©Operative Dentistry, 2021, **46-06,** 669-679

Effect of Cervical Lesions on Fracture Resistance and Failure Mode of Maxillary Central Incisors Restored with Fiber Posts and Complete Crowns

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Clinical Relevance

In the presence of a cervical cavity, placement of a fiber post is recommended to strengthen a maxillary central incisor. This increases the fracture resistance of the tooth, leading to a more favorable prognosis of the completed restoration.

SUMMARY

Purpose: To investigate the effect of a cervical cavity extending 1 mm apical to the cemento–enamel junction (CEJ) on fracture resistance and failure mode of maxillary central incisors that have been treated endodontically, present with complete and incomplete ferrules, and are restored with and without a fiber post.

Methods and Materials: 50 intact human maxillary central incisors were divided into five groups (n=10): CG (control group) 6-mm ferrule height, no cervical cavity, and without post; (CO) 6-mm ferrule height without post, with a cervical cavity (access to root canal and cervical cavity restored with composite resin), cervical cavity; and post with ferrule heights of 1 mm (CP1), 2 mm (CP2), and 6 mm (CP6) restored with fiberglass post and composite resin core. After complete metal crowns were cemented on all specimens, they were subjected to thermal cycling (6000 cycles, 5°C/55°C),

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https://doi.org/10.2341/20-164-L

followed by immediate testing of fracture resistance. After failure, the specimens were sectioned buccolingually to evaluate and identify the mode of failure. The data were analyzed with an analysis of variance (ANOVA) and the Student–Newman–Keuls multiple comparison tests (α=0.05).

Results: A 1-mm ferrule height (CP1) fracture resistance was significantly lower (531±125 N) compared to the 6-mm ferrule height (CP6) (769±175 N) ($p<0.05$). With respect to the groups with similar residual dentin, with and without a cervical cavity, CG (667±119 N) and CO (668±119 N), the presence of a post (CP6) increased the resistance to fracture, although no statistically significant difference was demonstrated. Partial decementation was observed in all specimens of CG and CP6, in nine of CP1 and CP2, and in three in CO. Root fractures occurred in 23 specimens. The root surface was exposed 2 mm below the CEJ to simulate bone level. Propagation of subosseous cracks occurred in four specimens in CG and CP2, in seven specimens in CP6, in two specimens in CP1, and in six specimens in CO. All were considered catastrophic failures.

Conclusions: Within the limitations of this study it is suggested that, when restoring an endodontically treated maxillary central incisor that has a cervical lesion and needs to be restored with a complete crown, a fiber post is cemented to improve fracture resistance.

INTRODUCTION

Complete crown restoration of endodontically treated maxillary central incisors is challenging due to extensive loss of tooth structure, which may have been caused by caries, fracture, endodontic access, and instrumentation and preparation for post and crown.[1-3] The greater the loss the more it negatively effects the resistance to fracture.[4-8] Furthermore, anterior teeth are stressed by horizontal forces, exposing them to a higher risk of biomechanical failures.[9,10] Quantity and location of the remaining dentin appears to be the most important factor in predicting the prognosis of a tooth.[11,12] If there is enough remaining dentin for the preparation of a complete ferrule, the outcome will be more favorable.[13] By definition, a circumferential ferrule is formed by four axial dentin walls that are 2-mm high from the cervical finish line to the coronal junction.[14-19] Several publications reported on the protective effect this offers on the final restoration as it reduces the concentration of stresses, thus decreasing clinical failures such as root fracture and/or decementation of the post.[20-22]

However, for various reasons, such as caries, erosion, abrasion or fracture, a circumferential ferrule is not always possible.[23] This affects the prognosis of a restoration.[24] Furthermore, the superiority of one partial ferrule over another depends on the height, number, and location of the remaining walls.[25-30] Because the ferrule effect is not entirely understood, it has been suggested that more studies are necessary.[31] In particular, maxillary incisors with cervical lesions and endodontic treatment has received little attention.[32] It is this type of defect that affects the thickness of the facial wall, which compromises the integrity of the ferrule.[32] When a cervical lesion involves the root, it is commonly associated with gingival recession.[33] As a result, the preparation of the cervical shoulder margin has to include the lesion on the root surface, which has less dentin thickness due to the conicity of the root.[14,34]

The thickness of the dentin wall plays an important role in the function of the ferrule, which most studies have not considered.[32] It has been advised to keep enough facial dentin in maxillary anterior teeth to counteract horizontally directed forces, as at least a 1-mm thick dentin ferrule may resist functional loads and prevent fracture.[35] However, there is insufficient research information available that supports the effectiveness of this ferrule. In reviewing the literature, the work of Tjan and Whang[35] can be considered a pioneering study with reference to the thickness of the facial wall of remaining dentin in maxillary central incisors at the level of the cemento–enamel junction (CEJ). The thickness was 1, 2, and 3 mm in combination with cast posts, without ferrule effect (no cemented crown). The authors compared fracture resistance under horizontal force, showing that although there were no statistically significant differences, the 1-mm thick facial dentin wall was more prone to fracture than to decementation. It should be noted that since the samples had no ferrules, and no complete crowns were cemented, the results should be interpreted with caution. Joseph and Ramachandran[36] demonstrated that more than 1-mm thickness is required in the facial dentin wall to prevent root fracture. Furthermore, a 2-mm high dentin ferrule improved fracture resistance. Recently, Fontana and others[37] suggested that when a ferrule thickness is 1 mm, it is more appropriate to use a fiber post. Naumann and others[38] observed that in excessively widened teeth it is not possible to establish a ferrule, because the preparation will cause even more loss of tooth structure, resulting in a very thin wall or no wall at all.

The authors found no studies in the literature regarding the effect of cervical lesions on fracture resistance in the maxillary endodontically treated central incisor restored with a complete crown, except for a single study using the direct resin composite technique with or without a fiber post.[39] The purpose of this study was to evaluate the effect of the cervical cavity extending 1-mm apical to the CEJ, with variations in height of the remaining coronal structure on fracture resistance and the mode of failure of endodontically treated maxillary central incisors and restored with a fiber post. The null hypothesis was that the placement of a fiber post in maxillary crowned central incisors and in the presence of a restored facial cervical lesion will not affect the fracture resistance.

