Effect of Inadequate Ferrule Segment Location on Fracture Resistance of Endodontically Treated Teeth

Abstract

Introduction: The circumferential 2 mm ferrule during the fabrication of the crown is strongly advocated for the long-term clinical success. During the routine clinical practice, the dentist encounters the endodontically treated tooth (ETT) with inadequacy of the ferrule in some segment due to caries, abrasion, and erosions. The aim of this in vitro study was to investigate the consequence of inadequate segmental ferrule location on fracture strength of the root canal-treated anterior and posterior teeth. Materials and Methods: Fifty each maxillary canine and mandibular premolar intact human teeth were root canal treated and sectioned at 2 mm above the cementum-enamel junction. The teeth samples were divided into 5 groups of 10 each. The G-I and G-V samples had the 360° ferrule and complete absence of the ferrule, respectively. The G-II had the inadequate ferrule on the palatal surface, while G-III and G-IV had inadequate ferrule at buccal and proximal area. Teeth samples were subsequently restored with glass-reinforced fiber post, composite core, and full veneer metal crown. The samples were tested with universal testing machine under static load to record the fracture resistance. The acquired data were subjected to ANOVA and Tukey’s post hoc statistical analysis. Results: The G-I with circumferential ferrule showed the higher fracture resistance. The teeth samples with lack of the ferrule had the least fracture resistance. Among the segmental absence of ferrule, teeth samples with lack of the proximal ferrule were least affected. Deficiency of a ferrule on the lingual wall significantly affected the fracture strength in both anterior and posterior ETT. Conclusions: The ETT with sectional inadequacy of the ferrule is significantly more effective in resisting the fracture in comparison to the complete absence of the ferrule.

Keywords: Buccal ferrule, fracture strength, lingual ferrule, postendodontic restoration, segmental ferrule

Introduction

The rising average life expectancy of world population, along with increased caries incidence, is likely to intensify the requirement of endodontic treatment.[1] Consequently, postendodontic restorative procedures occupy the larger part of restorative dental practice. The suitable coronal restoration is indispensable for adequate endodontic treatment. The coronal leakage is reported to be one of the primary reasons in endodontic treatment. The Materials and Methods: Fifty each maxillary canine and mandibular premolar intact human teeth were root canal treated and sectioned at 2 mm above the cementum-enamel junction. The teeth samples were divided into 5 groups of 10 each. The G-I and G-V samples had the 360° ferrule and complete absence of the ferrule, respectively. The G-II had the inadequate ferrule on the palatal surface, while G-III and G-IV had inadequate ferrule at buccal and proximal area. Teeth samples were subsequently restored with glass-reinforced fiber post, composite core, and full veneer metal crown. The samples were tested with universal testing machine under static load to record the fracture resistance. The acquired data were subjected to ANOVA and Tukey’s post hoc statistical analysis. Results: The G-I with circumferential ferrule showed the higher fracture resistance. The teeth samples with lack of the ferrule had the least fracture resistance. Among the segmental absence of ferrule, teeth samples with lack of the proximal ferrule were least affected. Deficiency of a ferrule on the lingual wall significantly affected the fracture strength in both anterior and posterior ETT. Conclusions: The ETT with sectional inadequacy of the ferrule is significantly more effective in resisting the fracture in comparison to the complete absence of the ferrule.

Keywords: Buccal ferrule, fracture strength, lingual ferrule, postendodontic restoration, segmental ferrule

The endodontic posts are routinely used during the restoration of ETT with insufficient coronal tooth structure. The researchers are unambiguous in their opinion that the endodontic post helps only in anchoring the coronal restoration to the root canal, fails to improve the fracture resistance of tooth.[2] The suggested post length is the two-third of root length and the diameter not to exceed one-third of the root diameter.[3] The long-term survival of post-restored ETT is influenced by numerous factors such as adequate ferrule, dowel dental hard tissues, and lack of protective feedback mechanism.[5] The findings from previous research indicated the improved clinical longevity of endodontically treated (ETT) teeth restored with full-coverage crown.[6] Dental researchers have proposed many procedures and techniques to improve the long-term prognosis of RTT restorations.

