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The Simulation of Fracture Resistance and Stress Distribution of Teeth In Endodontic Post-Treatment of Different Ferrule By Finite Element Analysis

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Abstract:- Post fiber, core, and crown restorations in post-endodontic treatment using ferrules strengthen teeth after post-restoration. To investigate the effect of different ferrule height designs on the resistance of dental fractures following endodontic treatment, using AUTOCAD as the basis for non-linear finite element analysis. Five models of 3D maxillary first incisors were constructed using AutoCAD 2016 with five different ferrule heights (mm) 0, 0.5, 1, 1.5, and 2, meshing and input mechanical properties, followed by loading 25 N and 170 N at an angle of 135° in the tooth palatal area which was analyzed by Finite element analysis (FEA) using ANSYS v 17.0 software. Von Mises analysis shows the maximum and minimum deformation values, equivalent elastic strain, and equivalent stress. The ferrule's total deformation value in the 25 N simulation was the highest at 0 mm (0.0093 mm) and the lowest at 2 mm (0.0091 mm). The simulation load was 170 N, the highest at 0 mm (0.0632 mm) and the lowest at 2 mm (0.0618 mm). The maximum equivalent elastic strain value of ferulle is highest at 1 mm (0.034814 mm) and lowest at 0 mm (0.03245 mm). The maximum equal stress value decreases in models with ferrules. In the 25 N and 170 N simulations, the highest values on the 3D model are at 0 mm (13,008 MPa and 88,452 MPa) and the lowest at 1 mm (11,567 MPa and 78,655 MPa). Conclusion.The addition of ferrule height can increase dental fractures' resistance after endodontic treatment by reducing deformation. Ferrule decreases stress on the tooth's labial cervical area and enlarges the strain on the cervical palatal dentine by holding non-axial loads from the palatal side.

Keywords:- *Ferrule, fracture resistance, restoration endodontic, stress.*

I. INTRODUCTION

Root canal treatment involves cleaning necrotic and infected tissue followed by appropriate obturation, causing the prevention of further microbial proliferation in the root canal system. The potential entry of microbes into the root canal system can cause endodontic treatment failure. For this reason, effective restoration of teeth after endodontic treatment is essential(Eliyas et al., 2015). However, post-endodontic treatment often presents challenges because endodontic tooth structure is generally weaker than healthy teeth due to loss of structure in the crown area and the roots of teeth (Kishen, 2015). Usually, the cause of tooth structure loss is due to extensive caries, fractures, or the removal of dental tissue during opening access, widening of the root canal, and loss of dentin moisture. These causes can increase the incidence of dental fractures (Marchionatti et al., 2017).

After root canal treatment, normal morphological integrity and tooth function can be obtained by performing a full crown or intra-coronal restoration (Kar et al., 2017). When the remaining tooth tissue structure cannot support the retention of a complete crown prosthesis, the post and core are known to replace the lost tooth tissue structure and provide retention for restoration. The post position's primary function is to give intracanal retention to core/ crown restoration and distribute the functional load more broadly to the area of the tooth crown structure and the remaining roots. Unfortunately, the root is not strengthened by the post (Seow et al., 2015). The ideal post system must replace lost tooth structure, be biocompatible, have a dentinal modulus that resembles dentin, have sufficient retention support, and distribute occlusal pressure during functional and parafunctional activities to prevent tooth fracture (Nagas et al., 2017).

The ferrule's mechanical effect on the cervical gingival area as a clinical crown holder is one approach to strengthening teeth after post-restoration. Ferulle consists of the crown's metal collars surrounding the dentine's parallel walls extending coronally to the shoulder of the preparation. Ferrules have been described as a critical element of tooth preparation in pins and cores in recent years. Ferrule preparation is generally accepted as a therapeutic strategy in

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dental preparations after endodontic treatment with a post and center and restored with a full crown (Ausiello et al., 2017). Placement of the ferrule around the preparation creates a protective 'ferrule effect' claimed to prevent the disintegration of the supporting tooth roots and assist in 'providing resistance to the release force and preventing fracture. A minimum height of 1-2 mm is required to achieve a protective effect (Dua et al., 2016). The ferrule has also been shown to increase resistance to dynamic mastication loads, maintain the integrity of cement density for full crown retention, and reduce the potential for stress concentration at the post and core junction.