METHODS AND MATERIALS

Specimens and Preparation of Root Canal

Fifty intact human maxillary central incisor teeth recently extracted for periodontal reasons were stored in a 0.9% physiologic saline solution (Laboratorios ALFA, Santo Domingo, Dominican Republic) with 0.1% Chloramine T (Sigma Aldrich, St. Louis, MO, USA) at room temperature. The teeth were cleaned to remove soft tissue and debris and were examined under 3.5× magnification (Double lens head-wearing, Gerleek, YTOM, China) for defects. X-rays were taken to verify the absence of fractures, internal root resorption, and obstructions or endodontic filling material. The teeth were stored at room temperature and were used within 3 months post-extraction.

The root lengths (13.8±0.9 mm) and the buccolingual diameters 6.6±0.4 mm) at the CEJ were measured with an electronic caliper (Mitutoyo Absolute 573-751, America Corp, Aurora, lII, USA). The teeth were divided into five experimental groups of 10 teeth each (n=10). The power test on the data was "Power of performed test with α=0.050: 0.998." Therefore, the sample size was sufficient. The nature of variability existing in all tissue is such that data must vary, and standard deviations will be relatively large.

The preparation of the endodontic access cavity was made with a round bur (No. 6801.31.014, Brasseler, Savannah, GA, USA), outlining a triangular cavity. All teeth received conventional endodontic treatment using manual instrumentation with files up to #40 (Dentsply Sirona, York, PA, USA), irrigation with 3% sodium hypochlorite (ChloridCid; Ultradent Products Inc., South Jordan, UT, USA), lateral condensation with gutta-percha (Dentsply Sirona), and use of a sealing cement (AH 26, Dentsply Sirona).

Preparation and Ferrule

In all teeth, except the control group (CG), the cervical cavity was prepared as follows. A round diamond bur (no. 6801.31.014, Brassaler) was used to prepare the cavity characterized by a gingival wall parallel to the CEJ and extending 1 mm apical to it, mesial and distal walls parallel to the long axis of the tooth, and an incisal wall following the contour of the incisal edge.[40] Subsequently, with a cylindrical carbide bur (SSW no. FG-558, SSW, New Jersey, NY, USA), the dimensions of the cavity were defined: height = 3 mm, width = 3 mm, and depth = 2 mm. Crown preparation was performed with a super coarse round-end taper FG diamond bur (no. 5856.31.018 Brasseler). Preparations were done under copious water cooling. The reduction of the crown was performed according to the height of the pre-established remaining walls in the experimental groups, following the contour of the CEJ as a reference.[41] The location of the facial cervical finish line of the preparation followed the contour of the cervical cavity and was located 1 mm apical to the CEJ, while it was located at the level of the CEJ in the remainder of the tooth. The finish line served as a reference for the linear measurement of the remaining coronal heights in each specimen. While the CG had no cervical cavity, the location of the finish line was similar to the other groups. Thus, the following five experimental groups were established (Fig. 1): CG (6-mm ferrule height, no cervical cavity, and no post), CO (6-mm ferrule height, with a cervical cavity), CP1 (1-mm ferrule height, cervical cavity, and post), CP2 (2-mm ferrule height, cervical cavity, and post), and CP6 (6-mm ferrule height, cervical cavity, and post). Table 1 presents the materials, composition, and protocols used in this study.

Post Groups Preparation

In the CP1, CP2, and CP6 groups, the Unicore Post and Drill System was used, which consisted of a radiopaque fiber post of conical design and a drill for the preparation of the post space. The post is characterized by prestressed quartz fibers encased in a bondable resin matrix that creates a monoblock