How to cite this article: Haralur SB, Alalyani AF, Almutiq MA, Alfaifi AA, Al-Shehri AA. Effect of inadequate ferrule segment location on fracture resistance of endodontically treated teeth. Indian J Dent Res 2018;29:206-11.
design, thickness of dentin, and direction of masticatory forces. Preservation of coronal and radicular tooth structure is emphasized during the root canal treatment, restorative and tooth preparation procedures. Obtaining the ferrule effect by placing the cervical finish line on the sound tooth structure and crown encompassing the 1–2 mm cervical tooth structure is critical for enhancing fracture resistance of the ETT. The uniform circumferential 2 mm cervical tooth structure on all four axial walls is strongly advocated for the optimum ferrule effect. During the clinical practice, the dentist routinely encounters the ETT with nonuniform height ferrule and segmental inadequacy of a ferrule. The cervical abrasion, erosion, and abfraction lead to the damage of the buccal wall. The deep caries or secondary caries beneath restoration at the proximal area in both anterior and posterior teeth results in a compromised proximal ferrule. The other clinical situation like deeper preparation during esthetic crown preparation again leads to the compromised ferrule, especially in labial surfaces. These teeth are regularly recommended for extraction or crown-lengthening procedures. The clinician should carefully evaluate the benefit and risk of attaining the uniform 360° ferrule. The crown-lengthening procedures could lead to compromised esthetics, loss of crown-to-root ratio, and damaging the adjacent teeth. It is critical for the restorative dentist to know the effect of segmental absence of the ferrule and its location of inadequacy on the long-term prognosis. The result will also help the dentist in reaching an informed decision on the necessary treatment required during restorative rehabilitation of these ETT. Although the effect of the ferrule over the fracture resistance of ETT is extensively studied, the influence of segmental absence of the ferrule and the consequence of its location needs further investigation. The expected outcome between anterior and posterior teeth due to sectional absence of the ferrule may be different due to the distinctive root morphology, variation in quantity and direction of masticatory force. Hence, this in vitro study was designed to estimate the influence of segmental absence of the ferrule on the fracture resistance on anterior and posterior ETT.

Materials and Methods
The study proposal was registered and approved from the Institutional Ethics Committee. Fifty each recently extracted intact maxillary canine and mandibular premolar human teeth with single root canals were utilized during the study. The teeth samples included within the study were extracted for orthodontic or periodontics reasons and stored in 0.1% thymol solution immediately after the extraction. The donor patients were informed about the research, and their written consent was obtained to utilize their extracted teeth for the research purpose. All the extracted teeth were examined under the ×2.5 magnification (Prism Loupes, Carl Zies Inc., NY, USA) to confirm the absence of microcracks. Exclusion criteria were the caries, microcracks, restorations, cervical abrasions, and large developmental anomalies.

The average length of the maxillary canine was 26 ± 2 mm and for mandibular premolars was 22.5 ± 2 mm. Adequate access cavity was prepared on all the teeth and working length was set at 1 mm short of an apical foramen. Following crown-down technique, the root canals were prepared up to the working length with nickel-titanium rotary system (ProTaper, Dentsply, maillefer USA). The root canals were shaped to the F5 size with an intervening 3% sodium hypochlorite irrigation between changes of files. The root canals were obturated with ProTaper gutta-percha cones and a sealer (AH Plus, Dentsply, Maillefer, Ballaigues) following the cold lateral condensation technique. Two layers of the adhesive tape were applied over the root surfaces of all teeth samples. Teeth were embedded vertically into the autopolymerizing polymethyl-methacrylate acrylic blocks with the help of a dental surveyor. A 2 mm tooth structure above cementoenamel junction (CEJ) was maintained during implanting into acrylic blocks.

