrule produced more favourable stress distribution at post-abutment and abutment-root interfaces and lesser stress at adhesive interface.
Chen A et al., (2015) [36]	Conducted a finite element analysis to investigate the stress distribution in a maxillary canine restored with each of four different postsystems at different levels of alveolar bone loss.	China	Four different postsystems: CAD/CAM zirconia, CAD/CAM glass fibre, cast titanium, and cast gold.	A force of 100 N was applied to the crown, and the Von Mises stresses were obtained.	CAD/CAM zirconia post produced lowest stress a dentin layer, while glass fibre post produced maximum stress. For a severely damaged anterior tooth, a zirconia postsystem is the best choice
Zhou TF et al., (2015) [37]	Analysed the biomechanics trait of one-piece computer aided design and computer aided manufacture (CAD/CAM) zirconia post and core by the three-dimensional finite element.	China	3D finite element models of three upper central incisors restored with one-piece CAD/CAM zirconia post and core (group 1), prefabricated zirconia post and hot-pressed porcelain core (group 2), and cast gold alloy post and core (group 3) were built by geometric method respectively	100 N vertical loading through the central incisor models long axis and 100 N loading along directing at an angle of 45° with the models long axis were used to imitate the central incisor stress state in biting. Maximum Von Mises stress value was calculated	One-piece zirconia post and core restoration is more beneficial to disperse the bite force, keep the restoration intact as compared to prefabricated post.

Meng Q et al., (2018) [38]	In-vitro study evaluating the effect of ferrule design on the fracture resistance of endodontically treated mandibular premolars restored with fibre posts.	China	40 mandibular premolars extracted for orthodontic purpose.	1) 1) - 0 mm ferrule with buccal and 2 mm from the lingual side 2) 2) - 1 mm ferrule from the buccal side and 3 mm from the lingual side 3) - 2 mm ferrule from the buccal side and 4 mm from the lingual side	Resistance to fractures in endodontically treated teeth with a high inclined ferrule was the highest, regardless of the type of load.
Haralur SB, et al (2021) [39]	Studied effect of inadequate ferrule segment location on fracture resistance of endodontically treated teeth.	Saudi Arabia	50 each maxillary canine and mandibular premolar intact RC treated and sectioned at 2 mm above the Cementoenamel junction. The teeth samples were divided into 5 groups of 10 each. Teeth samples were restored with glassreinforced fibre post, composite core, and full veneer metal crown.	GI -360° ferrule. GII -inadequate ferrule on the palatal surface GIII- inadequate ferrule at buccal GIV- inadequate ferrule at proximal area. GV- complete absence of the ferrule	The endodontically treated tooth with sectional inadequacy of the ferrule is significantly more effective in resisting the fracture in comparison to the complete absence of the ferrule.
Gupta N et al., (2021) [40]	Evaluated and compared the effect of ferrule height, configuration, and post and core approaches on stress distribution of endodontically treated teeth with flared root canal by Three-Dimensional (3D) finite element analysis.	Ghaziabad, Uttar Pradesh , India	13 3D models of single rooted maxillary second premolar. Groups I, II, III, and IV restored with no post, glass fibre, anatomic, and cast post and core, respectively. Group II, III, and IV were further subdivided into four subgroups a–no ferrule, b–3 mm circumferential, c– incomplete ferrule of 2.5 mm on buccal and 1.5 mm on palatal side, and d – incomplete ferrule of 1.5 mm on buccal and 2.5 mm on palatal side.	Load of 200 N at an angle of 45° was applied to buccal and palatal cusps. The maximum von Mises stresses were calculated within post, core, cervical, and radicular dentin and distribution at dentin and cement interface and cement and post interface	Ferrule allows for a uniform stress distribution and also reduces the stresses at the cervical region of the tooth. Palatal ferrule is more important to provide a fracture resistance to tooth as compared to buccal ferrule.
Kar S et al., (2017) [41]	Effect of different ferrule length on fracture resistance of endodontically treated teeth: An in-vitro study.	Uttar Pradesh, India	40 mandibular premolars divided into 4 groups of different ferrule lengths: Group I-no ferrule; Group II-1mm ferrule; Group III-2mm ferrule; Group IV-4mm ferrule.	Comparison of fracture resistance.	Increasing the length of the ferrule can significantly increase fracture resistance.

[Table/Fig-9] Comparison of the findings of present study with previous studies [2,3,7,30,32,41].
Computer-aided design and Computer-aided manufacturing (CAD/CAM)

Limitation(s)

The accuracy of finite element method for structural analysis has been proven beyond doubt. However, certain simplifications were considered in this part of the study, FEA is a mathematical in-vitro study and may not exactly simulate the clinical situation completely. All materials were assumed to be isotropic, linearly elastic and homogenous which are not absolute representations of the structure. Pre-stress due to endodontic treatment is neglected. The cement layer was not modelled in this study, although it is an important component of the postsystem. In general cement layer is too thin to be modelled in a finite element analysis. Bone and dentin exhibit a non linear model however a linear model was used in this analysis. Masticatory forces are dynamic in nature but the loads applied were static. In present study, maxillary central incisor with single root, single canal with dimensionally regularity of the canal anatomy with circular cross sections was taken into consideration which gives only a general insight into tendencies of stress variations under average conditions, without attempting to simulate clinical situations. Due to the limitations pertaining to this study, further research regarding 3D-FEA combined with long term clinical evaluation is necessary.

CONCLUSION(S)

The finite element analysis shows that there is association between increasing the ferrule height with reduced Von Mises stress in the zirconia post, postdentin interface and remaining radicular dentin. There is evident shift of von mises stress to the cervical end of root from midroot and apical end of root, on increase in ferrule height. Ferrule increases the resistance of endodontically treated teeth and prolongs the lifetime of the restoration. A minimum ferrule height of 1.5-2 mm is necessary to enhance the clinical survival of teeth treated endodontically and restored with post and core. The findings of 3D finite element requires experimental and clinical studies as it is purely analytical.

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