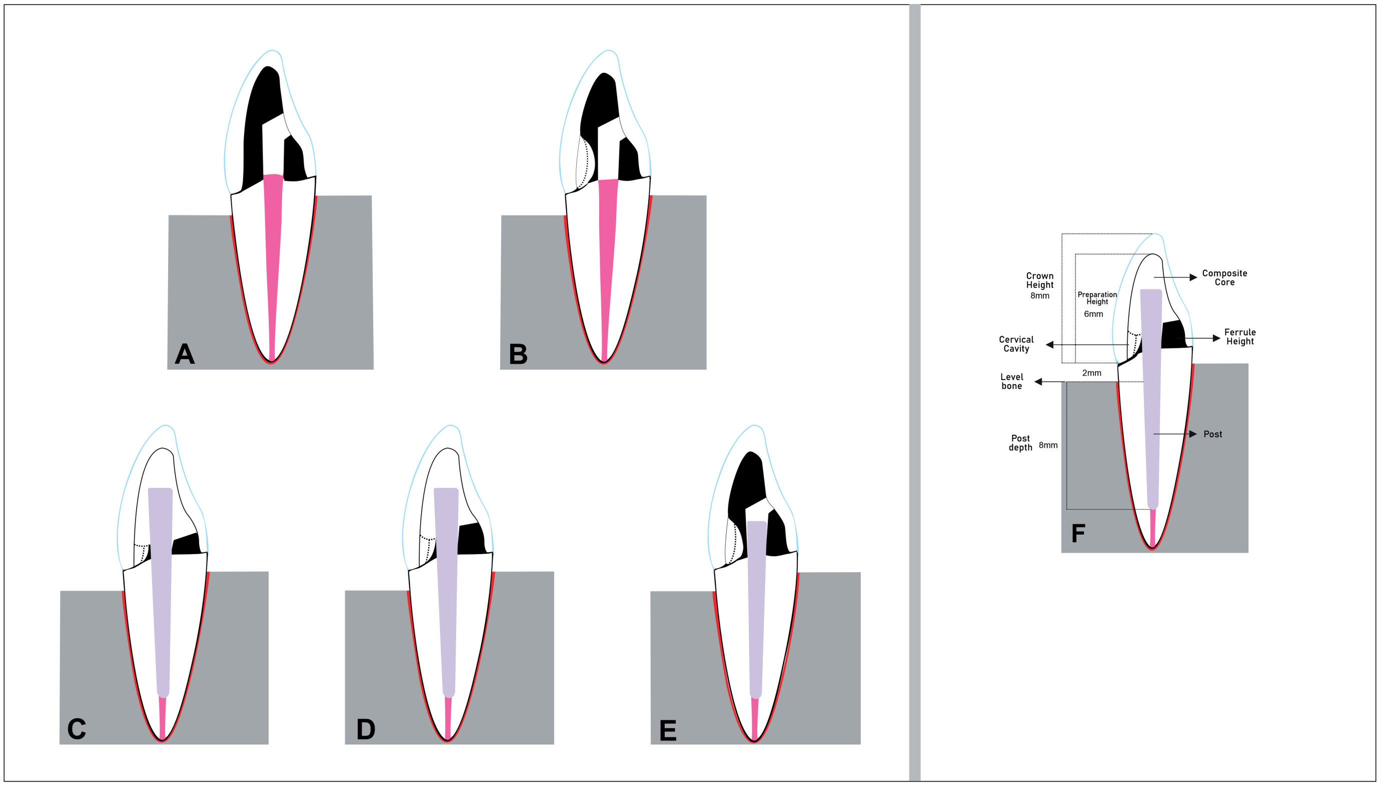

Figure 1. *The experimental groups showing the cervical cavity, preparation of the ferrule, fiber post-and-core and crown. (A): specimens of the control group (CG) 6-mm ferrule height, without cervical cavity and no post. (B): specimens of Group (CO) 6-mm ferrule height and only with cervical cavity. (C): specimens of Group (CP1) 1-mm-height ferrule with cervical cavity and fiber post. (D): specimens of Group (CP2) 2-mm-height ferrule with cervical cavity and fiber post. (E): specimens of Group (CP6) 6-mm-height ferrule with cervical cavity and fiber post (F): schematic design illustrating the dimensions of the preparation, post, and crown.*

Table 1: *Materials, Composition, and Protocols Used in This Study*

Material	Composition	Protocol Used in This Study
Fiber post	Quartz fibers Resin matrix	Manufacturer's instructions
Multilink N Monobond Plus Primer A and B	Monomer matrix of dimethacrylate and HEMA Inorganic fillers: Barium glass, ytterbium and spheroid mixed oxide Silane methacrylate, phosphoric methacrylate, sulfide methacrylate Primer A: Water, initiators, sulfonate amine Primer B: HEMA, phosphonic acid acrylate, methacrylate modified polyacrylic acid, stabilizers	Manufacturer's instructions
Single bond universal	*Bis*-GMA, HEMA, dimethacrylates, ethanol,water, polyacrylic and polytaconic acids	Manufacturer's instructions and cured for 40 s
Composite resin Z350 Filtex	*Bis*-GMA, TEGDMA, *Bis*-EMA, UDMA, Zirconia/silica filler	Manufacturer's instructions
Nickel-cromo alloy VeraBond II	Ni 76.5%, Cr 11.5%, Mo 3.5%, Nb, Al, Si, Ti	Manufacturer's instructions
Glass ionomer cement Fuji Plus	Ingredient—Powder: Aluminosilicate 100% Ingredient—Liquid: Distilled water 35%, polyacrylic acid 45%, HEMA 15%, dimethacrylate 5%	Manufacturer's instructions
Self-curing acrylic resin for tooth mounting	2-Propenoic acid, 2-methyl-, ethyl ester, homopolymer, benzoyl peroxide	Manufacturer's instructions

Abbreviations: Bis-GMA, bisphenol A diglycidyl methacrylate; Bis-EMA, bisphenol A diglycidyl methacrylate ethoxylated; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate; HEMA, 2-Hydroxyethyl metacrylate.

when the core material is placed. The post selected in the study was size 3 (blue), with an apical diameter of 1.17 mm and coronal diameter of 1.56 mm (UniCore UP, Ultradent Products). For the post preparation in CP1, a Peeso No. 2 reamer (Union Broach Co, York, PA, USA) was used to remove the gutta-percha to a depth of 9 mm measured with a stop from the remaining coronal structure. In the groups, CP2 (2 mm) and CP6 (6 mm), the stop was placed at 10 and 14 mm, respectively. As a result, the length of the post space was consistent at 8 mm for all the groups. The post space was then gradually widened using a Peeso reamer No. 3 and 4 (Union Broach Co). For the final preparation of the post space, a blue helicoidal bur size 3 (UniCore UP 7123, Ultradent Products) was used to a depth of 8 mm, which more precisely defined the shape of the post space to the matching post.

The posts were cemented with a self-curing resin cement (Multilink N, Ivoclar Vivadent), following the manufacturer's instructions. The surface of the post was cleaned with an alcohol-saturated cotton swab, then Monobond N (Ivoclar Vivadent) was brushed on the surface of the post, allowing it to react for 60 seconds before air dispersing with dry clean air. The post space was irrigated with distilled water and dried with paper points (Coltene Whaledent, Altstätten, Switzerland). Primer A and B (Multilink N, Ivoclar Vivadent) were mixed with a microbrush and introduced into the post space. After 15 seconds, excess material was removed with paper points (Coltene). The cement mix was coated on the fiber post, and the post was seated using light repetitive torsional movements to reduce hydraulic pressure and prevent air entrapment. Digital pressure consistent with clinical practice was applied followed by visible light irradiation for 20 seconds (VALO Cordless, Ultradent Products). The LED light activation produces a higher adhesion strength of the resin cement to the intraradicular dentin in the coronal region.[42] The remaining coronal walls of groups CP1, CP2, and CP6, as well as the root canal access and cervical cavity of the groups CG and CO were etched with 37% phosphoric acid (Prime Dental) for 15 seconds, rinsed with a triple air–water syringe and then gently dried. With a microbrush, a dentin adhesive was applied (Single Bond Universal, 3M Oral Care, Seefeld, Germany), which was light cured for 40 seconds (VALO Cordless; Ultradent Products) because when a long photoactivation time is used in adhesive systems, the level of polymerization increases.[43,44] The VALO light is high intensity and had an output of 1000 mW/cm^2. Then, the cervical cavity and core were built in increments with composite resin (Z350 Filtex, 3M Oral Care), each increment light cured for 20 seconds.

With a diamond high speed bur (no. 5856.31.018; Brasseler), under copious irrigation, the preparations were finalized to meet the following parameters: a height of 6 mm, a rounded shoulder finish line extending apically to the cervical cavity and in the other areas at the CEJ with a reduction of 1.0 mm on the facial, 1.0 mm interproximally and lingually, and an incisal reduction of 2 mm.

Fabrication and Cementation Crowns

One specimen was coated with 1 layer of die spacer (Die Spacer, Keystone Industries, Gibbstown, NJ, USA), and a complete contour wax pattern was fabricated. This pattern measured 8-mm high, with a circumferential thickness of, approximately, 1–1.5 mm. A rectangular-shaped stop with a central concavity was added 2-mm apical to the incisal edge on the lingual surface. This stop facilitated loading during the fracture resistance tests. An impression in vinyl polysiloxane (Putty Normal Set, Elite HD, Zhermack, Badia, Polesine, Italy) was made of the wax pattern, which served as a mold for replicas of all other samples. Final adjustment of the wax replicas was carried out for each individual sample to obtain good marginal adaptation.

