

## Stress analysis of maxillary central incisors endodontically -treated with varying ferrule heights and three different post dowel materials - a finite element analysis.

Análisis de tensión de los incisivos centrales superiores tratados endodónticamente con diferentes alturas de férula y tres materiales diferentes de clavija posterior: un análisis de elementos finitos.

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**Abstract:** Statement of problem : fracture of endodontically treated teeth is reduced by the use of a post with ferrule, but the effect of different ferrule configurations and dowel materials is not clear. Purpose: to evaluate the effect of ferrules with different configurations and heights on the stress of endodontically treated teeth restored with three different post and dowel materials. Materials and Methods: fifteen models of maxillary central incisors restored with porcelain fused to metal crowns were obtained using pro engineer software. the models were divided into three groups, each consisting of five models with ferrule heights of 0mm, 2mm, 4mm, 2mm with oblique fracture, 4mm with oblique fracture, the models under group GFR were restored with fiberglass reinforced post (GFR) and composite core build-up, group NiCr with a custom cast post metal alloy (NiCr), and group Zr with zirconia post (Zr) and composite core build-up. an oblique load of 100N and 150N at an angle of 135 degrees was applied to the palatal surface of the tooth, a vertical load of 100N and 150N at an angle of 90 degrees was applied to the incisal tip of the tooth. The maximum principal stress and the von mises stress was calculated for the remaining tooth structure and post apex using the finite element analysis (FEA) software. Results: the maximum von misses stress was observed in the apex of the post ( $p<0.05$ ). Group Zr showed the highest mean stress (6.39Mpa) followed by group NiCr (5.65Mpa). There was a significant difference between post and between NiCr and Zr post for 2mm and 4mm ferrule height, while for 0mm ferrule there was a significant difference between the GFR and NiCr groups ( $p<0.05$ ). Under oblique load, the maximum mean stress was observed in remaining tooth structures while for vertical load, it was observed at the apex of the post. Regarding ferrule heights, there were significant differences between 0mm-2mm, and 0mm-4mm uniform ferrule in post apex in the case of NiCr posts ( $p<0.05$ ). Absence of ferrule resulted in higher stress for the NiCr group. Conclusion: higher loads that led to fracture were observed only at the apex of the post. Zirconia posts (group Zr) had higher fracture loads, whereas absence of ferrule resulted in higher fracture load with custom cast posts (group NiCr). Fracture thresholds were high on the remaining tooth structure for all the dowel systems especially for composite core build up irrespective of ferrule height and configuration. Clinical implications: appropriate selection of post and dowel materials in different configurations of ferrule heights ensures clinical success.

**Keywords:** Dental materials; post and core technique; mechanical stress; finite element analysis.

**Resumen:** Indicación del problema: la fractura de los dientes tratados endodónticamente se reduce mediante el uso de un poste con férula, pero el efecto de diferentes configuraciones de férula y materiales de clavija no está claro. Propósito: evaluar el efecto de los casquillos con diferentes configuraciones y alturas sobre el estrés de los dientes tratados endodónticamente restaurados con tres materiales diferentes de postes y tacos. materiales y métodos: quince modelos de incisivos centrales superiores restaurados con porcelana fundida a coronas de metal se obtuvieron con el software Pro Engineer. Los modelos se dividieron en tres grupos, cada uno de los cuales consta de cinco modelos con alturas de casquillo de 0mm, 2mm, 4mm, 2mm con fractura oblicua, 4mm con fractura oblicua. los modelos del grupo GFR

fueron restaurados con poste reforzado con fibra de vidrio (GFR) y acumulación de núcleo compuesto, grupo NiCr con una aleación de metal de poste fundido personalizado (NiCr) y grupo Zr con poste de zirconia (Zr) y acumulación de núcleo compuesto. se aplicó una carga oblicua de 100N y 150N en un ángulo de 135° a la superficie palatina del diente. se aplicó una carga vertical de 100N y 150N en un ángulo de 90° a la punta incisal del diente. la tensión principal máxima y la tensión de von mises se calcularon para la estructura dental restante y después del vértice utilizando el software de análisis de elementos finitos (FEA). Resultados: el estrés máximo de von falta se observó en el vértice de la publicación ( $p < 0.05$ ). El grupo Zr mostró el mayor estrés medio (6.39Mpa) seguido del grupo NiCr (5.65Mpa). Hubo una diferencia significativa entre la publicación NiCr y Zr para la altura de la férula de 2mm y 4mm, mientras que para la férula de 0mm hubo una diferencia significativa entre los grupos GFR y NiCr ( $p < 0,05$ ), bajo la carga oblicua, la tensión media máxima en las estructuras dentales restantes, mientras que para la carga vertical, se