In the case of damage to hard tissue, where the height of a circular ferrule of 2 mm is difficult to achieve, causing the design of the size of the ferrule used in the case be different. In vitro study conducted by Sherfudhin (2011) reported that different ferrule height designs affect fracture of post-endodontic tooth resistance (Sherfudhin et al., 2011a). Meanwhile, other studies have not found the effect of varying ferrule heights on teeth restored with fiber post and resin core (Muangamphan et al., 2015). Dikbas et al. (2007) reported that different ferrule designs did not significantly affect the fracture resistance of teeth with fiber posts (Dikbas et al., 2007). This study evaluates fracture resistance and stress distribution of teeth in endodontic post-treatment restored with prefabricated posts and full crowns with different ferrule designs based on finite element analysis

II. MATERIAL AND METHODS

This study has obtained ethical permission from the Faculty of Medicine's ethics commission, Universitas Sumatra Utara, Medan Indonesia No.318 / TGL / KEPK FK USU-HAMUP/2019. This type of research is a simulation with finite element analysis. In this study, the first five maxillary 3D incisors were built on a computer using the 2016 version of AutoCAD for simulation. The construction of five different ferrule heights (0 mm, 0.5 mm, 1 mm, 1.5 mm, and 2 mm) compares fracture resistance and stress distribution at various ferrule sizes in the dental model.

A. *Finite element analysis*

The finite element analysis (FEA) simulation process is carried out in the Laboratory of Measurement and Regulation of the Mechanical Engineering Department, Faculty of Engineering, Universitas Sumatera Utara, Medan. Using a software program (ANSYS v 17.0; ANSYS Inc., Canonsburg, PA, USA). In order to obtain clinically relevant FEA results, special attention must be given to getting an accurate computer construction to assess the influence of the ferrule height as a geometry variable.

B. *Modeling Teeth of Three Dimensional*

An upper right central incisor was constructed on a computer using the AUTOCAD version 2016. This modeling uses the working principle of the clinical guidelines reported by Ozan (2009) (Ozan et al., 2009). The digital model is then constructed to accommodate the gutta-percha, post-restoration, core, and full crown. The post's diameter on the cervical and apical portions is one-third of the root's diameter, and the post extends apically to two-thirds of the root length. The gutta-percha filling is left 4 mm apically, and the core height is 6.5mm. The crown has a uniform thickness of 1 mm, except for the incisal edge, where the area's thickness is 1.5 mm, and the shoulder margin is at the cementum-enamel boundary. The crowns and posts are maintained with luting resin cement thickness of 0.1 mm. The periodontal ligament is modeled as a 250-μm thick layer that uniformly surrounds the root and stops at 1.5 mm apically from the cementum-enamel boundary. Then the five models are constructed with 0 mm, 0.5 mm, 1 mm, 1.5 mm, and 2 mm ferrules in a sequence with a constant dentin thickness of 1 mm.

C. *Simulation of fracture resistance and stress distribution of Teeth*

The study began by constructing the right upper central incisor on a computer using AutoCAD 2016. Based on clinical guidelines[11], the digital model was built to accommodate gutta-percha, post-restoration, core, and full crown. The post's diameter on the cervical and apical portions is one-third of the root's diameter, and the post extends apically to two-thirds of the root length. The gutta-percha filling is left 4 mm apically, and the core height is 6.5 mm. Full crowns have a uniform thickness of 1 mm, except for the incisal edge, where the area's thickness is 1.5 mm, and the shoulder margins are at the cementum-enamel boundary. The crowns and posts are maintained with a luting resin cement thickness of 0.1 mm. The periodontal ligament (PDL) is a 250-μm thick layer that uniformly surrounds the root and stops at 1.5 mm apically from the cementum-enamel boundary. Then the five models are constructed with 0 mm, 0.5 mm, 1 mm, 1.5 mm, and 2 mm ferrules in a sequence with a constant dentin thickness of 1 mm.

Dental structures usually get a load within their elastic limits, and the purpose of this study is to analyze the consequences of design changes in ferrule preparations. Therefore, static linear analysis is carried out for each case. All loads are applied completely and gradually to the maximum value in a linear statistical study. The load remains consistent (and not calculated by time), and the FE calculation is made until convergent (no variation). The inputting data of the model components' mechanical properties is based on the FEA model's materials' properties(Seo et al., 2009). The geometry model is then paired with the Analysis software and continued with meshing. The model is put together using linear tetrahedral elements, and to reduce the variability of all models put together using 2456888 features which produce an average of 3707102 aspects of each model.

The model is mounted on the periodontal ligament's outer surface without rotation or translation to simulate the inner socket wall's effect. The boundary between the periodontal ligament and the root's external surface is considered bound, while the contact between all other parts is of the contact gap type. Contact gap conditions allow surfaces to move away from one another while maintaining physical properties not to penetrate each other. Besides, it can also be used to analyze the effects of the ferrule design, the coefficient of friction between the various components of the

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setting to zero so that any changes that occur between components are not limited by friction.