The wax patterns were cast in nickel–chrome alloy (VeraBond II, AalbaDent, Inc, Fairfield, CA, USA). After finishing, a resin-reinforced glass ionomer cement was mixed, according to the manufacturer's instructions (Fuji Plus, GC, Alsip, IL, USA), and used for cementation. The castings were held under finger pressure until initial set had occurred.

Fracture Load Test

After 24 hour storage in water at room temperature, the specimens were thermocycled in distilled water (6000 cycles; 5°C/55°C, 2 minutes each cycle) to mimic clinical conditions.[45] The roots were embedded in self-curing translucent acrylic resin that had a curing time of 5-8 minutes (SamplKwich Kit, Buehler, Lake Bluff, IL, USA), leaving 2 mm of the root surface exposed while following the contour of the CEJ to mimic bone support.

Each sample was subjected to a fracture resistance test using a universal testing machine (5567, Instron, Norwood, MA, USA). A compression force was applied to the stop on the lingual surface of the crowns by means of a spherical tip with a 3-mm

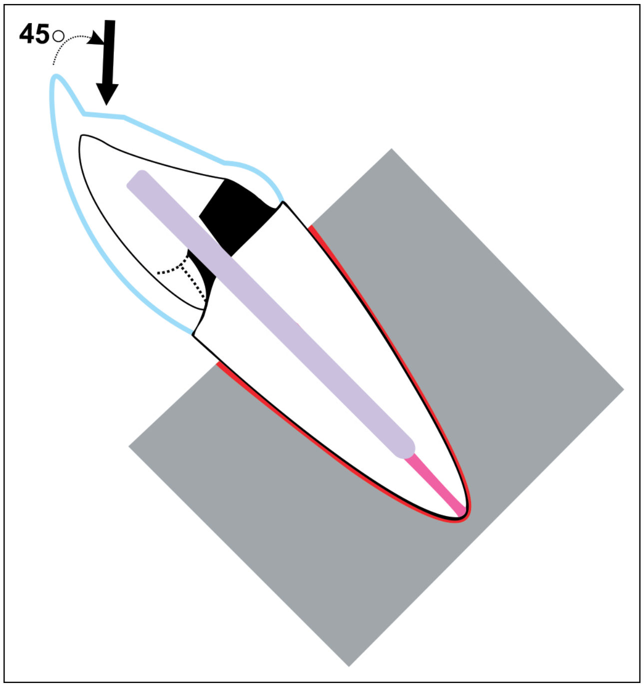

Figure 2. *Schematic representation of the tooth under static load.*

diameter. The force was directed at an angle of 45° to the longitudinal axis of the tooth at a crosshead speed of 0.5 mm/min, until fracture. This angle was based on the natural occlusal forces on maxillary incisors in a Class I occlusion[41] (Figure 2).

Failure Mode Analysis

The mode of failure was evaluated by embedding the specimens in self-curing acrylic resin (SamplKwich, Buehler). Two sections were made in a bucco-lingual direction, using a low-speed diamond blade under water irrigation (IsoMet 5000, Buehler). They were photographed with a digital microscope (VHX-1000, Keyence, Osaka, Japan) at $x20\times$ magnification. The failure mode, based on Fokkinga and others[46], was characterized as follows: complete decementation of the post-and-core and crown; partial decementation of the post-and-core and/or crown; fracture of resin composite foundation–coronal dentin; dislodgement of lingual cervical margin of the crown; root fracture trajectory (oblique or horizontal); fracture propagation (subosseous, supraosseous); favorable failure (failure allows restoration of the tooth); and unfavorable failure (failure does not allow predictable restoration).

Data Analysis

The data were analyzed by analysis of variance (ANOVA) and the Student–Newman–Keuls (SNK) multiple comparison statistical test (α=0.05) (SigmaPlot 14; Sytat Software, San Jose, CA, USA).

Table 2: *Fracture Load (N) of Different Groups*

	Group	Mean±SD
CG	6-mm ferrule height, no cervical cavity and no post	667±119
CO	6-mm ferrule height with cervical cavity	668±119
CP1	1-mm ferrule height with cervical cavity and post	531±125*
CP2	2-mm ferrule height with cervical cavity and post	608±192
CP6	6-mm ferrule with height cervical cavity and post	769±175*

**Statistically significant differences ($p<0.05$) between groups.*

RESULTS

The fracture resistance and standard deviation data are presented in Table 2. The CP6 group presented the highest fracture load resistance (769±175 N), the CP1 group being the lowest (531±125 N). An ANOVA analysis showed a statistically significant difference between these two groups ($p<0.05$). With respect to the groups with 6-mm high dentinal axial walls, without and with a cervical cavity, fracture resistance was similar CG (667±119 N) and CO (668±119 N). In the CP6 group with cervical cavity and 6-mm-height remaining walls, the placement of the post increased fracture resistance (769±175 N), although this was not statistically significant in relation to the CG and CO groups. In the CP2 group with 2-mm-high remaining walls with cervical cavity and with a post, the fracture resistance was 608 ± 192 N, close to the CG and CO group values.

A partial post-core and/or crown decementation was identified in all CG and CP6 specimens, in nine CP1 and CP2 specimens, and in three CO specimens. The dislodgement of the cervical margin on the lingual of the crowns occurred in seven CG specimens and in all CO, CP1, CP2, and CP6 specimens. Fracture of the composite resin–dentin core occurred in seven CP1 specimens, in five CP2 specimens, and in four specimens of groups CG, CO, and CP6. Horizontal and oblique fractures occurred in few specimens, mostly in CP6. The location and trajectory were more frequently at the level of the cervical and middle-thirds of the root, and at the apical limit of the post. The propagation of subosseous cracks occurred in approximately half of all the specimens, slightly below the margin of the acrylic resin that simulated the level of the bone crest. Failures were considered favorable when there was sufficient

Table 3: *Failure Modes*

	Experimental Groups				
Failure Modes[a]	**CG**	**CO**	**CP1**	**CP2**	**CP6**
Complete decementation of postcore and crown				1	
Partial decementation of postcore and/or crown	10	3	9	9	10
Fracture composite resin foundation–coronal dentin	4	4	7	5	4
Dislodgement of lingual cervical margin crown	7	10	10	10	10
Oblique fracture		2	1		3
Horizontal fracture	5	4		4	4
Propagation fracture subosseous	4	6	2	4	7
Propagation fracture supraosseous	6	1	3		3
Failure favorable/unfavorable total	6/4	4/6	8/2	6/4	3/7

[a] *Based on Fokkinga and others,[46] and Santos Pantaleón and others.[28]*

remaining dentin to allow for a preparation of a new cervical finish line. While unfavorable failures compromised the integrity of the tooth, making it unrestorable (Table 3). Figure 3 shows specimens with failures.

