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Influence of size-anatomy of the maxillary central incisor on the biomechanical performance of post-and-core restoration with different ferrule heights

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PURPOSE. The study aims to investigate the influence of the ferrule effect and types of posts on the stress distribution in three morphological types of the maxillary central incisor. **MATERIALS AND METHODS.** Nine models were created for 3 maxillary central incisor morphology types: "Fat" type - crown 12.5 mm, root 13 mm, and buccolingual cervical diameter 7.5 mm, "Medium" type - crown 11 mm, root 14 mm, and buccolingual cervical diameter 6.5 mm, and "Slim" type - crown 9.5 mm, root 15 mm, and buccolingual cervical diameter 5.5 mm. Each model received an anatomical castable post-and-core or glass-fiber post with resin composite core and three ferrule heights (nonexistent, 1 mm, and 2 mm). Then, a load of 14 N was applied at the cingulum with a 45° slope to the long axis of the tooth. The Maximum Principal Stress and the Minimum Principal Stress were calculated in the root dentin, crown, and core. **RESULTS.** Higher tensile and compression stress values were observed in root dentin using the metallic post compared to the fiber post, being higher in the slim type maxillary central incisor than in the medium and fat types. Concerning the three anatomical types of maxillary central incisors, the slim type without ferrule height in mm presented the highest tensile stress in the dentin, for both types of metal and fiber posts. **CONCLUSION.** Post system and tooth morphology were able to modify the biomechanical response of restored endodontically-treated incisors, showing the importance of personalized dental treatment for each case. [J Adv Prosthodont 2024;16:77-90]

KEYWORDS
Dental materials; Dental restoration failure; Endodontically treated teeth; Finite element analysis

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INTRODUCTION

Restoration of endodontically treated anterior teeth with severe loss of crown structure has attracted considerable attention in the scientific literature,[1] particularly the maxillary central incisor when post-and-core is recommended.[2-11] One argument could be that anterior teeth are exposed to functional horizontal forces and are more susceptible to failure.[12-14] In the search for a better protocol to fabricate the definitive restoration in the long term, the tendencies of many studies are towards the analysis of the effect of the post (elastic modulus)[15,16] and the preservation of the remaining coronary structure (ferrule effect).[17,18] A conceived attribute of the post is to improve the biomechanical behavior and increase the resistance of the tooth.[19,20] But, the presence of the post is also associated with biomechanical failures such as decementation and dental fracture,[21] although it has been stated that the resistance to dentin fracture is directly proportional to the volume of the remaining tooth structure.[22] However, its importance is not clearly defined regarding the tooth's anatomical conditions, and many studies do not include the analysis of other important variables such as anatomical dimensions.[23] There is a lack of scientific information about the size anatomy parameters of the tooth and their effect on the biomechanical behavior of the post-restoration. For that reason, the influence of these parameters must be evaluated.

Trabert *et al*.[24] analyzed the impact resistance of the maxillary central incisor with its crowns intact. The results showed that variables such as mesiodistal diameter, root length, and pulp chamber width can be used to predict absorbed impact energy. Libman and Nicholls[25] studied the fatigue load in maxillary central incisors with ferrule heights of 0.5, 1.0, 1.5 and 2.0 mm. The number of cycles until preliminary failure was correlated with the buccolingual dimensions measured at the level of the cervical finish line of the test teeth, and no significant correlation was found. Greenfeld *et al*.[26] reported on maxillary central incisors and canines that the remaining buccolingual dentin thickness had a high correlation with the final failure load. The canines showed a higher load resistance compared to the central incisors. Using finite element analysis, Savychuk *et al*.[27] compared the impact of the type of post (fiber post-composite core or post-cast core) together with the effect of ferrule on the fields generated by tension in endodontically treated lateral incisors and mandibular canines. The results indicated that post-restored mandibular lateral incisors are prone to greater stresses on the dentin and major components of the restoration compared with teeth in greater anatomy.

Some studies have observed that the maxillary central incisor tooth presents a great variability in natural size and dimension.[28] Dental anatomy textbooks only report crown diameters, root length, and crown/root ratios in an axial direction with no scientific information regarding the buccolingual direction.[29] Furthermore, research demonstrated that there is a direct relationship between the characteristics of the crown and the root, which allows the prediction of root diameters through crown measurement with an accuracy of 95%, and also reported a great variability in root length.[29] Based on the data obtained, three morphological groups of maxillary central incisors were established: Stout type (56.67%), intermediate type (22.67%), and strangled type (20.67%). The researchers conclude that accurate knowledge of the volumetric description of tooth diameters and crown-root ratio allows for improved treatment planning.[29,30]

In vitro studies of static load,[31] simulated chewing[32] or strain gauge,[33] generally make anatomical measurements of each selected human tooth. However, they apply the averages of the measurements to represent the sample size of the study. In addition, the fabricated prosthetic crown has the same pattern anatomical dimensions for all specimens, which could alter the real crown-root relationship of the natural tooth. Therefore, under these conditions, the results of *in vitro* studies should be interpreted with caution. Similarly, in the finite element analysis method, the anatomical dimensions of the simulated tooth are taken from standard measurements from anatomy books[34] or from a single intact natural tooth arbitrarily selected as a pattern,[35] which can be an unrealistic condition.