observó en el vértice del poste. En cuanto a las alturas de la férula, hubo diferencias significativas entre la férula uniforme de 0mm-2mm y de 0mm-4mm en el post-apex en el caso de los postes de NiCr ( $p < 0.05$ ), la ausencia de férula dio como resultado un mayor estrés para el grupo NiCr. Conclusión: las cargas más altas que llevaron a la fractura se observaron solo en el vértice del poste; Los postes de zirconia (grupo Zr) tuvieron mayores cargas de fractura, mientras que la ausencia de férula dio como resultado una mayor carga de fractura con postes moldeados personalizados (NiCr de grupo). Los umbrales de fractura fueron altos en la estructura dental restante para todos los sistemas de clavijas, especialmente para la acumulación de núcleos compuestos independientemente de la altura y configuración de la férula. Implicaciones clínicas: la selección adecuada de materiales de postes y tacos en diferentes configuraciones de alturas de férulas asegura el éxito clínico.

**Palabras Clave:** *Materiales dentales; post y técnica básica; estrés mecánico; análisis de elementos finitos.*

## INTRODUCTION.

The chances of superstructure fracture during functional load are high for an endodontically treated tooth because of considerable tooth structure loss due to caries, any previous restoration, endodontic access or brittleness of the tooth.<sup>1</sup> Loss of coronal tooth structure over 50% requires post and core build up prior to prosthetic restoration.<sup>2</sup> To improve the long-term survival of teeth endodontically treated with a post and core, a remaining tooth structure of 1.5-2mm directly above the margin is preserved.<sup>3</sup> This encircling band in coronal structure is termed a ferrule which resists leveraged functional forces, wedging effect of tapered post and the lateral forces applied by the post during function.<sup>4</sup>

The ferrule ensures that the margin of the core and crown are at different levels, thereby significantly increasing the resistance to fatigue failure.<sup>5</sup> By creating compression, the ferrule compensates for the tensile stress and reduces the lateral occlusal forces.<sup>6</sup> The ferrule is effective when the crown comprises a relatively parallel prepared tooth structure rather than when it involves a beveled/sloping tooth surfaces, but studies evaluating the effect of ferrule height are lacking. The vast majority of literature data suggests that the presence of a ferrule is a vital factor for improving fracture resistance for different types of post material, such as cast post and core,<sup>7,8</sup> all ceramic post and core,<sup>9</sup> prefabricated metallic posts,<sup>10-12</sup> and prefabricated fiber reinforced composite posts.<sup>13,14</sup> The custom cast posts have close adaptations to the post space preparation, but the literature suggests that the usage of

metallic dowels with a high modulus of elasticity increases the stress on the apical third of the root, which could cause vertical root fracture;<sup>6</sup> hence fiberglass posts with a modulus of elasticity similar to dentin deliver better stress distribution on the remaining tooth structure.<sup>15,16</sup>

The longevity of posts not only depends on post material but also on the placement of a dowel, contributing to the biomechanical property of the tooth.<sup>8,17</sup> Though the literature highlights the efficacy of materials and the presence of ferrule, there is lack of evidence regarding the influence of varying ferrule heights with different post and dowel material.

Hence the aim of the present study is to analyse the stress of endodontically treated teeth by means of 3-dimensional finite element analysis on the remaining tooth structure and apex of the post, the effect of various ferrule heights with different post and dowel materials, the difference between uniform and non-uniform ferrules and, the effect of oblique and vertical loads in conjunction with various ferrule heights.

## MATERIALS AND METHODS.

A 3-dimensional finite element model of a maxillary central incisor with post and core build up, restored with porcelain fused to a metal crown was designed for the present study. The maxillary central incisor was designed with the dimensions of crown length 10mm, mesio distal width 8mm, and the root length 12.5mm. All models were considered to be endodontically treated with the configurations for uniform ferrule designed at 0mm,

2mm, 4mm, and for non-uniform ferrule at 2mm, and 4mm with an oblique fracture at an angle of 300.