DISCUSSION

The reason for this laboratory research was based on published arguments by Jotkowitz & Samet.[32] The authors stated: "The evidence relating to restoring the endodontic treated tooth with extensive destruction is

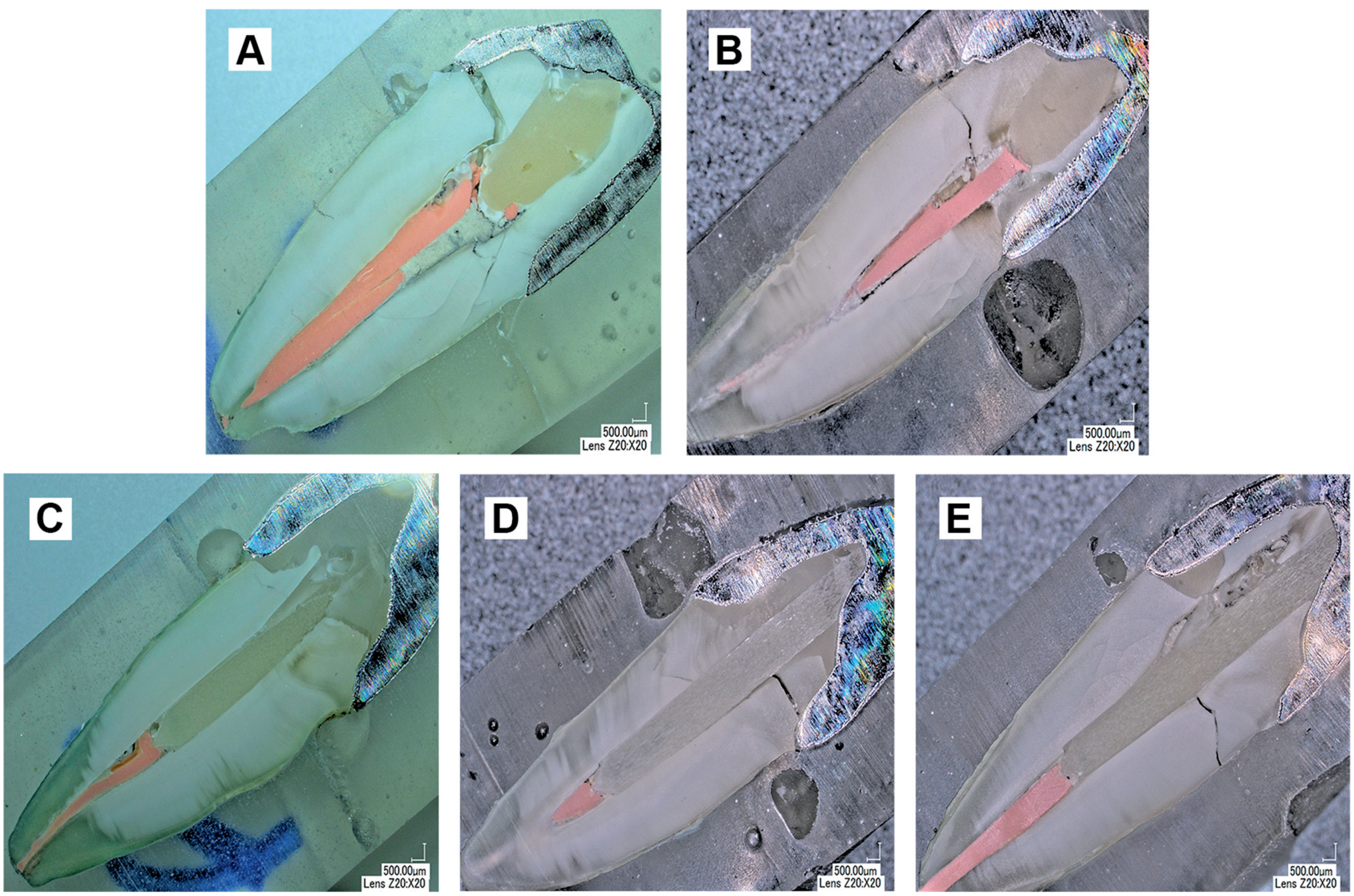

Figure 3. *Representative samples of failures observed using digital microscopy. A: Group CG specimen with coronal dentin fracture and dislodgement of lingual cervical crown margin; B, Group CO lingual supraosseous fracture; C, Group CP1 dislodgement of lingual cervical crown margin and core displacement; D, Group CP2 horizontal fracture of coronal dentin; E, Group CP6 oblique root fracture.*

deficient." To the best of our knowledge, this was the first study to investigate the effect of facial cervical lesions on fracture resistance in the endodontically treated maxillary central incisor restored with a complete crown. While this does not occur frequently,[39] it is still of clinical importance. The fracture resistance of the CO group (668 N) with dentin walls 6 mm in height with a cervical cavity and without a post was similar to the CG group (667 N) that had a ferrule of 6 mm in height without a cervical cavity and post. While in the CP6 group (769 N) with 6-mm-high walls and a cervical cavity and a post, the fracture resistance increased, although there was no statistically significant difference. According to these results, the null hypothesis that placement of a fiber post would not affect the fracture resistance of maxillary central incisors restored with a complete crown and a facial cervical lesion was rejected.

The samples that had endodontic treatment only (CG) recorded no difference in fracture load compared to the teeth that had endodontic treatment and a cervical lesion (CO). This may be due to a combination of facts, such as the large amount of the remaining coronal structure, height of dentinal walls, and the protective effect of the complete crown, all contributing to a better distribution of stress.[20] This suggests that the loss of dentin caused by a cervical lesion did not affect the fracture resistance between these two groups.