The crowns are loaded by simulating 25 N and 170 N loads directed at an angle of 135° to the longitudinal axis of the teeth in an area of 5 mm from the incisal palatal surface to the cingulum(Milot and Stein, 1992). This load corresponds to the range of occlusal load limits during functioning on incisors that have already been measured in the incisal area. Then, input of the desired yield parameter is performed. Analysis of the results in the form of Von Mises, which shows the maximum and minimum values of total deformation, equivalent elastic strain, and equivalent stress 15.13 Analysis of the results in the form of Von Mises shows the maximum and minimum values of total deformation, equivalent elastic strain and equivalent stress.

D. Data Analysis

This study uses the ANSYS 17.0 program, while the dental model design uses the AutoCAD2016 program to perform the FEA analysis test. Analysis of Von Mises's (color contour) results shows the maximum and minimum values of total deformation, equivalent elastic strain, and equivalent stress. The red color is the ultimate point, while the blue color is the lowest voltage point. Furthermore, observations were made by looking at areas with maximum effectiveness and comparing the maximum values of the five 3D models to see the effect of different ferrule design heights.

III. RESULTS AND DISCUSSION

Figure 1 shows the geometry model analyzed with Ansys software. Based on the two images analyzed, the tooth's structure gives a load within the elastic limit to analyze the consequences of design changes in ferrule preparation based on static linear analysis. In linear statistical studies, all loads are applied completely and gradually until they reach the maximum value. The load remains consistent (not time-dependent), and FEA calculation is performed for convergence (no variation). In the inner socket wall effect simulation, the periodontal ligament model's external surface is mounted without rotation or translation. The boundary between the periodontal ligament and the root's external surface is considered bound, whereas contact between other parts is of the contact gap type. Contact gap conditions allow surfaces to move away from one another while maintaining physical properties not to penetrate each other. In addition to comprehensively analyzing the effects of the ferrule design, the friction between the various components is set to zero to prevent restrictions on any movement between the members.

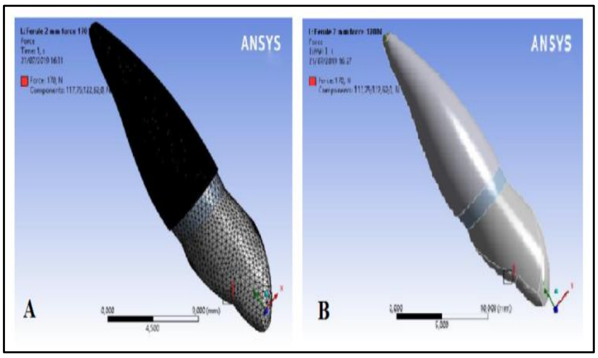

Fig. 1: Geometry model in Ansys software with meshing.
(A) 3D Meshing Model with ANSYS software
(B) Model shows the load area on the palatal surface and resistance on the external surface of the root.

Figure 2 shows the total deformation value decreases in line with the ferrule's increasing height, where the highest value in the 3D model is at the 0 mm ferrule, which shows the importance of 0.0093 mm. For the 25 N load simulation, the lowest total deformation value in the 3D model is a 2 mm ferrule, which shows a value of 0.0091 mm in the checking area. In the simulation with a load of 170 N, the highest value is found in the 3D model with a 0 mm ferrule which in the checking area shows a value of 0.06319 mm.