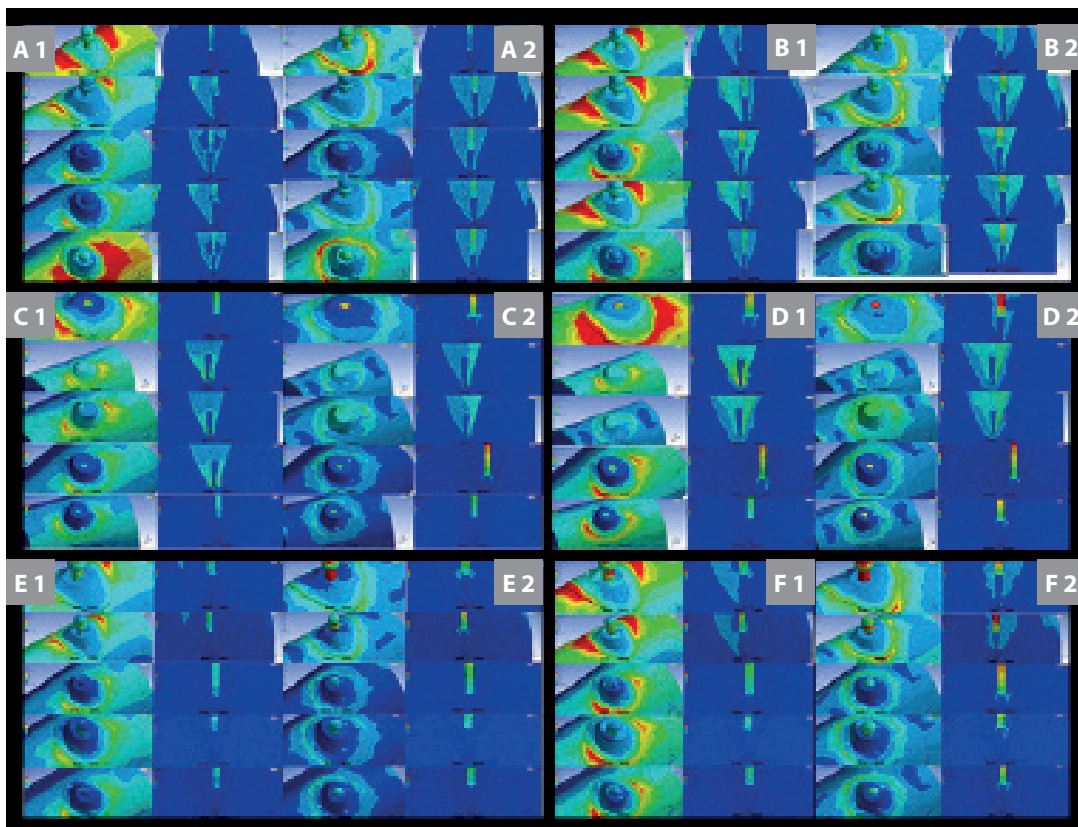
Three different types of materials were utilized for post-core fabrication: fiberglass reinforced post with a composite core build up (group GFR); zirconia post with a composite core build up (group Zr); and custom cast nickel chromium post and core (group NiCr). The length of the post was designed with a canal depth of 8mm and coronal height of 4mm. The GFR post and the Zr post had diameters of 1.54mm and the composite core build up was designed with a coronal height of 7mm and width of 1.5mm thickness around the post. The NiCr post was designed as one unit with a coronal height of 7mm and post length of 8mm into the canal. The models were divided into three groups based on the post and core materials as described, with five models in each group corresponding to the ferrule configurations. The geometric models of the teeth and other supporting elements were designed using Pro Engineer software. Mechanical properties (Elastic

modulus [E] and Poisson ratio [ν]) were obtained from the literature,<sup>18</sup> with all the model structures isotropic, homogeneous and linear elastic. (Table 1)