The so-called ferrule effect is suggested as the most important factor for the longevity of post-restored tooth because it dissipates the concentration of force and increases the resistance to fracture.[36] *In vitro* studies frequently use, as an isolated criterion, the height of the axial walls to assess the effectiveness of the ferrule effect.[37] However, in the maxillary central incisor the results are controversial. A 1.0 mm height of the axial walls is suggested,[38] while another study considers 2.0 mm more appropriate.[39] According to these studies, these results have been based mainly on the post's elastic modulus and the cementing agent's adhesion. Meanwhile, some finite element studies suggest a 2.0 mm wall height for better stress distribution.[40-42] However, the tendency to consider dental morphology is growing, because it affects the distribution of stress.[43] In this regard, a finite element study suggests that the ferrule height on the maxillary central incisor should be determined on a case-by-case basis, based on the buccolingual cervical root diameter.[44] Therefore, the ferrule effect is a topic which needs a more exhaustive approach to its understanding.[45]

Finite element analysis (FEA) uses a mathematical model that is capable of computationally calculating the stress distribution generated in the structure and materials. This methodology has been chosen because it has shown to be a useful tool when investigating complex systems that are difficult to standardize during *in vitro* and *in vivo* studies.[46-49] However, anatomic variations have been rarely considered in previous FEA studies with post-and-core restorations.

The purpose of this study is to investigate the influence of the ferrule effect and types of posts on the stress distribution in three morphological types of the maxillary central incisor. The null hypothesis to be tested was that the mechanical behaviors of the three morphological types "fat", "medium" and "slim" would be similar when restored with different ferrule heights with cast post or fiber.

MATERIALS AND METHODS

Using finite element analysis, the stress distribution was evaluated in maxillary central incisors with anatomical differences. From a sample of extracted maxillary central incisors made up of variations in size and morphology, 3 types of representative maxillary central incisors were selected. The "fat" type had crown dimensions of 12.5 mm, root of 13 mm, and a buccolingual cervical diameter of 7.5 mm. The "medium" type had crown dimensions of 11 mm, root of 14 mm, and a buccolingual cervical diameter of 6.5 mm. The "slim" type had crown dimensions of 9.5 mm, root of 15 mm, and a buccolingual cervical diameter of 5.5 mm. The two-dimensional (2D) finite element model was used.

The modeling of the two-dimensional external anatomy was made from a periapical radiograph, which was taken from a buccolingual section of each extracted tooth of the 3 representative morphological types. Each radiograph was digitized using a scanner and imported into a software program that digitizes framework landmarks. From those points, a fine distribution of surface elements was generated using the software Rhinoceros, v. 5.0 SR8 (McNeel North America). Then, the geometric model for finite element analysis was created using the computer-aided engineering (CAE) software (ANSYS Inc., v. 17.2, Houston, TX, USA) generating the element meshes. Two types of posts were modeled (cast and fiber post). The length of both posts was 9 mm. The diameters of the posts were: apical 1.2 mm, cervical 1.55 mm, and the taper of 1.8°. Three ferrule heights (0, 1, and 2 mm) were modeled. There was a difference in the crown-root ratio among the 3 morphological types of maxillary central incisors.

Six bi-dimensional numerical models were generated with the same geometry of each restored morphological type. The models are shown in Figure 1. In total, eighteen finite element models were created based on post-material (×2), tooth anatomy (×3), and ferrule height (×3). Deformation elements in a quadrilateral plane were used for the cross-sectional meshes of the models. The meshes are summarized in Figure 2.

The applied properties of the tissues and materials are shown in Table 1. Only the linear elastic response was calculated. All the properties were isotropic except that of the fiber post, which had orthotropic properties with greater hardness in the longitudinal axis. All material interfaces were continuous, except for interfaces with gutta-percha and interfaces between the metal post and root dentin. The coefficient of friction with gutta-percha was 0 and between the