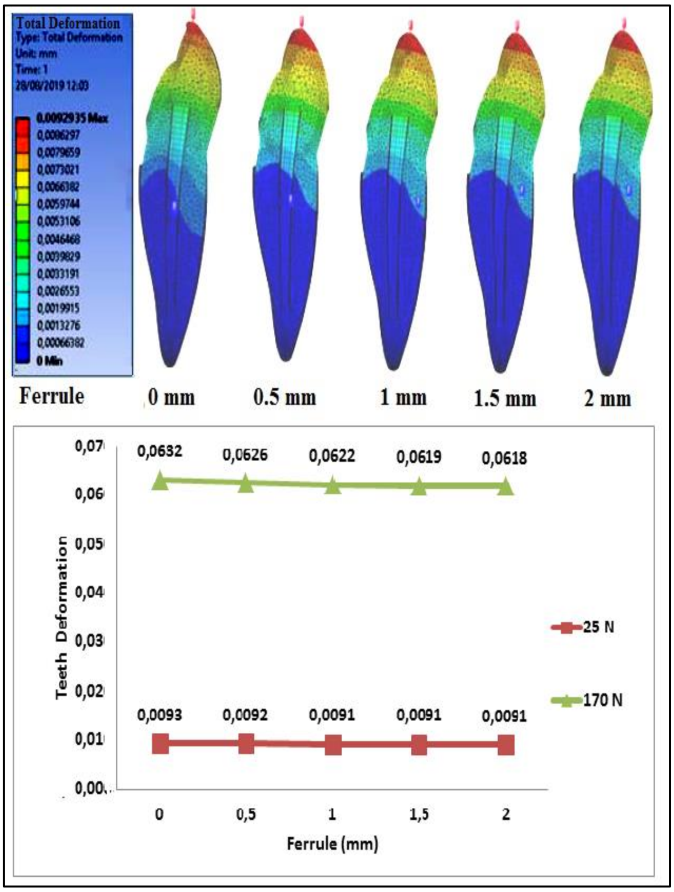

Fig. 2: Total deformation color contour plot (Top).

Graph of total deformation simulation of load 25 N and 170 N (below). The 170N load showed a higher total deformation of the teeth than 25N. The total deformation value does not differ between ferrule sizes.

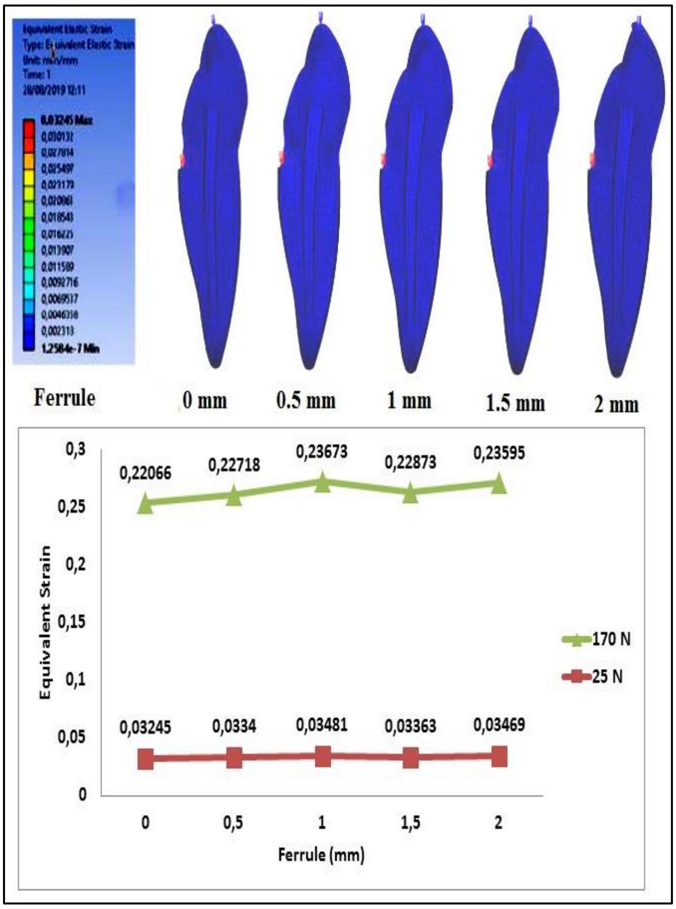

Fig.3:- Equivalent elastic strain color contour plot (top). Identical stress simulation graph of load 25 N and 170 N (below). Equal strains at 170 N load tend to change based on ferrules compared to 25 N loads.

Figure 3 shows the maximum value of equivalent elastic strain decreases in 3D models with 0 mm ferrule compared to 3D models with ferrules. The highest value of 3D models in ferrules is 1 mm (0.034814 mm). The lowest equivalent elastic strain value is found in the 3D model with a 0 mm (0.03245 mm) ferrule. However, the value of equal elastic strains between the five 3D models does not differ in contrast. In the simulation of 170 N load, the equivalent elastic strain value decreases in the 3D model with a 0 mm ferrule. The highest value is found in the 3D model with 1 mm ferrule with 0.23673 mm. The lowest equivalent strain value in the 3D model is 0 mm (0.22066 mm) ferrule.