The post space preparation was initiated with the sequential use of Gates-Glidden and Peeso Reamers up to the size 3. The post space length for all the teeth sample was 18 mm for canine and 15 mm space for mandibular premolar, it was standardized by the help from an endo-ruler. The denture was observed to maintain a minimum of 5 mm gutta-percha obturation in the apical area. The post space was irrigated with 3% sodium hypochlorite followed by normal saline. The post space was dried thoroughly with paper points. The coronal section of the teeth samples was sectioned at 2 mm above the CEJ. The ferrule height was calibrated with the help of a digital caliper (Mitutoyo, Tokyo, Japan).

The maxillary canines and mandibular premolar teeth samples were randomly divided into 5 groups (n = 10) according to the ferrule design.
• Group I: Uniform ferrule height of 2 mm circumferentially
• Group II: Uniform ferrule height of 2 mm except 0.5 mm ferrule height at palatal surface
• Group III: Uniform ferrule height of 2 mm except 0.5 mm ferrule height at buccal surface
• Group IV: Uniform ferrule height of 2 mm except deficient ferrule height of 0.5 mm at proximal surface restored
• Group V: Circumferential absence of ferrule.

The glass fiber-reinforced resin posts (RelnyX Fiber post, 3M ESPE, Maplewood, MN, USA) were used to restore the teeth samples. The posts were cleaned with alcohol swab and gently air-dried. They were cemented without any dentin pretreatment using the self-adhesive resin cement (RelnyX Unicem, 3M ESPE, Maplewood, MN, USA) and light cured for 20 s. The core built up was...
accomplished using the posterior composite restorative material (Filtek, 3M ESPE, Maplewood, MN, USA). The core dimensions across the samples were kept uniform at 5 mm height and taper of 6 mm. The uniformity of taper was verified with parallel milling machine and digital calipers. The full veneer metal coping for the teeth samples was fabricated as per standard dental casting procedure with nickel-chromium alloys. The ledge was made at 2 mm from the incisal margin on the lingual surface of the anterior teeth metal coping for the uniform, stable loading. The metal castings were divested, cleaned, and cemented using the Type-I glass ionomer luting cement (GC Fuji I. Alsip, IL, USA). The adhesive tapes over the root surface on all the teeth samples were removed. The space gained within an acrylic block was relined with light body additional silicone impression material to simulate the cushioning effect of periodontal ligaments. The teeth samples were mounted on the universal testing machine, and the loading jig had a rounded tip 4 mm in diameter [Figure 1]. The load was applied at the 130° to the long axis of the tooth for canine and 45°s to the longitudinal axis for the premolars. Static load at the crosshead speed of 0.5 mm/min was applied until the tooth fracture occurred. The force at fracture was recorded as the maximum fracture resistance of the individual samples. The obtained data were statistically analyzed using the ANOVA and Student’s t-test with SPSS 19 software (IBM Corporation, Armonk, New York, USA) to find the difference between the tested groups at 0.05 significance level.

Results

The mean fracture strength and the standard deviation among all five groups are described in Table 1. The highest fracture resistance on both canine and premolar was recorded in Group I with circumferential 2 mm ferrule. The fracture resistance for Group I was at 821.56 N and 730.75 N for canine and premolar, respectively. The least fracture was documented by the Group V with complete absence of the ferrule at 566.39 N for canine and 500.90 N for premolar. The ferrule segment missing, which had the least effect upon the fracture resistance both in canine and premolar, was G-IV (proximal) at 773.63 N and 679.34 N. The missing ferrule on the palatal wall had the significant effect upon the fracture resistance at 586.65 N in premolar. The most deleterious effect over the fracture strength in canine was again observed with absent palatal ferrule segment at 656.79 N. The lack of a ferrule in buccal segment was still significantly better than complete absence of the ferrule in both the teeth.