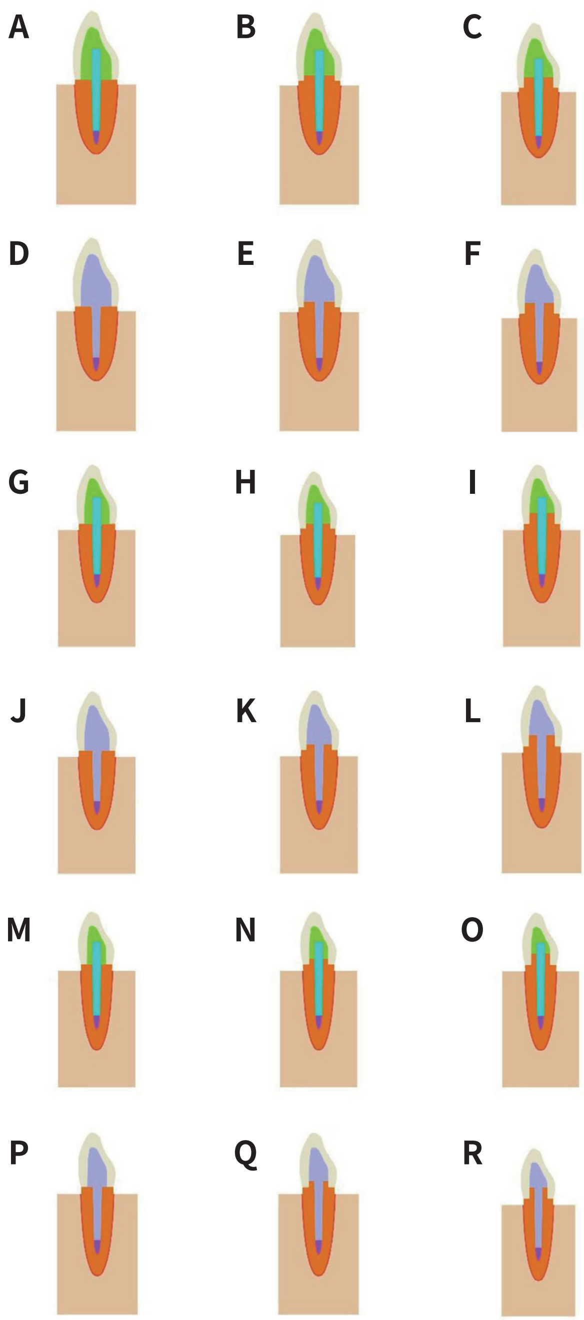

Fig. 1. Fat model restored with glass-fiber post and composite core. (A) No ferrule, (B) 1 mm of ferrule and (C) 2 mm of ferrule. Fat model restored with metal post- and- core. (D) No ferrule, (E) 1 mm of ferrule and (F) 2 mm of ferrule. Medium model restored with glass-fiber post and composite core. (G) No ferrule, (H) 1 mm of ferrule and (I) 2 mm of ferrule. Medium model restored with metal post- and- core. (J) No ferrule, (K) 1 mm of ferrule and (L) 2 mm of ferrule. Slim model restored with glass-fiber post and composite core. (M) No ferrule, (N) 1 mm of ferrule and (O) 2 mm of ferrule. Slim model restored with metal post- and- core. (P) No ferrule, (Q) 1 mm of ferrule and (R) 2 mm of ferrule.

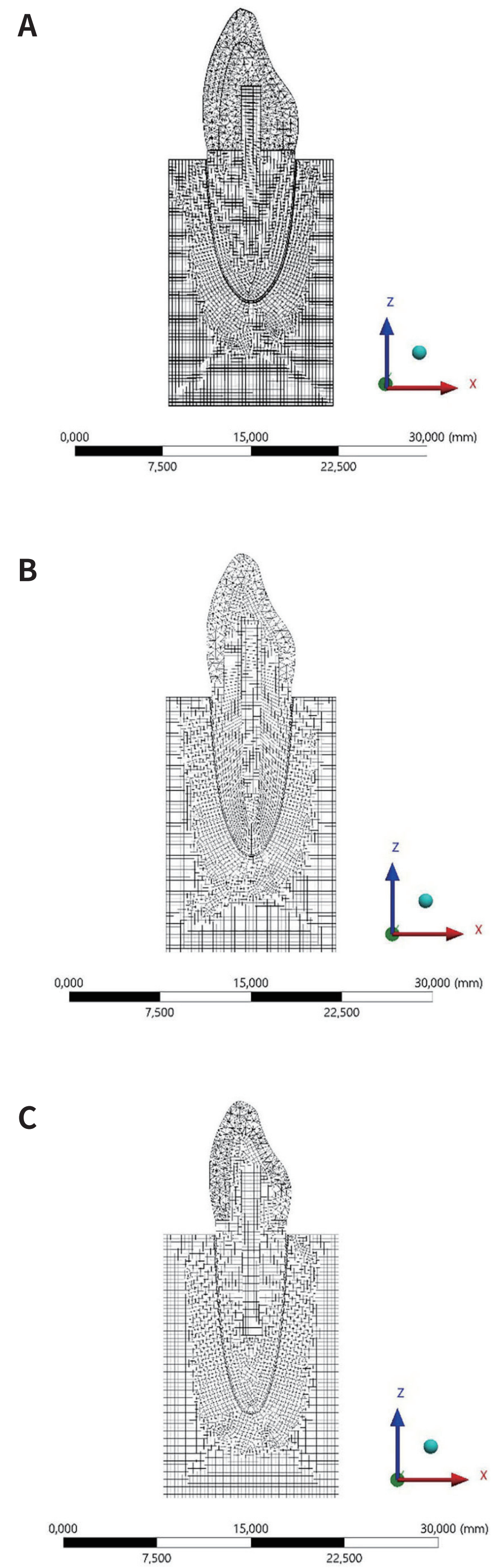

Fig. 2. Finite element mesh from (A) fat model, (B) medium model and (C) slim model.

Table 1. Mechanical properties of the materials/structures used in this study

Material	Elastic modulus (GPa)	Poisson ratio	References
Bone tissue	13.7	0.3	Tribst *et al.*[18]
Periodontal ligament	0.00118	0.5	Rundquist *et al.*[47]
Dentin	14.7	0.31	Rundquist *et al.*[47]
Gutta percha	0.16	0.45	Rundquist *et al.*[47]
Metal post	200	0.3	Santos *et al.*[48]
Glass fiber post (longitudinal/ lateral)	37/9.5	0.27/0.34	Santos *et al.*[48]
Lithium disilicate	96	0.26	Della Bona *et al.*[49]
Composite	12	0.33	Della Bona *et al.*[49]

metallic post and root dentin was 0.25.