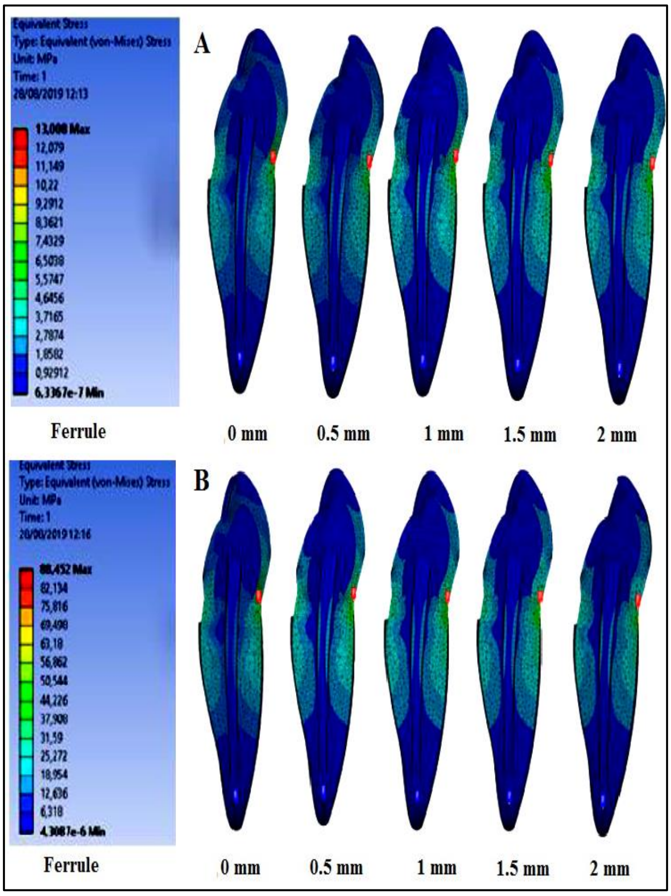

Fig. 4: Color contour plots equivalent stress simulation load (A) 25 N and (B) 170 N

Figure 4 shows the results of the finite element analysis simulation next to the equivalent stress. Equivalent stress is a von-mises color contour plot that shows stress distribution. The von-mises color contour plot shows the highest stress occurring at the junction area of the crown and cervical labial model. The five 3D models appear that the stress distribution occurs at the crown and spreads to apical 3/5. Throughout the post, the stress distribution is evenly distributed without any stress concentration area in any particular location.

Figure 5 shows that the maximum Equivalent stress value occurs in the area where the crown and the cervical meet in the labial model. The maximum equivalent stress value decreases in models with ferrule compared to models without ferrules. The 25 N and 170 N simulations with the highest values are seen in 3D models with ferrules of 0 mm (13,008 MPa and 88,452 MPa), and the lowest ones appear in 3D models with ferrule 1 mm (11,567 MPa and 78,655 MPa).

Restoration of teeth after endodontic treatment returns to their original form, function, and aesthetics is essential. The sustainability and success of an endodontic treatment depend on how the quality restoration performs. Post-endodontic teeth are prone to fractures due to dryness or moisture loss (Dikbas et al., 2007).

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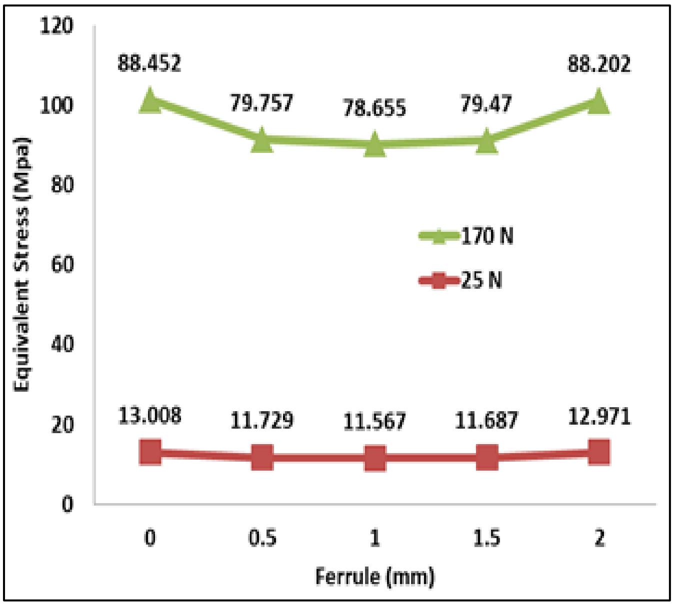

Fig.5: Graph of equivalent stress simulation of 25 N and 170 N. load. The load given has the equivalent stress effect on the teeth according to the change in the ferrule.

The use of posts with low modulus of elasticity, such as fiber posts, results in a homogeneous stress distribution that can cause stress drops with the advantage that the restored tooth properties become similar to natural teeth(Roscoe et al., 2013). Ferrule increases resistance to dynamic mastication loads, supporting the integration of cement density for full crown retention and reducing potential stress concentrations at the junction between the post and core(Sherfudhin et al., 2011a). This simulation was conducted to determine the effect of different ferrule designs on fracture resistance and stress distribution in teeth roots after endodontic treatment constructed with Finite Element Analysis (FEA)as shown in Figure 1.