The one-way ANOVA test [Table 2] for the mean fracture strength in both canine and premolar indicated the statistically significant difference with \( P = 0.000 \). The Tukey post-hoc multiple comparison tests [Table 3] indicated the statistically significant difference between all the groups in canine except between Group-I v/s Group-IV with \( P = 0.168 \), and Group-III v/s Group-IV with \( P = 0.581 \). The Tukey post-hoc test [Table 4] in premolar showed the absence of statistically significant difference between Group-II and Group-III with \( P = 0.070 \). The one-way ANOVA test [Table 2] for the mean fracture strength in both canine and premolar indicated the statistically significant difference with \( P = 0.000 \). The Tukey post-hoc multiple comparison tests [Table 3] indicated the statistically significant difference between all the groups in canine except between Group-I v/s Group-IV with \( P = 0.168 \), and Group-III v/s Group-IV with \( P = 0.581 \). The Tukey post-hoc test [Table 4] in premolar showed the absence of statistically significant difference between Group-II and Group-III with \( P = 0.070 \). The extension of a crown margin on the sound dentin provides the encircling metal band around the

| Sample  | Group I   | Group II  | Group III  | Group IV | Group V   |
|---------|-----------|-----------|------------|----------|-----------|
| Canine  | 821.56±46.54 | 656.79±37.89 | 742.64±51.69 | 773.63±49.29 | 566.39±47.59 |
| Premolar| 730.75±27.91 | 586.65±33.26 | 622.04±32.29 | 679.34±27.09 | 500.90±25.05 |

| Fracture strength | ANOVA |
|-------------------|-------|
| Sample            | Sum of squares | df | Mean square | F   | Significant |
| Canine            | Between groups | 409,908.077 | 4 | 102,477.019 | 46.710 | 0.000 |
|                   | Within groups  | 98,725.305 | 45 | 2193.896 |
|                   | Total          | 508,633.383 | 49 |
| Premolar          | Between groups | 310,100.987 | 4 | 77,525.247 | 90.439 | 0.000 |
|                   | Within groups  | 38,574.352 | 45 | 857.208 |
|                   | Total          | 348,675.339 | 49 |
Haralur, et al.: Segmental inadequacy of ferrule and fracture resistance of root canal-treated teeth

Table 3: Tukey post hoc test for multiple comparison between the groups in canine

| Group (I) | Group (J) | Mean difference (I-J) | SE   | Significant | 95% CI  |
|-----------|-----------|-----------------------|------|-------------|---------|
|           |           |                       |      |             | Lower bound | Upper bound |
| Full ferrule | Buccal ferrule | 164.77110*              | 20.94706 | 0.000       | 105.2511 | 224.2911 |
| Full ferrule | Proximal ferrule | 78.91980*               | 20.94706 | 0.004       | 19.3998 | 138.4398 |
| No ferrule | Buccal ferrule | 47.93260                | 20.94706 | 0.168       | -11.5874 | 107.4526 |
| No ferrule | Proximal ferrule | 255.17110*              | 20.94706 | 0.000       | 195.6511 | 314.6911 |
| Lingual ferrule | Full ferrule | -164.77110*             | 20.94706 | 0.000       | -224.2911 | -105.2511 |
| Lingual ferrule | Buccal ferrule | -85.85130*              | 20.94706 | 0.002       | -145.3713 | -26.3313 |
| No ferrule | Proximal ferrule | -116.83850*             | 20.94706 | 0.000       | -176.3585 | -57.3185 |
| No ferrule | Buccal ferrule | 90.40000*               | 20.94706 | 0.001       | 30.8800 | 149.9200 |
| Buccal ferrule | Full ferrule | -78.91980*              | 20.94706 | 0.004       | -138.4398 | -19.3998 |
| Buccal ferrule | Lingual ferrule | 85.85130*               | 20.94706 | 0.002       | 26.3313 | 145.3713 |
| Proximal ferrule | No ferrule | -30.98720               | 20.94706 | 0.581       | -90.5072 | 28.5328 |
| Proximal ferrule | Buccal ferrule | 176.25130*              | 20.94706 | 0.000       | 116.7313 | 235.7713 |
| No ferrule | Full ferrule | -47.93260               | 20.94706 | 0.168       | -107.4526 | 11.5874 |
| No ferrule | Lingual ferrule | 116.83850*              | 20.94706 | 0.000       | 57.3185 | 176.3585 |
| No ferrule | Buccal ferrule | 30.98720                | 20.94706 | 0.000       | -28.5328 | 90.5072 |
| No ferrule | Proximal ferrule | 207.23850*              | 20.94706 | 0.000       | 147.7185 | 266.7585 |
| No ferrule | Full ferrule | -255.17110*             | 20.94706 | 0.000       | -314.6911 | -195.6511 |
| No ferrule | Lingual ferrule | -90.40000*              | 20.94706 | 0.001       | -149.9200 | -30.8800 |
| No ferrule | Buccal ferrule | -176.25130*             | 20.94706 | 0.000       | -235.7713 | -116.7313 |
| No ferrule | Proximal ferrule | -207.23850*             | 20.94706 | 0.000       | -266.7585 | -147.7185 |