The average anatomical dimensions corresponding to the alveolar bone and periodontal ligament were generated according to data from the literature.[47-49] The roots were embedded in a 0.2 mm-thick periodontal ligament and simulated bone section. The inferior and lateral sides of the bone section were fixed. In a buccal direction, a compressive load of 14 N was applied on the incisal third of the palatal surface at an angle of 45 degrees to the axial axis of the tooth (Fig. 3).

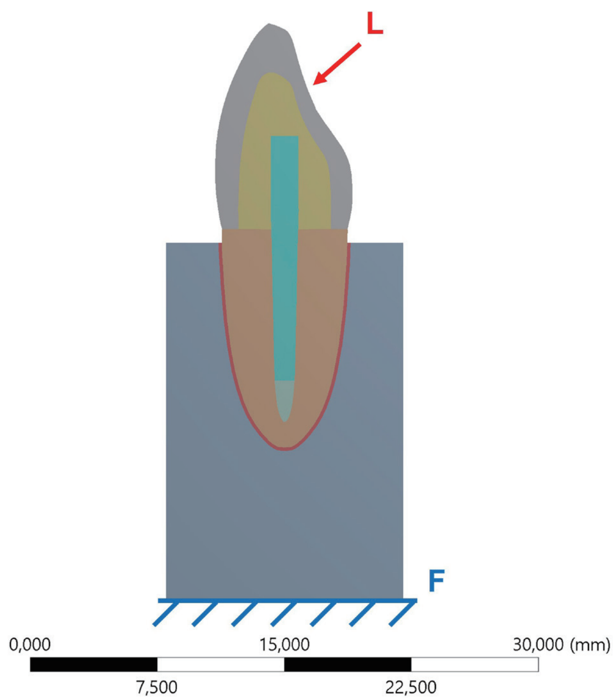

Fig. 3. Boundary conditions showing the loading region (L) and the fixation support (F).

RESULTS

In this study, the results of the three anatomical types of maxillary central incisor subjected to occlusal loading are presented as the first ('maximum') and third ('minimum') principal stresses on root, crown, and core dentin. The stress distribution is shown in Figures 4 and 5. Note that root and crown dentin each have their stress scale. Table 2 lists the stress peak of the maximum and minimum principal stresses for root, crown, and core dentin. For each maxillary central incisor anatomical type (fat, medium and slim) restored with 0 mm, 1.0 mm, and 2.0 mm ferrule height and fiber and metal posts, the relationships between maximum principal stress and minimum principal stress are presented. The tensile stress values were positive and the compressive stress values were negative.

In the root dentin, when the metal post was used as compared to the fiber post, higher values of tensile and compression stresses were observed regardless of the maxillary central incisor anatomy. It was shown that the fat-type maxillary central incisor generated less stress, probably because it had more dentin volume and larger buccolingual diameter (Fig. 4, Fig. 5).

The location of the maximum principal stress in the root dentin of the slim, medium, and fat types, due to the direction of the occlusal load, prevailed on the lingual side, encompassing the cervical-middle thirds of the root surface and apex of the post. The highest stress concentration was observed when the metal post was used compared to the fiber post, which was the most evident in the slim maxillary central incisor (Fig. 4).