Figure 2 shows the FEA analysis in this study producing a picture: of total deformation, equivalent stress, and equivalent elastic strains in each treatment group based on the contour staining to obtain an image of fracture resistance and stress distribution.The rainbow color provided by the contour plot allows researchers to find: stress distribution, high-stress areas, excessive deformation, and the structure of a material. In the Finite element analysis (FEA) analysis, the red color is the maximum point while the blue color is the minimum point. In this simulation, the model's design is made according to the anatomy and size of the maxillary 1 incisors. In order, to simulate the stress distribution and predict the area of stress concentration as a trigger point for failure (fracture), it is necessary to design a suitable model. The finite element model analysis (FEM) also provides information needed when experimental research does not (Sorensen and Engelman, 1990).

During the deformation process, the material absorbs energy due to forces that affect changes in shape and dimensions. Physical deformation in objects consists of two, namely, plastic deformation and elastic deformation. At the start of loading, the material will exhibit elastic deformation.It undergoes plastic deformation (Li et al., 2016).

It is prohibited to add loads to the material at maximum strength. Indeed, under these conditions, the material will experience total deformation. When the load increases, it will increase strain where the material looks like it is strengthening (strain hardening). Still, the material immediately breaks down in the fracture's strength (Singh and Chauhan, 2016). In this simulation, the increase in height can withstand the deformation of the material. Furthermore, the simulation shows that the model's fracture resistance with 2 mm ferrule height is the best among the other models.

Ichim (2006) reports the Finite element analysis (FEA) application to analyze the effect of the ferrule's height on the mechanical endurance of the constructed teeth, showing that the displacement decreases with the increasing size of the ferrule(Ichim et al., 2006).In another study, Ishak (2017) reported that when a ferrule greater than the radius of rotation of this crown would further increase efficiency, although shorter ferrules were less efficient at resisting displacement, but could reduce the axial arm from the rotational force, which results in a reduction in flexural strength on the post, reducing stresses in the center and axial displacement forces are known to reduce the potential for debonding luting and post-fracture(Ishak et al., 2017). It can be assumed that the ferrule can increase the mechanical resistance of the crown. In this simulation, expanding the ferrule's height decreases the model's deformation value, reducing the possibility of plastic deformation in the model, which results in a fracture. In other words, it is stated that increasing the height of the ferrule will increase the resistance of the tooth fracture after endodontic treatment(Sherfudhin et al., 2011b).In further studies, analysis is needed to see the displacement of the crown.

Figure 3 shows that the simulation results show the equivalent elastic strain maximum value occurring in the palatal cervical region in all 3D models. In the 25N and 170N simulations, the maximum equal elastic strain value decreases in the 3D model with 0 mm ferrule compared to the 3D model with ferrule. The highest value appears in 3D models with a 1 mm ferrule. The equivalent elastic strain value between the five 3D models is not different. The presence of ferrules is associated with an increase in strain values on the palatal surface. The presence of ferrules creates a larger palatal dentin area under tensile stress, which may be a favorable condition for cracks in the root palatal aspect(Elavarasu et al., 2019). The ferrules company makes a larger palatal dentin area under tensile stress, which is suitable for damages in the root palatal aspect(Mamoun and Napoletano, 2015). It might explain the more significant strain in the palatal cervical region of the 3D model with ferrule preparation compared to the 0 mm 3D ferrule model

Roscoe (2013) reinforces this study's results where the effect of bone loss, post type, and ferrule can impact the biomechanical properties of canine teeth after endodontics(Roscoe et al., 2013). Silva (2010) states that dentin roots left after conservative post chamber preparation can reduce surface strain. This study also states lower strain values are associated with high fracture resistance (Da Silva et al., 2010).Pantaleón (2018) reports that the ferrule determines the durability of tooth structure on the palatal surface of the maxillary incisors because when the palatal wall is lost, the load is held by a non-axial load from the palatal side of the maxillary anterior crown (Pantaleón et al., 2018).

Figure 4 and 5 mentions that the value of the equivalent stress contour plot of the simulated load is 25 N and 170 N. The maximum equivalent stress occurs at the junction of the crown with decreased labial cervical endings in 3D models compared to 3D models without ferrules. Due to the absence of a ferrule, apical-labial force is applied to the crown's palatal aspect, which produces tilting details on the height and core to the labial and axial forces move the post/nucleus to the occlusal. Due to the periodontal labial membrane's power and limitations, compressive stress develops in the root canal's labial dentin and palatal wall at the post's apical border (Naik et al., 2017). The palatal periodontal ligament's elastic nature and the direction of force cause tensile stress to form in the palatal root dentin and the post on the coronal aspect close to the post-core border (Zhen et al., 2016).