However the model structure of GFR was considered to be orthotropic, homogeneous, and linear elastic, since GFR exhibits properties relative to the direction of measurement while isotropic models exhibit the same property in all directions. The finite element models were subjected to ANSYS (Analysis System Software) by von Mises stress for finite element analysis and processing of the results. Each model was subjected to a vertical load of 100N and 150N applied to the incisal tip of the tooth at a 90 degree angle, and an oblique load of 100N and 150N applied to the palatal surface of the tooth at a 135 degree angle. (Figure 1)

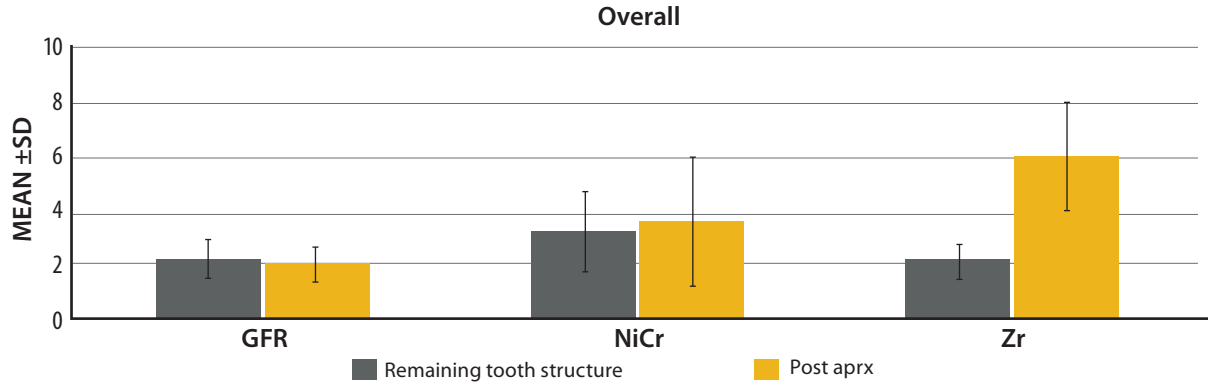
The statistical analysis was done with SPSS version 16.0 and the descriptive status was used to find the distribution of data. Analysis of variance (ANOVA), Tukey Post Hoc, and Paired t-test were used for the multivariate analysis.

**Figure 1.** Participation flowchart of stomatology students in a Cuban university.



**A:** GFR post for 0mm, 2mm, 4mm uniform ferrule and 2mm, 4mm non uniform ferrule (arranged top to bottom). **A1:** 100 N oblique load. **A2:** 100 N vertical load. **B:** GFR post for 0mm, 2mm, 4mm uniform ferrule and 2mm, 4mm non uniform ferrule (arranged top to bottom). **B1:** 150 N oblique load. **B2:** 150 N vertical load. **C:** Cast metal post for 0mm, 2mm, 4mm uniform ferrule and 2mm, 4mm non uniform ferrule (arranged top to bottom). **C1:** 100 N oblique load. **C2:** 100 N vertical load. **D:** Cast metal post for 0mm, 2mm, 4mm uniform ferrule and 2mm, 4mm non uniform ferrule (arranged top to bottom). **D1:** 150 N oblique load. **D2:** 150 N vertical load. **E:** Zirconia post for 0mm, 2mm, 4mm uniform ferrule and 2mm, 4mm non uniform ferrule (arranged top to bottom). **E1:** 100 N oblique load. **E2:** 100 N vertical load. **F:** Zirconia post for 0mm, 2mm, 4mm uniform ferrule and 2mm, 4mm non uniform ferrule (arranged top to bottom). **F1:** 150 N oblique load. **F2:** 150 N vertical load.

**Figure 2.** Mean stress of post material on remaining tooth structure and post apex.



**Table 1.** Material properties of the materials used in the model.<sup>18</sup>

Material	Modulus_of elasticity (MPa)	Poisson's ratio
Enamel	84100	0.33
Dentin	18000	0.31
Pulp	20	0.45
Periodontal ligament	69	0.45
Cancellous bone	1370	0.30
Cortical bone	13700	0.30
Composite resin	15800	0.24
Ceramic	95000	0.24
Gutta percha	0.0069	0.45

**Table 2.** Comparison of stress at the apex of the post between the three groups (GFR, NiCr, Zr) for ferrules of 0mm, 2mm, 4mm, 2mm ferrule with oblique fracture, and 4mm ferrule with oblique fracture using paired t-test.