*The mean difference is significant at the 0.05 level. CI=Confidence interval, HSD=Honest significant difference, SE=Standard error

Table 4: Tukey post hoc test for multiple comparison between the groups in premolar

| Group (I) | Group (J) | Mean difference (I-J) | SE   | Significant | 95% CI  |
|-----------|-----------|-----------------------|------|-------------|---------|
|           |           |                       |      |             | Lower bound | Upper bound |
| Full ferrule | Lingual ferrule | 144.103600*            | 13.0935695 | 0.000      | 106.898877 | 181.308323 |
| Full ferrule | Buccal ferrule | 108.750900*            | 13.0935695 | 0.000      | 71.546177 | 145.955623 |
| Full ferrule | Proximal ferrule | 51.413300*            | 13.0935695 | 0.003      | 14.208577 | 88.618023 |
| Full ferrule | No ferrule | 229.848000*            | 13.0935695 | 0.000      | 192.643277 | 267.052723 |
| Buccal ferrule | Full ferrule | -144.103600*           | 13.0935695 | 0.000      | -181.308323 | -106.898877 |
| Buccal ferrule | Buccal ferrule | -35.352700*           | 13.0935695 | 0.070      | -72.557423 | 1.852023 |
| Buccal ferrule | Proximal ferrule | -92.690300*           | 13.0935695 | 0.000      | -129.895023 | -55.485577 |
| Buccal ferrule | No ferrule | 85.7444000*           | 13.0935695 | 0.000      | 48.539677 | 122.949123 |
| Lingual ferrule | Full ferrule | -108.750900*           | 13.0935695 | 0.000      | -145.955623 | -71.546177 |
| Lingual ferrule | Lingual ferrule | 35.352700*           | 13.0935695 | 0.070      | -1.852023 | 72.557423 |
| Lingual ferrule | Proximal ferrule | -52.337600*          | 13.0935695 | 0.001      | -94.542323 | -20.132877 |
| Lingual ferrule | No ferrule | 121.0971000*          | 13.0935695 | 0.000      | 83.892377 | 158.301823 |
| Proximal ferrule | Full ferrule | -51.413300*           | 13.0935695 | 0.003      | -88.618023 | -14.208577 |
| Proximal ferrule | Buccal ferrule | 92.6903000*          | 13.0935695 | 0.000      | 55.485577 | 129.895023 |
| Proximal ferrule | No ferrule | 57.3376000*          | 13.0935695 | 0.001      | 20.132877 | 94.542323 |
| No ferrule | Full ferrule | 178.4347000*         | 13.0935695 | 0.000      | 141.299777 | 215.639423 |
| No ferrule | Buccal ferrule | -229.8480000*        | 13.0935695 | 0.000      | -267.052723 | -192.643277 |
| No ferrule | Lingual ferrule | -85.7444000*        | 13.0935695 | 0.000      | -122.949123 | -48.539677 |
| No ferrule | Proximal ferrule | -121.0971000*       | 13.0935695 | 0.000      | -158.301823 | -83.892377 |
| No ferrule | Proximal ferrule | -178.4347000*      | 13.0935695 | 0.000      | -215.639423 | -141.299777 |