Groups CP6 and CO had similar-height walls in dentin and cervical lesions. It was observed that the placement of a fiber post created a positive effect, because it increased the fracture resistance CP6 (769 N) compared to the CO group (668 N) without a post, albeit it was not statistically significant. This finding suggests that a fiber post and resin cement contribute to the strengthening of the tooth, which is in accordance with other studies.[7,9] Posts also play a role in absorbing energy[47] and reduce stress on the tooth due to the distribution of the occlusal load within the root dentin.[48] This is consistent with the previous reports showing that a post increases fracture resistance when compared to a CG without post with the same remaining wall height.[17,41,49] In addition, the reduction of tooth structure due to preparation and endodontic treatment causes an increase in the deflection of the tooth, exposing it to more stress.[48] In that sense, the fiber post increases the load values and decreases the deflection of the compromised tooth structure.[50] Another factor that could explain the findings mentioned above is the location of the defect in the tooth. A study has shown that there was no difference in fracture resistance compared to indirect restoration with a ceramic crown when the defect is a Class III (mesial and distal restored with direct composite resin).[3] This indicates that whether or not a fiber post is present, the fracture resistance is not affected.[3,12] On the other hand, if a cervical cavity is present in the facial, a post exerts a positive effect, as was demonstrated by an increase in fracture resistance.[39] This difference between cervical cavity and class III defects can be explained, as the endodontically restored tooth is subject to more stress in the cervical region,[16,19,31] while the presence of a post reduces stress.[19] According to a finite element study, a decrease in root dentin thickness in the cervical area contributes to high levels of tension within the root canal.[15]

Regarding the type of coronal restoration, it has been suggested that the mechanical properties of the crown affects the resistance to fracture,[7] and the level of stress and strain along the dentin–cement–post interface.[9] Although the use of ceramic crowns has increased considerably in the anterior region due to its esthetic qualities and advantage to be adhesively cemented,[26] metal–ceramic crowns continue to be indicated in clinical practice.[7] The aim of the present study was to compare the influence of the facial cervical cavity and a fiber post on the resistance to fracture. For this purpose, the use of a metal crown is preferable, because it is more suitable for evaluating the ferrule effect, as it allows stresses to concentrate more on the remaining coronal dentin, according to a finite element study.[16]

The microscopic evaluation of the failure mode of the sections of the selected specimens allowed precise detection of the type of failure. The CP6 group presented a greater number of catastrophic failures, identifying seven specimens, in relation to CO and CG with 6 and 4 catastrophic failures, respectively. This result can be attributed to the presence of a fiber post, as it serves as a distributor of stress and load to the core and crown within the root canal.[9,19] In the absence of a post, the concentration of stress in the canal was insignificant.[19] That could explain the horizontal and oblique root fractures located in the middle-third and at the apical limit of the post in the CP6 group. Subosseous propagation of crack also occurred in the majority of the CP6 group and was characterized to a greater extent on the surface of the dentin. The results of the present study show 70% nonrepairable failures in CP6, while another study showed 100% and has questioned the use of a fiber post.[2]

The fracture resistance of CP1 with a cervical cavity, a post and 1-mm-high ferrule (531 N) was inferior compared to CP6 that had a cervical cavity, a post and 6-mm-high ferrule (769 N); the difference was statistically significant ($p<0.05$). This showed that tooth resistance is directly related to the amount of remaining dentin, which corroborates the findings of other studies.[17,27] However, the CP1 group had an unfavorable failure in only two specimens compared to the CP6 group with seven specimens. Due to the minimal coronal structure, high stresses are concentrated in the cervical area,[6] which causes fracture at the level of the resin composite–dentin foundation, which was characterized as a favorable failure. With an increase in coronal structure, stresses are transmitted to the apical area,[6,22] causing a greater number of root fractures, as evidenced in CP6.

Despite the intrinsic limitations of a static load, it is a frequently applied methodology in laboratory studies to evaluate the ability to resist fracture, because it is an efficient method due to its low cost while being less time consuming. Reproducing exact oral conditions in laboratory studies is not possible. However, in this study, the specimens were subjected to thermocycling to mimic clinical conditions and simulate aging of the restoration before a load was applied. This study observed that facial cervical lesions affect the configuration of the ferrule and influence fracture resistance in maxillary central incisors under static load. More studies are needed to assess the significance of the thickness of remaining dentin in the cervical lesion after the ferrule preparation. Furthermore, the performance of different types of fiber posts, cementation protocols, and luting agents and the composition of crown materials need to be examined after applying dynamic load testing.

CONCLUSIONS

Within the limitations of this study it is suggested that, when an endodontically treated maxillary central incisor that has a cervical lesion needs to be restored with a complete crown, a fiber post is cemented to improve fracture resistance.

Conflict of Interest

The authors of the present study certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in the present article.

Regulatory Statement

The author represents that the study was performed in compliance with author's institution's appropriate policies related to the use of animal and/or human subjects and human-derived material and the policies of National Council of Bioethics in Health of the Dominican Republic CONABIOS. The approval code issued for this study is 16/1/2015.

Acknowledgements

The authors thank MESCYT—Dominican Republic Ministry of Higher Education Science and Technology (FONDOCYT—National Fund for Innovation, Scientific, and Technological Development: code 2014-2A4-010) for partially funding this research.

(Accepted 19 February 2021)