Types of Ferrule	GFR - NiCr			NiCr - Zr			GFR - Zr		
	Mean Difference	Std. Deviation	Sig.	Mean Difference	Std. Deviation	Sig.	Mean Difference	Std. Deviation	Sig.
0mm	-3.70	1.14	.025	0.19	1.14	.984	3.51	1.13	.032
2mm	0.51	0.88	.834	-4.54	0.88	.002	4.02	0.88	.004
4mm	0.65	1.03	.806	-4.88	1.03	.003	4.22	1.03	.007

GFR: Fiberglass reinforced post. Zr: Zirconia post. NiCr: Custom cast nickel chromium post. Sig: Significance.

**Table 3.** Comparison of stress in the remaining tooth structure between the three groups (GFR, NiCr, Zr) for ferrules of 0mm, 2mm, 4mm, 2mm ferrule with oblique fracture, and 4mm ferrule with oblique fracture using paired t-test.

Types of Ferrule	GFR - NiCr			NiCr - Zr			GFR - Zr		
	Mean Difference	Std. Deviation	Sig.	Mean Difference	Std. Deviation	Sig.	Mean Difference	Std. Deviation	Sig.
0mm	-0.27	0.57	.886	0.57	0.57	.591	-0.30	0.57	.856
2mm	2.24	0.84	.061	2.34	0.84	.051	-0.09	0.84	.993
4mm	2.18	0.82	.061	2.19	0.82	.060	-0.01	0.82	1.000
2mm oblique fracture	0.016	0.58	1.000	0.84	0.58	.988	-0.10	0.58	.984
4mm oblique fracture	-0.33	0.55	.818	0.46	0.55	.685	-0.13	0.55	.969

GFR: Fiberglass reinforced post. Zr: Zirconia post. NiCr: Custom cast nickel chromium post. Sig: Significance.

**Table 4.** Comparison of stress on the remaining tooth structure in GFR, NiCr, Zr between different ferrule heights (0mm, 2mm, 4mm, 2mm oblique fracture, 4mm oblique fracture) using paired t-test.

Types of Ferrule	GFR - NiCr			NiCr - Zr			GFR - Zr		
	Mean Difference	Std. Deviation	Sig.	Mean Difference	Std. Deviation	Sig.	Mean Difference	Std. Deviation	Sig.
0-2mm	-0.05	0.59	1.000	-2.03	0.87	.188	-0.26	0.54	.989
0-4mm	-0.10	0.59	1.000	-2.02	0.87	.189	-0.40	0.54	.946
0-2mm [oblique]	-0.11	0.59	1.000	-0.18	0.87	1.000	-0.31	0.54	.978
0-4mm [oblique]	-0.12	0.59	1.000	-0.18	0.87	.999	-0.29	0.54	.982
2-4mm	-0.06	0.59	1.000	0.003	0.87	1.000	-0.14	0.54	.999
2-2mm [oblique]	-0.06	0.59	1.000	2.20	0.87	.134	-0.05	0.54	1.000
2-4mm [oblique]	-0.07	0.59	1.000	1.84	0.87	.261	-0.03	0.54	1.000
4-4mm [oblique]	-0.01	0.59	1.000	-1.84	0.87	.263	-0.11	0.54	1.000

GFR: Fiberglass reinforced post. Zr: Zirconia post. NiCr: Custom cast nickel chromium post. Sig: Significance.

**Table 5.** Comparison of stress on the post apex of GFR, NiCr, Zr groups between different ferrule heights (0mm, 2mm, 4mm, 2mm oblique fracture, 4mm oblique fracture) using paired t-test.