Chuang (2010) conducted a study of fiber pegs and ferrule designs to demonstrate the stages and validation of 3D images with cone-computed tomographic beams to Determine the Effect of the ferrule design on the left and right sides of the central incisors restored with glass fiber post (Chuang et al., 2010, Valdivia et al., 2012). Based on the stress analysis, the creation of the ferrule plays a significant role in the stress relationship between the glass fiber post and the tooth root (Juloski et al., 2014). This study shows how robust the ferrule design is in maintaining coronal structures in teeth after endodontic treatment to influence the circumference along the root in increasing stress distribution. Other studies have shown that the ferrule effect can reduce fracture risk in non-vital teeth by redistributing the force received and strengthening the tooth's external surface (Naumann et al., 2006). These simulation results show the clinician's conservative effort during root dentin preparation in the clinical aspect. Moreover, clinicians are also expected to consider the remaining coronal teeth' structure to obtain various ferrules. Endodontic tooth restoration focuses on maintaining the highest coronal system during root canal treatment, post chambers, and complete crown preparation.

IV. CONCLUSION

Based on simulation results, the addition of ferrule height can increase the resistance of dental fractures after endodontic treatment by reducing deformation. Ferrule decreases stress on the labial cervical area of the tooth and enlarges the strain on the cervical palatal dentine by holding non-axial loads from the palatal side.

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REFERENCES

[1.] Eliyas S, Jalili J, Martin N. Restoration of the root canal treated tooth. British dental journal 2015;218(2):53.
[2.] Kishen A. Biomechanics of fractures in endodontically treated teeth. Endodontic topics 2015;33(1):3-13.
[3.] MARCHIONATTI AME, Wandscher VF, Rippe MP, Kaizer OB, Valandro LF. Clinical performance and failure modes of pulpless teeth restored with posts: a systematic review. Brazilian oral research 2017;31.
[4.] Kar S, Tripathi A, Trivedi C. Effect of different ferrule length on fracture resistance of endodontically treated teeth: An in vitro study. Journal of clinical and diagnostic research: JCDR 2017;11(4):ZC49.
[5.] Seow LL, Toh CG, Wilson NH. Strain measurements and fracture resistance of endodontically treated premolars restored with all-ceramic restorations. Journal of dentistry 2015;43(1):126-32.
[6.] Nagas E, Cekic-Nagas I, Egilmez F, et al. Bond strength of fiber posts and short fiber-reinforced composite to root canal dentin following cyclic loading. Journal of adhesion science and Technology 2017;31(13):1397-407.
[7.] Ausiello P, Ciaramella S, Martorelli M, et al. Mechanical behavior of endodontically restored canine teeth: Effects of ferrule, post material and shape. Dental Materials 2017;33(12):1466-72.
[8.] Dua N, Kumar B, Arunagiri D, et al. Comparative evaluation of the effect of different crown ferrule designs on the fracture resistance of endodontically treated mandibular premolars restored with fiber posts, composite cores, and crowns: An ex-vivo study. Journal of conservative dentistry: JCD 2016;19(3):264.
[9.] Sherfudhin H, Hobeich J, Carvalho CA, et al. Effect of different ferrule designs on the fracture resistance and failure pattern of endodontically treated teeth restored with fiber posts and all-ceramic crowns. Journal of Applied Oral Science 2011;19(1):28-33.
[10.] Muangamphan P, Sattapan B, Kukiattrakoon B, Thammasitboon K. The effect of incomplete crown ferrules on fracture resistance and failure modes of endodontically treated maxillary incisors restored with quartz fiber post, composite core, and crowns. Journal of conservative dentistry: JCD 2015;18(3):187.
[11.] Dikbas I, Tanalp J, Ozel E, Koksal T, Ersoy M. Evaluation of the effect of different ferrule designs on the fracture resistance of endodontically treated maxillary central incisors incorporating fiber posts, composite cores and crown restorations. J Contemp Dent Pract 2007;8(7):62-9.
[12.] Ozan O, Turkyilmaz I, Ersoy AE, McGlumphy EA, Rosenstiel SF. Clinical accuracy of 3 different types of computed tomography-derived stereolithographic surgical guides in implant placement. Journal of Oral and Maxillofacial Surgery 2009;67(2):394-401.
[13.] Seo M, Shon W, Lee W, et al. Finite element analysis of maxillary central incisors restored with various post-and-core applications. Journal of Korean Academy of Conservative Dentistry 2009;34(4):324-32.
[14.] Milot P, Stein RS. Root fracture in endodontically treated teeth related to post selection and crown design. Journal of prosthetic dentistry 1992;68(3):428-35.