*The mean difference is significant at the 0.05 level. CI=Confidence interval, HSD=Honest significant difference, SE=Standard error

coronal tooth structure, and it is known as ferrule effect. The ferrule height of circumferential 1.5–2 mm is proposed by the researchers to improve the long-term survival of ETT.13,14 ETT with an absence of a ferrule in buccal or lingual segments and nonuniform ferrule height weighed down the dentist in clinical practice. The present study examined the influence of the lack of a ferrule in different locations on the fracture resistance of the ETT. The
glass-reinforced fiber posts were used during the study due to multiple advantages such as similar modulus of elasticity to dentin,\textsuperscript{[13]} esthetics, simple application procedure, and is most commonly used in the contemporary dental practice. The fracture strength of the Group I sample with 360° uniform ferrule was significantly higher in comparison to other tested groups. The Group V with complete absence of the ferrule recorded the lowest fracture strength. This result reconfirms the finding of the previous studies that the substantial role of a ferrule in enhancing the fracture resistance of ETT.\textsuperscript{[16‑18]} Some researchers propose the greater ferrule height of remaining tooth structure to enhance the fracture resistance in ETT.\textsuperscript{[19]} The anterior and posterior teeth are distinctive due to their size and direction of masticatory load. The force on the anterior teeth is nonaxial, while the load on the posterior teeth in an occlusal-gingival direction. The force on the anterior teeth due to their overlap is applied from the lingual surface at approximately at 130°. The present study’s result indicated that the lack of the palatal wall ferrule significantly reduced the fracture resistance in anterior teeth. The finding was in agreement with the results of Ng et al.;\textsuperscript{[20]} they reported that the good palatal ferrule was equally effective as the circumferential ferrule. The absence of the lingual ferrule in axial loading at anterior teeth concentrates the stress at post-crown junction, hence leading to the significant loss of fracture resistance. The results of the present study also indicated that the partial ferrule is superior to the complete lack of a ferrule. The reports from previous researchers indicated that the presence of an adequate ferrule in the buccal wall in anterior teeth had significantly higher fracture resistance.\textsuperscript{[21]} Arunpradikut et al.;\textsuperscript{[22]} reported the insignificant contribution of the single buccal wall ferrule on fracture resistance in ETT. The difference in result could be due to the fact that the load was directed from the buccal wall and it does not reflect the clinical situation.

The masticatory force over the posterior teeth is predominantly in occlusal-gingival direction and buccal-lingual direction approximately 45°. The loss of a ferrule at the proximal region in posterior teeth due to caries is common. The study results indicated that the loss of a ferrule in the proximal area had less effect on the fracture resistance. The result again reinforces the critical role of the lingual wall ferrule in improving the fracture resistance of premolar teeth. Hemmings et al.;\textsuperscript{[23]} reported that the cervical ferrule enhances the resistance of the post and core to torsion forces. The masticatory occlusal forces directed from lingual surfaces lead to the compressive stress on the buccal surfaces and tensile stress on the lingual surfaces.\textsuperscript{[24]} The presence of the lingual wall ferrule offers the resistance to resultant tensile stress. The results from the present in vitro study indicate that the segmental inadequacy of the ferrule, especially in proximal areas, can be restored successfully. The clinician should take the factors such as opposing teeth, prosthesis, expected masticatory forces, absence of opposing teeth, and type of occlusion during consideration for the evaluation of segmental absence of the ferrule in ETT.

Further researches are indicated to confirm the results under cyclic fatigue load. The effect of sectional inadequacy of the ferrule on other post types such as custom-made cast post, zirconia post, and ceramic post also needs an investigation. The limitation of the study includes the results from the in vitro studies have limited extrapolation to the complexity of oral environment. The load applied in the study was static load, against the dynamic fatigue load during mastication.

**Conclusions**

Within the limitation of this in vitro study, the following conclusions were drawn.