Types of Ferrule	GFR - NiCr			NiCr - Zr			GFR - Zr		
	Mean Difference	Std. Deviation	Sig.	Mean Difference	Std. Deviation	Sig.	Mean Difference	Std. Deviation	Sig.
0-2 mm	-0.05	0.47	1.000	4.16	1.14	.018	-0.57	1.54	.995
0-4 mm	-0.23	0.47	.988	4.13	1.14	.019	-0.94	1.54	.971
0-2mm [oblique]	-0.19	0.47	.994	0.87	1.14	.939	-0.67	1.54	.992
0-4mm [oblique]	-0.26	0.47	.980	0.74	1.14	.964	-0.93	1.54	.972
2-4mm	-0.17	0.47	.996	-0.03	1.14	1.000	-0.37	1.54	.999
2-2mm [oblique]	-0.13	0.47	.998	-3.29	1.14	.074	-0.10	1.54	1.000
2-4mm [oblique]	-0.21	0.47	.992	-3.41	1.14	.060	-0.36	1.54	.999
4-4mm [oblique]	-0.07	0.47	1.000	-3.38	1.14	.060	-0.36	1.54	1.000

GFR: Fiberglass reinforced post. Zr: Zirconia post. NiCr: Custom cast nickel chromium post. Sig: Significance.

**Table 6.** Comparison of stress on the remaining tooth structure and apex of the post between the three groups (GFR, NiCr, Zr) under vertical load and oblique load using ANOVA analysis.

Material		Oblique Load			Vertical Load		
		Mean	Std. Deviation	Sig.	Mean	Std. Deviation	Sig.
Remaining tooth structure	GFR	2.85	0.58	.020	1.72	0.36	.002
	NiCr	4.00	1.68		2.57	0.87	
	Zr	2.67	0.58		1.65	0.10	
<b>Total</b>		<b>3.17</b>	<b>1.20</b>		<b>1.98</b>	<b>0.70</b>	
Post apex	GFR	1.73	0.37	.000	2.46	0.58	.000
	NiCr	2.93	1.86		4.40	2.62	
	Zr	4.68	0.97		7.47	1.71	
<b>Total</b>		<b>3.12</b>	<b>1.71</b>		<b>4.77</b>	<b>2.74</b>	

GFR: Fiberglass reinforced post. Zr: Zirconia post. NiCr: Custom cast nickel chromium post. Sig: Significance.



## RESULTS.

The multivariate analysis of Von Mises stress on the post between the three groups (GFR, NiCr, Zr), for each specific ferrule height showed there was a significant difference between GFR and Zr posts (Table 2) with the maximum mean stress in Zr of 6.39 MPa in the apex of the post. For 2mm and 4mm uniform ferrule there was also significant stress between NiCr and Zr post (Table 2) with the maximum mean stress in Zr post, while for 0mm ferrule there was significant difference between the GFR and NiCr groups (Table 2) with maximum stress in NiCr of 5.65 MPa ( $p < 0.05$ ). On comparing the stress on the remaining tooth structure for all the ferrule heights, there was no significant difference between the groups at the apex of the post (Table 3) ( $p > 0.05$ ). But, considering the core structure, the NiCr core structure had higher mean stress compared to composite core of groups GFR and Zr. (Figure 2)

The paired t-test for different ferrule heights within the group showed there was no significant difference in stress with varying ferrule in the GFR and Zr posts, both in the remaining tooth structure and post apex (Table 4 and Table 5), whereas in the case of NiCr posts there was a significant difference between 0mm-2mm, and 0mm-4mm uniform ferrule in post apex (Table 5), ( $p < 0.05$ ) with maximum mean stress in 0mm ferrule of 5.65Mpa. There was no significant difference in the stress value between uniform and non-uniform ferrules ( $p > 0.05$ ).

According to the type of load (oblique or vertical) within the group, the higher mean stress was observed in the remaining tooth structure for oblique load in all the three groups, with the mean of 2.84, 4.00, and 2.67 MPa respectively, while it was observed for vertical load in the post apex for all the three groups a mean of 2.45, 4.39, and 7.46 MPa respectively. (Table 6)

Between the groups, higher mean stress was observed in in the apex of the Zr post, with 4.68 MPa for oblique loading, and 7.46 MPa for vertical loading.