REFERENCES

1. Shu X, Mai Q, Blatz M, Price R, Wang X, & Zhao K (2018) Direct and indirect restorations for endodontically treated teeth: A systematic review and meta-analysis, IAAD 2017 consensus conference paper *Journal of Adhesive Dentistry* **20(3)** 183-194. https://doi.org/10.3290/j.jad.a40762
2. Magne P, Lazari PC, Carvalho M, Johnson T, & Del Bel Cury AA (2017) Ferrule-effect dominates over use of a fiber post when restoring endodontically treated incisors: An in vitro study *Operative Dentistry* **42(4)** 396-406. https://doi.org/10.2341/16-243-L
3. von Stein-Lausnitz M, Mehnert A, Bruhnke M, Sterzenbach G, Rosentrit M, Spies BC, Bitter K, & Naumann M (2018) Direct or indirect restoration of endodontically treated maxillary central incisors with class III defects? Composite vs veneer or crown restoration *Journal of Adhesive Dentistry* **20(6)** 519-526. https://doi.org/ 10.3290/j.jad.a41635
4. de Andrade G, Tribst JPM, Flores-Orozco EI, Gullo Augusto M, Bottino MA, Souto Borges AL, Anami L, & Anzaloni Saavedra GS (2020) Influence of different post-endodontic restoration on the fatigue survival and biomechanical behavior of central incisors *American Journal of Dentistry* **33(5)** 227-234.
5. Schwartz RS & Robbins JW (2004) Post placement and restoration of endodonticallly treated teeth: A literatura review *Journal of Endodontics* **30(5)** 289-301. https://doi.org/10.1097/00004770-200405000-00001
6. Ichim I, Kuzmanovic DV, & Love RM (2006) A finite element analysis of ferrule design on restoration resistance and distribution of stress within a root *International of Endodontics Journal* **39(6)** 443-452. https://doi.org/10.1111/j.1365-2591.2006.01085.x
7. Salameh Z, Sorrentino R, Ounsi HF, Sadig W, Atiyeh F, & Ferrari M (2008) The effect of different full-coverage crown systems on fracture resistance and failure pattern of endodontically treated maxillary incisors restored with and without glass fiber posts *Journal of Endodontics* **34(7)** 842-846. https://doi.org/10.1016/j.joen.2008.03.025
8. Naumann M, Schmitter M, Frankenberger R, & Krastl G (2018) "Ferrule comes first. post is second!" Fake news and alternative facts? A systematic review *Journal of Endodontics* **44(2)** 212-219. https://doi.org/10.1016/j.joen.2017.09.020
9. Sorrentino R, Aversa R, Ferro V, Auriemma T, Zarone F, Ferrari M, & Apicella A (2007) Three-dimensional finite element analysis of strain and stress distributions in

endodontically treated maxillary central incisors restored with different post, core and crown materials *Dental Materials* **23(8)** 983-993. https://doi.org/10.1016/j.dental.2006.08.006

10. Assif D & Gorfil C (1994) Biomechanical considerations in restoring endodontically treated teeth *Journal of Prosthetic Dentistry* **71(6)** 565-567.

11. Valdívia AD, Raposo LH, Simamoto-Júnior PC, Rezende Novais V, & Soares CJ (2012) The effect of fiber post presence and restorative technique on the biomechanical behavior of endodontically treated maxillary incisors: An in vitro study *Journal of Prosthetic Dentistry* **108(3)** 147-157. https://doi.org/10.1016/S0022-3913(12)60138-3

12. Heydecke G, Butz F, & Strub JR (2001) Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: An in-vitro study *Journal of Dentistry* **29(6)** 427-433. https://doi.org/10.1016/s0300-5712(01)00038-0

13. Morgano SM (1996) Restoration of pulpless teeth: Application of traditional principles in present and future contexts *Journal of Prosthetic Dentistry* **75(4)** 375-380.

14. Gegauff AG (2000) Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns *Journal of Prosthetic Dentistry* **84(2)** 169-179. https://doi.org/10.1067/mpr.2000.107583

15. Santos-Filho PC, Veríssimo C, Araújo Raposo LH, Yosbito Noritomi P, & Marcondes Martins LR (2014) Influence of ferrule, post system, and length on stress distribution of weakened root-filled teeth *Journal of Endodontics* **40(11)** 1874-1878. https://doi.org/10.1016/j.joen.2014.07.015

16. Veríssimo C, Simamoto Jr PC, Soares CJ, Yoshito Noritomi P, & Santos-Filho PCF (2014) Effect of the crown, post, and remaining coronal dentin on the biomechanical behavior of endodontically treated maxillary central incisors *Journal of Prosthetic Dentistry* 111(3) 234-246. https://doi.org/10.1016/j.prosdent.2013.07.006

17. Zhi-Yue L & Yu-Xing Z (2003) Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors *Journal Prosthetic Dentistry* **89(4)** 368-373. https://doi.org/10.1067/mpr.2003.73

18. Batista VES, Bitencourt SB, Bastos NA, Piza Pellizzer E, Coelho Goiato M, & dos Santos DM (2020) Influence of the ferrule effect on the failure of fiber-reinforced composite post-and-core restorations: A systematic review and meta-analysis *Journal of Prosthetic Dentistry* **123(2)** 239-245. https://doi.org/10.1016/j.prosdent.2019.01.004

19. Pierrisnard L, Bohin F, Renault P, & Barquins M (2002) Corono-radicular reconstruction of pulpless teeth: A mechanical study using finite element analysis *Journal of Prosthetic Dentistry* **88(4)** 442-448. https://doi.org/10.1067/mpr.2002.128376

20. Dietschi D, Duc O, Krejci I, & Sadan A (2008) Biomechanical considerations for the restoration of endodontically treated teeth: A systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies) *Quintessence International* **39(2)** 117-129.

21. Mancebo JC, Jiménez-Castellanos E, & Cañadas D (2010) Effect of tooth type and ferrule on the survival of pulpless teeth restored with fiber posts: A 3-year clinical study *American Journal of Dentistry* **23(6)** 351-356.

22. Hayashi M, Takahashi Y, Imazato S, & Ebisu S (2006) Fracture resistance of pulpless teeth restored with post-cores and crowns *Dental Materials* **22(5)** 477-485. https://doi.org/10.1016/j.dental.2005.03.017

23. Juloski J, Radovic I, Goracci C, Vulicevic ZR, & Ferrari M (2012) Ferrule effect: A literature review *Journal of Endodontics* **38(1)** 11-19. https://doi.org/10.1016/j.joen.2011.09.024

24. Tan PL, Aquilino SA, Gratton DG, Stanford CM, Chian Tan S, Johnson WT, & Dawson D (2005) In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations *Journal of Prosthetic Dentistry* **93(4)** 331-336. https://doi.org/10.1016/j.prosdent.2005.01.013

25. Ng CC, Dumbrigue HB, Al-Bayat MI, Griggs JA, & Wakefield CW (2006) Influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth *Journal of Prosthetic Dentistry* **95(4)** 290-296. https://doi.org/10.1016/j.prosdent.2006.02.026

26. Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, & Ravera G (2009) Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage *Journal of Dentistry* **37(2)** 115-121. https://doi.org/10.1016/j.dent.2008.10.007

27. Zhang YY, Peng MD, Wang YN, & Li Q (2015) The effects of ferrule configuration on the anti-fracture ability of fiber post-restored teeth *Journal of Dentistry* **43(1)** 117-125. https://doi.org/10.1016/j.jdent.2014.10.003