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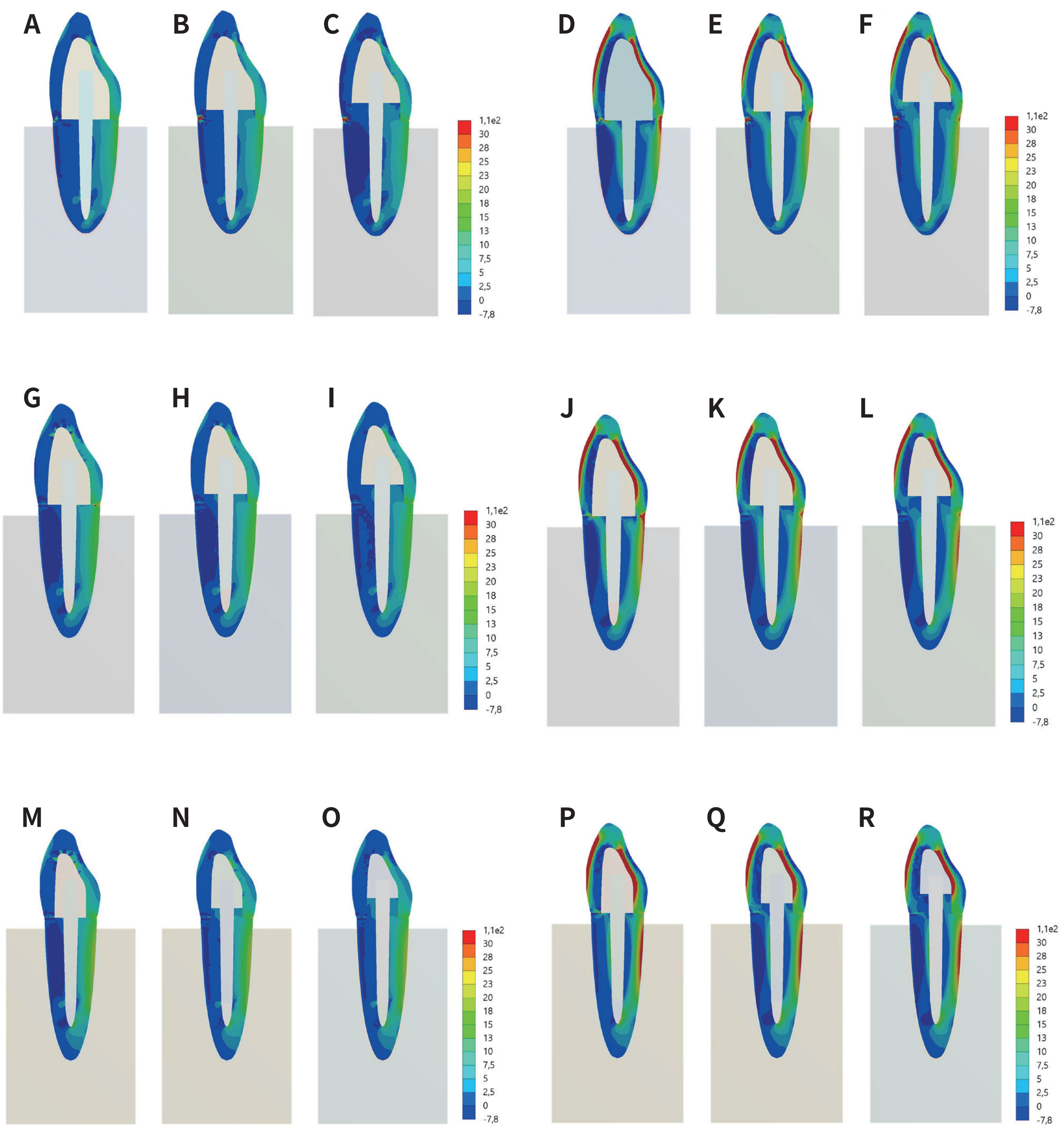

Fig. 4. Maximum principal stress in the fat model restored with glass-fiber post and composite core. (A) No ferrule, (B) 1 mm of ferrule and (C) 2 mm of ferrule. Maximum principal stress in the fat model restored with metal post- and- core. (D) No ferrule, (E) 1 mm of ferrule and (F) 2 mm of ferrule. Maximum principal stress in the medium model restored with glass-fiber post and composite core. (G) No ferrule, (H) 1 mm of ferrule and (I) 2 mm of ferrule. Maximum principal stress in the medium model restored with metal post- and- core. (J) No ferrule, (K) 1 mm of ferrule and (L) 2 mm of ferrule. Maximum principal stress in the slim model restored with glass-fiber post and composite core. (M) No ferrule, (N) 1 mm of ferrule and (O) 2 mm of ferrule. Maximum principal stress in the slim model restored with metal post- and- core. (P) No ferrule, (Q) 1 mm of ferrule and (R) 2 mm of ferrule.