## DISCUSSION.

Over the years several hypotheses have been cited to explain the predisposal to failure in endodontically treated teeth regarding endodontic access and fracture resistance of the tooth structure.<sup>19</sup> Reeh, Messer and

Douglas showed that the endodontic access eliminates the structural integrity of the coronal dentin in the pulpal roof and enables greater flexing of the tooth under function.<sup>20</sup> To strengthen the tooth, it is essential to appropriately select the post system, material and design. Prefabricated posts provide a good option as it decreases chairside time and provides adequate results.<sup>11</sup> Moreover, authors found prefabricated posts produced significantly less internal forces when compared to cast posts.<sup>7</sup> However, in a canal with extensive preparation and varied cross section, a well-adapted cast post and core restoration would be highly retentive compared to a prefabricated post.<sup>21</sup> The vast majority of the literature suggests that the ferrule is a vital factor in increasing resistance to fracture for different types of posts and core.<sup>7,8</sup> The present study designed varying ferrule height to analyze the stress distribution in the post apex and remaining tooth structure with different post material.

The present study showed that the apex of the post had higher von Mises stress for GFR, Zr and NiCr posts indicating high fracture loads in the post apex compared to the remaining tooth structure, causing root fracture. It was also observed that the higher stresses were observed in the Zr post compared to GFR and NiCr posts. The study conducted also revealed that the maximum mean stress in post apex were observed during vertical load while in the remaining tooth structure the maximum mean stress was observed during oblique loading. Moreover, the fracture load was higher in the apex of the post and the results were not significant in the remaining tooth structure thereby indicating higher fracture thresholds for the remaining tooth structure.

It was observed that the Zr post suffered higher stress compared to other materials in both vertical and oblique loading on post apex, while NiCr showed higher mean stress in the remaining tooth structure during oblique loading. Though Hayashi *et al.*,<sup>22</sup> revealed that on vertical loading, the fracture load was greatest in teeth restored with the cast metal post and cores, the present study showed higher stress with zirconia at the apex of the post, which means that the high modulus of elasticity (200GPa) of a zirconia post created higher stress. The stiffness and hardness of zirconia posts would lead to catastrophic failures of the root and eventually to great

difficulty in removal of a fractured post.<sup>23</sup>

On comparing different ferrule heights, maximum stress was observed in 0mm ferrules in congruence with the previous study that showed that the ferrule preparation increased the mechanical resistance of the restoration.<sup>24</sup> In addition it was observed that the fracture threshold for a NiCr post is reduced compared to Zr and GFR posts with a 0mm ferrule. This is in agreement with the study conducted by Sherfudhin, 25 which suggests that teeth restored with cast posts and core (NiCr) had a higher compressive load leading to catastrophic fracture, but this was applicable only to 0mm ferrule. In addition the study also shows that there were no significant difference in the stress among the groups between uniform and non-uniform ferrule and the amount of stress were similar.<sup>26</sup> On evaluation of fracture thresholds for the dowel systems, this was higher on the remaining tooth structure especially for composite core build up compared to NiCr core superstructure indicating the elastic modulus of composite material is similar to dentin and is influenced by stress likewise.

The present study shows maximum stress in the zirconia post followed by custom cast metal (NiCr) post and core when compared to fiberglass post (GFR), with higher stress at post apex. It is inferred that material with low elastic modulus similar to that of dentin, may be more suitable for post restoration with respect to the stress distribution.<sup>27</sup> Several studies have shown that custom cast post and core (NiCr) lead to catastrophic failure<sup>8</sup> but the present study revealed that it is less compared to zirconia (Zr) posts. Rosentritt *et al.*,<sup>28</sup> stated that the physical and mechanical properties of zirconia posts increases the strength of the tooth, but the present FEA analysis showed lower fracture resistance with a zirconia (Zr) post indicating that a stiffer post causes catastrophic failure while the composite core

created less stress on the remaining tooth structure. The limitations of the study include that the modes of failure observed do not represent failure as seen clinically. The reason for failure of endodontically treated teeth cannot be attributed to static loads as repetitive mechanical loading and thermal changes occur in the mouth.

## CONCLUSION.

Within the imitations of this three dimensional finite element analysis, the findings provided evidence that the higher fracture loads were observed only at the apex of the post. Prefabricated zirconia posts had maximum mean stress followed by custom cast post. The fracture thresholds were high on the remaining tooth structure for the dowel irrespective of the ferrule height and configuration, especially for composite core build up. The present study confirmed that varying the ferrule height in a maxillary central incisor did not have any effect on the fracture resistance of endodontically treated teeth for all three post materials, but the absence of ferrule was found to be suitable for custom cast metal posts compared to prefabricated posts.

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