28. Santos Pantaleón D, Morrow BR, Cagna DR, Pameijer CH, & Garcia-Godoy F (2018) Influence of remaining coronal tooth structure on fracture resistance and failure mode of restored endodontically treated maxillary incisors *Journal of Prosthetic Dentistry* **119(3)** 390-396. https://doi.org/10.1016/j.prosdent.2017.05.007

29. Santos Pantaleón D, Valenzuela FM, Morrow BR, Pameijer CH, & García-Godoy F (2019) Effect of ferrule location with varying heights on fracture resistance and failure mode of restored endodontically treated maxillary incisors *Journal of Prosthodontics* **28(6)** 677-683. https://doi.org/10.1111/jopr.13090

30. Rodrigues MP, Soares PBF, Valdivia ADCM, Sales Pessoa R, Veríssimo C, Versluis A, & Soares CJ (2017) Patient-specific finite element analysis of fiber post and ferrule design *Journal of Endodontics* **43(9)** 1539-1544. https://doi.org/10.1016/j.joen.2017.04.024

31. Yang A, Lamichhane A, & Xu C (2015) Remaining coronal dentin and risk of fiber-reinforced composite post-core restoration failure: A meta-analysis *International Journal of Prosthodontics* **28(3)** 258-264. https://doi.org/10.11607/ijp.4157

32. Jotkowitz A & Samet N (2010) Rethinking ferrule-a new approach to an old dilemma *British Dental Journal* **209(1)** 25-33. https://doi.org/10.1038/sj.bdj.2010.580

33. Zucchelli G, Gori G, Mele M, Stefanini M, Mazzotti C, Marzadori M, Montebugnoli L, & De Sanctis M (2011) Non-carious cervical lesions associated with gingival recessions: A decision-making process *Journal of Periodontology* **82(12)** 1713-1724. https://doi.org/10.1902/jop.2011.110080

34. Shillingburg HT, Sather DA, & Stone SE (2012) *Fundamentals of Fixed Prosthodontics* Quintessence Publishing, Chicago.

35. Tjan AH & Whang SB (1985) Resistance to root fracture of dowel channels with various thicknesses of buccal dentin walls *Journal of Prosthetic Dentistry* **53(4)** 496-500.

36. Joseph J & Ramachandran G (1990) Fracture resistance of dowel channel preparations with various dentin thickness *Federation of Operative Dentistry* **1(1)** 32-35.

37. Fontana PE, Bohrer TC, Wandscher VF, Valandro LF, Limberger IF, & Kaizer OB (2019) Effect of ferrule thickness on fracture resistance of teeth restored with a glass fiber post or cast post *Operative Dentistry* **44(6)** E299-E308. https://doi.org/10.2341/18-241-L

38. Naumann M, Preuss A, & Frankenberger R (2006) Load capability of excessively flared teeth restored with fiber-reinforced composite posts and all-ceramic crowns *Operative Dentistry* **31(6)** 699-704. https://doi.org/10.2341/05-142

39. Abduljawad M, Samran A, Kadour J, Al-Afandi M, Ghazal M, & Kern M (2016) Effect of fiber post on the fracture resistance of endodontically treated anterior teeth with cervical cavities: An in vitro study *Journal of Prosthetic Dentistry* **116(1)** 80-84. https://doi.org/10.1016/j.prosdent.2015.12.011

40. Mondelli J, Ishikiriama A, & Franco EB (2006) *Fundamentos de Dentística Operatória* Livraria Santos Editora, São Paulo.

41. Varvara G, Perinetti G, Di lorio D, Murmura G, & Caputi S (2007) In vitro evaluation of fracture resistance and failure mode of internally restored endodontically treated maxillary incisors with differing heights of residual dentin *Journal of Prosthetic Dentistry* **98(5)** 365-372. https://doi.org/10.1016/S0022-3913(07)60121-8

42. Miguel-Almeida ME, Costa da Azevedo ML, Rached-Júnior FA, Oliveira CF, Silva RG, & Messias DC (2012) Effect of light-activation with different light-curing units and time intervals on resin cement bond strength to intraradicular dentin *Brazilian Dental Journal* **23(4)** 362-366. https://doi.org/10.1590/s0103-64402012000400009

43. Cadenaro M, Breschi L, Rueggeberg FA, Agee K, Di Lenarda R, Carrilho M, Tay FR, & Pashley DH (2009) Effect of adhesive hydrophilicity and curing time on the permeability of resin bonded to water vs. ethanol-saturated acid-etched dentin *Dental Materials* **25(1)** 39-47. https://doi.org/10.1016/j.dental.2008.05.004

44. Ye Q, Wang Y, Williams K, & Spencer P (2007) Characterization of photopolymerization of dentin as a function of light source and irradiance *Journal of Biomedical Materials Research Part B Applied Biomaterials* **80(2)** 440-446. https://doi.org/10.1002/jbm.b.30615

45. Naumann M, Preuss A, & Rosentritt M (2006) 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* **64(1)** 31-36. https://doi.org/10.1080/00016350500331120

46. Fokkinga WA, Kreulen CM, Vallittu PK, & Creugers NH (2004) A structured analysis of in vitro failure loads and failure modes of fiber, metal, and ceramic post-and-core systems *International Journal of Prosthodontics* **17(4)** 476-482.

47. Ferrari M, Sorrentino R, Zarone F, Apicella D, Aversa R, & Apicella A (2008) Non-linear viscoelastic finite element analysis of the effect of the length of glass fiber posts on the biomechanical behaviour of directly restored incisors and surrounding alveolar bone *Dental Materials Journal* **27(4)** 485-498. https://doi.org/10.4012/dmj.27.485

48. Kishen A (2015) Biomechanics of fractures in endodontically treated teeth *Endodontic Topics* **33(1)** 3-13. https://doi.org/10.1111/etp.12089

49. Akkayan B (2004) An in vitro study evaluating the effect ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems *Journal of Prosthetic Dentistry* **92(2)** 155-162. https://doi.org/10.1016/j.prosdent. 2004.04.027

50. D'Arcangelo C, De Angelis F, Vadini M, Zazzeroni S, Ciampoli C, & D'Amario M (2008) In vitro fracture resistance and deflection of pulpless teeth restored with fiber posts and prepared for veneers *Journal Endodontic* **34(7)** 838-841. https://doi.org/10.1016/j.joen.2008.03.026