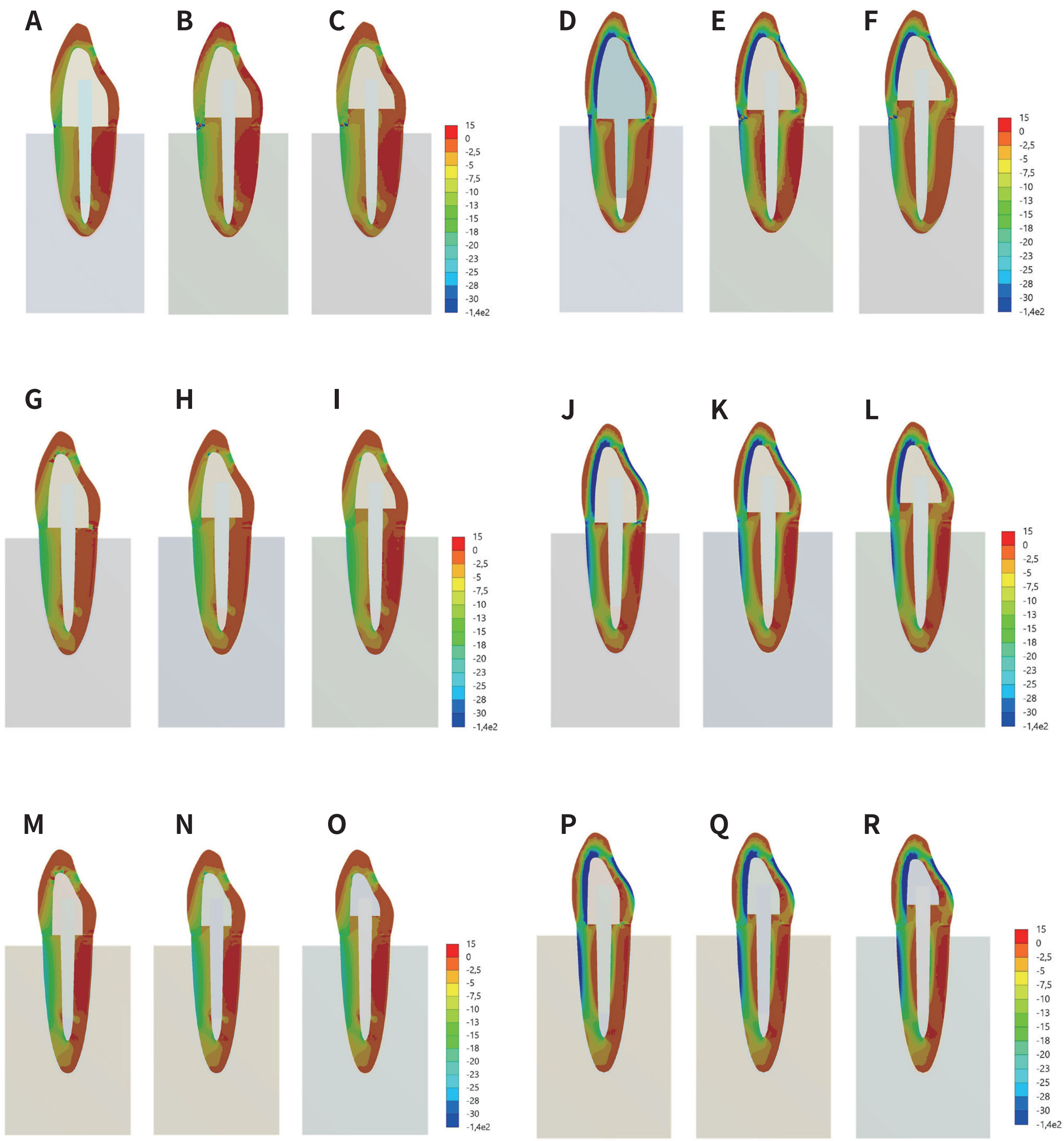

Fig. 5. Minimum principal stress in the fat model restored with glass-fiber post and composite core. (A) No ferrule, (B) 1 mm of ferrule and (C) 2 mm of ferrule. Minimum principal stress in the fat model restored with metal post- and- core. (D) No ferrule, (E) 1 mm of ferrule and (F) 2 mm of ferrule. Minimum principal stress in the medium model restored with glass-fiber post and composite core. (G) No ferrule, (H) 1 mm of ferrule and (I) 2 mm of ferrule. Minimum principal stress in the medium model restored with metal post- and- core. (J) No ferrule, (K) 1 mm of ferrule and (L) 2 mm of ferrule. Minimum principal stress in the slim model restored with glass-fiber post and composite core. (M) No ferrule, (N) 1 mm of ferrule and (O) 2 mm of ferrule. Minimum principal stress in the slim model restored with metal post- and- core. (P) No ferrule, (Q) 1 mm of ferrule and (R) 2 mm of ferrule.

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The minimum principal stress, also called compression stress, was in located in the dentin of the vestibular surface of the cervical-middle root thirds and apex of the post. Regarding the use of the metallic post, it was observed that it generated a greater concentration of stress, with greater magnitude in the slim-type maxillary central incisor compared to the medium and fat types. When the fiber post was used, the compressive stress distribution was more homogeneous in the root dentin of the fat-type maxillary central incisor. However, in the medium anatomical type, stress concentration of lesser magnitude is observed located on the external vestibular surface of the cervical third. Instead, a higher concentration of stress was found in the mid-cervical third and apex of the post in the slim-type maxillary central incisor (Fig. 5).

Regarding the preparation of the height of the ferrule, alterations of the maximum principal stress were observed in the remaining coronary dentin of the slim, medium and fat maxillary central incisors. In summary, the maximum principal stress was lower with higher ferrule walls (Table 2). The difference is the most evident when using the metal post where the tensile stress is the highest with no ferrule height, followed by 1 mm and 2 mm height. When the fiber post was used, the tensile stress decreased in the remaining coronary structure with higher ferrule walls, but this difference was less evident for metal posts. Concerning the three anatomical types of maxillary central incisors, the slim type without ferrule height presented the highest tensile stress in the dentin, for both types metal and fiber posts.

The ferrule height variations did not affect the minimum principal stress in the root dentin once the stress peak per maximum and minimum principal stresses remained proportional for each anatomical type of maxillary central incisor (Table 2).

Table 2. Stress peaks (MPa) in the dentin, crown and core according to each simulated model

Tooth	Post	Ferrule (mm)	Stress in root dentin (MPa)		Stress in crown (MPa)		Stress in core (MPa)	
			Max principal stress	Min principal stress	Max principal stress	Min principal stress	Max principal stress	Min principal stress
Fat	Cast	0	34.71	-35.97	111.73	-121.15	21.63	-12.79
		1	33.90	-34.13	107.66	-104.67	21.74	-12.24
		2	30.12	-33.10	106.59	-138.97	22.01	-16.84
	Fiber	0	30.16	-29.13	23.95	-49.95	7.43	-7.03
		1	21.74	-27.33	22.76	-40.61	6.80	-6.51
		2	20.80	-28.40	20.02	-36.77	6.47	-5.06
Medium	Cast	0	35.88	-32.21	100.69	-127.23	22.38	-11.81
		1	33.70	-32.27	96.48	-128.69	22.27	-12.86
		2	30.23	-31.92	94.53	-130.38	23.31	-13.06
	Fiber	0	31.87	-20.20	31.26	-32.44	9.82	-4.44
		1	22.95	-21.70	24.07	-30.47	7.43	-8.67
		2	21.61	-21.45	23.75	-30.07	7.44	-6.89
Slim	Cast	0	40.05	-37.94	179.80	-142.17	25.40	-12.97
		1	36.42	-37.08	163.20	-134.81	25.52	-13.05
		2	30.65	-36.80	118.18	-134.85	26.23	-12.86
	Fiber	0	33.44	-23.39	38.47	-29.83	9.85	-7.62
		1	31.20	-25.16	34.27	-30.42	8.38	-6.05
		2	28.15	-24.56	34.10	-24.93	8.25	-6.48