[15.] Roscoe MG, Noritomi PY, Novais VR, Soares CJ. Influence of alveolar bone loss, post type, and ferrule presence on the biomechanical behavior of endodontically treated maxillary canines: strain measurement and stress distribution. The Journal of prosthetic dentistry 2013;110(2):116-26.
[16.] Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. Journal of Prosthetic Dentistry 1990;63(5):529-36.
[17.] Li J, Liu B, Luo H, et al. A molecular dynamics investigation into plastic deformation mechanism of nanocrystalline copper for different nanoscratching rates. Computational Materials Science 2016;118:66-76.
[18.] Singh J, Chauhan A. Overview of wear performance of aluminium matrix composites reinforced with ceramic materials under the influence of controllable variables. Ceramics International 2016;42(1):56-81.
[19.] Ichim I, Kuzmanovic D, Love R. A finite element analysis of ferrule design on restoration resistance and distribution of stress within a root. International Endodontic Journal 2006;39(6):443-52.
[20.] Ishak MI, Shafi AA, Kadir MRA, Sulaiman E. Effect of ferrule height and post length on mechanical stress and displacement of endodontically treated maxillary central incisor: A Finite element analysis. Journal of Medical and Biological Engineering 2017;37(3):336-44.
[21.] Sherfudhin H, Hobeich J, Carvalho CA, et al. Effect of different ferrule designs on the fracture resistance and failure pattern of endodontically treated teeth restored with fiber posts and all-ceramic crowns. Journal of applied oral science : revista FOB 2011;19(1):28-33.
[22.] Elavarasu P, Karumaran CS, Indira R, et al. An In Vitro Evaluation of Fracture Resistance of Endodontically Treated Maxillary Central Incisor Restored with Custom-Made Cast Post and Core with Uniform and Nonuniform Core Ferrule Heights. Journal of pharmacy & bioallied sciences 2019;11(Suppl 2):S407-S12.
[23.] Mamoun JS, Napoletano D. Cracked tooth diagnosis and treatment: An alternative paradigm. European journal of dentistry 2015;9(2):293-303.
[24.] Da Silva NR, Raposo LHA, Versluis A, Fernandes-Neto AJ, Soares CJ. The effect of post, core, crown type, and ferrule presence on the biomechanical behavior of endodontically treated bovine anterior teeth. The Journal of prosthetic dentistry 2010;104(5):306-17.
[25.] Pantaleón DS, Morrow BR, Cagna DR, Pameijer CH, Garcia-Godoy F. Influence of remaining coronal tooth structure on fracture resistance and failure mode of restored endodontically treated maxillary incisors. The Journal of prosthetic dentistry 2018;119(3):390-96.
[26.] Naik MM, de Ataide IdN, Fernandes M, Lambor R. A novel technique of sculpting Biodentine in the restoration of iatrogenic dentin loss. Journal of conservative dentistry : JCD 2017;20(5):365-69.
[27.] Zhen M, Wei YP, Hu WJ, Rong QG, Zhang H. [Finite element analysis of the maxillary central incisor with traditional and modified crown lengthening surgery and post-core restoration in management of crown-root fracture]. Zhonghua Kou Qiang Yi Xue Za Zhi 2016;51(6):362-7.
[28.] Chuang S-F, Yaman P, Herrero A, Dennison JB, Chang C-H. Influence of post material and length on endodontically treated incisors: an in vitro and finite element study. The Journal of prosthetic dentistry 2010;104(6):379-88.
[29.] Valdivia ADCM, Raposo LHA, Simamoto-Júnior PC, Novais VR, Soares CJ. The effect of fiber post presence and restorative technique on the biomechanical behavior of endodontically treated maxillary incisors: an in vitro study. The Journal of prosthetic dentistry 2012;108(3):147-57.
[30.] Juloski J, Apicella D, Ferrari M. The effect of ferrule height on stress distribution within a tooth restored with fibre posts and ceramic crown: a finite element analysis. Dental Materials 2014;30(12):1304-15.
[31.] Naumann M, Preuss A, Rosentritt M. Effect of incomplete crown ferrules on load capacity of endodontically treated maxillary incisors restored with fiber posts, composite build-ups, and all-ceramic crowns: an in vitro evaluation after chewing simulation. Acta Odontologica Scandinavica 2006;64(1):3