It must be noted that the core materials were different between the cast and fiber post models and therefore the stress values should not be directly compared. About the composite resin core, the stress increased in the slim type central incisor compared to the medium and fat type. As for the ferrule effect, it had a significant impact. Therefore, in the model 0 ferrule, the tensile and compression stress increased in the composite resin core, producing a decrease in stress in the models with ferrule height of 1.0 and 2.0 mm.

In the cast core models, the maximum principal stress and the minimum principal stress were higher in the slim maxillary central incisor than in the medium and fat types. Regarding the ferrule effect, it caused an impact on the stress in the cast core according to the type of maxillary central incisor. In the maxillary central incisor with 2.0 mm ferrule, the stress of tensile and compression was higher, decreasing in models 1.0 mm and 0 mm ferrule; however, the differences were below 2 MPa between the models (Table 2). This effect was observed regardless of the tooth anatomy.

DISCUSSION

To our knowledge, this is the first study in the scientific literature that evaluates the size-morphology effect of endodontically treated maxillary central incisor restored with post-and-core. Commonly, previous finite element analysis studies that investigated stress distribution in the maxillary central incisor considered the design of an average tooth with consistent anatomical dimension.[2,3,10,11,13,20] However, there is great variation in size and anatomy in the natural human dentition.[30] According to the results of the present study, the three morphological types of maxillary central incisors considered predominant, which are “fat” type (56.67%), the “medium” type (22.67%) and the “slim” type (20.67%),[30] showed differences in stress distribution when using different types of posts, with and without ferrule wall height. This confirms the important role of dental anatomy in the biomechanical performance of post-crown restoration. Therefore, the results determined that the null hypothesis was rejected.

Analyzing the effects reported in Table 2 on root dentin, it is clear that the slim type model exhibited higher tensile stress values than the fat and medium types. The increase in the principal tensile stress could be detrimental to the remaining dentin structure.[2] Regarding the maxillary central incisor, the slim type has a comparatively smaller dentin volume and thin root dentin walls. The present simulated study suggests that this post-and-core restored tooth might be more susceptible to the debonding and/or fracture failure process. Regarding the role of the post material, it influenced the stress distribution in the root dentin. It was noticed that due to the high elastic modulus of the metal post, the maximum principal stress in the slim model increased. Instead, fiberglass posts are known for their ability to flex and distribute stress more similarly to natural tooth structure. Despite not being a consensus, it was reported that this flexibility can help absorb and distribute forces during biting and chewing, potentially reducing the stress on the remaining tooth structure.[13,19] In this study, the usage of orthotropic glass fiber and composite resin core reduced the amount of stress generated at the root dentin and crown in comparison with metal ones.

The present study showed that the presence of a ferrule reduces the maximum principal stress in the three maxillary central incisor models, compared to the results of the models without a ferrule. However, the mechanical behavior differs between the three types of maxillary central incisor size and morphology. In this sense, the slim model restored with the metal post in the absence of the ferrule presented the highest stress concentration, being a significant contributing factor in increasing the risk of fracture. Furthermore, the development of stress concentration in the region adjacent to the apex of the metal post is in agreement with previous finite element analyses.[3,41,42] Traditionally, it has been noted that the selection of a post and core material depends on several factors, such as the remaining tooth structure, occlusal forces, aesthetic requirements, patient habits, and the dentist’s professional judgment.[13] In this sense, the results of the present study point to the need to more thoroughly incorporate dental morphology into the treatment plan. Particular attention is needed to the maxillary central incisor, due to the variations in size

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and anatomical volume they present. This can provide better post system selection and more efficiently match ferrule height.

After root canal treatment, an endodontically treated incisor typically requires crown restoration to provide additional strength and protection.[18,21,22] The design,[18] material,[34,37] and dimenions[28] of the crown can influence the distribution of forces on the tooth. A well-fitting and properly contoured crown can help reduce stress concentration and increase the longevity of the tooth.[32] In this study, the crown was perfectly fitted in the simulation. However, the stress magnitude was different between the models even when the same post material and ferrule height were considered. This demonstrated that the teeth' anatomy can also affect the load distribution.

Like other human characteristics, teeth can differ in shape and size, even within the same individual's mouth. Variations can include differences in the overall shape (e.g., square, triangular, oval), the dimensions (length, width), and the proportions between the different surfaces of a tooth (e.g., height of the crown, size and shape of cusps).[29,30] Despite that, most dental treatments are not fully personalized and sometimes cannot fulfill the ideal requirements to promote long-term success for some individuals in comparison with others. In this sense, the present results showed that a larger tooth with more tissue and robust structure would be less affected by the post-endodontic treatment than a slim central incisor.

An interesting observation is about some dissimilar and at the same time compensatory anatomical characteristics among the maxillary central incisor groups of the present study. That is, the fat type has practically the same length, the crown 12.5 mm and the root 13 mm. However, in compensation, this tooth has a greater volume, which suggests increasing periodontal support. On the other hand, in the slim type, the crown measures 9.5 mm and the root, 15.0 mm. As can be seen, a tooth with a smaller dentin volume has a longer root as compensation to increase periodontal support. In this sense, they are anatomical conformations of the human dentition to respond to functional demands.[50] In the slim type maxillary central incisor, the use of different posts and ferrule heights showed a greater increase in tensile stress compared to the fat type, which could be explained by the differences in the buccolingual diameter.[27] However, these results are obtained by isolating each tooth without taking into account, for example, the labial inclination of the tooth, the anterior guidance (horizontal and vertical overpasses), and the type of occlusion. Therefore, there is a need for clinical research to evaluate the biomechanical performance of the ferrule height and type post in the prosthetic restoration in the different types of maxillary central incisor size-morphology and the incidence of these previously mentioned variables.

In the field of biomechanics, the concept of "Maximum Principal Stress" is used to describe the maximum tensile stress experienced by a material or structure in a particular direction.[10,11,15] When considering teeth biomechanics, the maximum principal stress can play a role in understanding the mechanical behavior of the tooth structure under different loads and forces.[13,18,33] Based on Table 2, the tensile stress peaks were higher at the crown, illustrating that in a situation with low-loading magnitude incidence, the ceramic crown would be more prone to failure than the root dentin. It corroborates the findings from previous investigations.[11,12,17]

On the other hand, the consideration of minimum principal stresses is relevant in engineering and material science contexts when analyzing the behavior of structures under different loading conditions correlated with the compressive strength of the set.[18] A previous investigation calculated that the compressive strength of lithium disilicate was higher than 670 MPa.[34] According to that, it is possible to observe that the applied load would not damage the crown by the compression side (buccal) but instead by the tensile side (lingual). The compression strength from dentin is 297 MPa, showing that depending on the load intensity and direction, this structure could fail by compression.[49]

The focus is primarily on understanding the distribution of forces, stresses, and strains within the tooth structure and its surrounding tissues, involving evaluating factors such as occlusal forces, material properties of the tooth, and the response of the supporting structures.[2,3,10,11,13,15,18,20,34] However, the two-dimensional analysis assumes that the structure being analyzed is planar and neglects the effects of the third dimension.[34] Plane strain assumes that the structure is infinitely thick in the third dimension and experiences strains only in the two dimensions of the analysis.[20,43] These assumptions may not accurately represent the actual stress and strain distributions in complex three-dimensional structures. Despite these limitations, 2D-FEA remains a valuable tool for initial analysis, design optimization, and gaining insights into the behavior of structures.

A previous investigation compared the resistance of endodontically treated teeth with different amounts of remaining coronal structure. Despite variations in coronal dentin height, the study found that teeth without remaining coronal structure had significantly higher fracture strength than those with remaining coronal structure.[51] This indicates that the presence of coronal dentin did not significantly affect the fracture strength of teeth with intraradicular retainers. However, another report demonstrated that an increased amount of coronal dentin significantly increased the fracture resistance of endodontically treated teeth.[52] Furthermore, failures in teeth without coronal structure (no ferrule) primarily occurred due to core fracture, emphasizing the importance of ferrule design in preventing adhesive failure. It was also reported that the presence of a ferrule significantly increased fracture strength in endodontically treated teeth.[53] These previous studies suggest that incorporating a ferrule design can enhance the resistance of teeth to adhesive failure; however, this information can be complemented with the present investigation showing that this effect can be dependent on the tooth anatomy and post-endodontic restorative procedure.

Another crucial limitation inherent to FEA pertains to the simulation of ideal adhesive interfaces between various structures. While FEA offers valuable insights into stress distributions and structural behaviors, it assumes a perfect cement layer, which may not accurately reflect clinical scenarios. Achieving such ideal adhesive interfaces, particularly in cases involving non-uniform cement layers like those encountered in bonding post-and-core structures within root canals, poses significant challenges.[30,35,50] The practical application of dental restorations involves a complex combination of clinical protocols that can influence adhesive performance, including variations in cement types, composition, and bonding agents. These factors introduce complexities that are often difficult to replicate in computational models. As a result, the predictive accuracy of FEA in assessing adhesive behavior may be limited, leading to potential discrepancies between simulated and actual clinical outcomes.

CONCLUSION

Within the limitations of the FEA study, the following conclusions were drawn:

The use of a ferrule between 1 - 2 mm in post-treated endodontically treated teeth reduces the stresses on the tooth-restoration complex.

Additionally, both post-system and tooth morphology were able to modify the biomechanical response of restored endodontically treated incisors, showing the importance of personalized dental treatment for each case.

Slim-shaped central incisors are more prone to failure due to higher stress concentration. This effect can be attenuated with longer ferrules and glass-fiber post instead of cast post-and-core.

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