1. The presence of 2 mm circumferential ferrule significantly improves the fracture resistance of ETT
2. The ETT with sectional inadequacy of the ferrule is significantly more effective in resisting the fracture in comparison to the complete absence of the ferrule
3. The absence of a ferrule in the proximal area in both anterior and premolar teeth does not significantly affect fracture resistance of ETT
4. The lack of a ferrule on the lingual on anterior and premolar teeth significantly reduces the fracture resistance of ETT.

**Financial support and sponsorship**

Nil.

**Conflicts of interest**

There are no conflicts of interest.

**References**

1. Hebling E, Coutinho LA, Ferraz CC, Cunha FL, Queluz Dde P. Periapical status and prevalence of endodontic treatment in institutionalized elderly. Braz Dent J 2014;25:123-8.
2. Eliyas S, Jalili J, Martin N. Restoration of the root canal treated tooth. Br Dent J 2015;218:53-62.
3. Fennis WM, Kuji RH, Kreulen CM, Roeters FJ, Creugers NH, Burgersdijk RC, et al. A survey of cusp fractures in a population of general dental practices. Int J Prosthodont 2002;15:559-63.
4. Belli S, Erdemir A, Yıldırım C. Reinforcement effect of polyethylene fibre in root-filled teeth: Comparison of two restoration techniques. Int Endod J 2006;39:136-42.
5. Tikkur AP, Chandra A, Bharti R. Are full cast crowns mandatory after endodontic treatment in posterior teeth? J Conserv Dent 2010;13:246-8.
6. Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: A retrospective cohort study. J Prosthodont 2005;9:164-70.
7. Pontius O, Nathanson D, Giordano R, Hutter JW. Survival rate and fracture strength of incisors restored with different post and core systems and endodontically treated incisors without coronoradicular reinforcement. J Endod 2002;28:710-5.
8. Tait CM, Ricketts DN, Higgins AJ. Restoration of the root-filled tooth: Pre-operative assessment. Br Dent J 2005;198:395-404.
9. Pereira JR, de Ornelas F, Conti PC, do Valle AL. Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. J Prosthodont 2006;95:50-4.
10. Robbins JW. Restoration of the endodontically treated tooth. Dent Clin North Am 2002;46:367-84.
11. Dietschi D, Duc O, Krejci I, Sadan A. 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 Int 2008;39:117-29.
12. 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. J Prosthodont 2013;110:116-26.
13. da Silva NR, Raposo LH, 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. J Prosthodont 2010;104:306-17.
14. Kar S, Tripathi A, Trivedi C. Effect of different ferrule length on fracture resistance of endodontically treated teeth: An in vitro study. J Clin Diagn Res 2017;11:ZC49-52.
15. Hayashi M, Sugeta A, Takahashi Y, Imazato S, Ebisu S. Static and fatigue fracture resistances of pulpless teeth restored with post-cores. Dent Mater 2008;24:1176-86.
16. Tan PL, Aquilino SA, Gratton DG, Stanford CM, Tan SC, Johnson WT, et al. In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. J Prosthodont 2005;93:331-6.
17. Magne P, Lazari PC, Carvalho MA, Johnson T, Del Bel Cury AA. Ferrule-effect dominates over use of a fiber post when restoring endodontically treated incisors: An in vitro study. Oper Dent 2017;42:396-406.
18. Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M. Ferrule effect: A literature review. J Endod 2012;38:11-9.
19. Samran A, El Bahra S, Kern M. The influence of substance loss and ferrule height on the fracture resistance of endodontically treated premolars. An in vitro study. Dent Mater 2013;29:1280-6.
20. Ng CC, Dumbrigue HB, Al-Bayat MI, Griggs JA, Wakefield CW. Influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth. J Prosthodont 2006;95:290-6.
21. Al-Wahadni A, Gutteridge DL. An in vitro investigation into the effects of retained coronal dentine on the strength of a tooth restored with a cemented post and partial core restoration. Int Endod J 2002;35:913-8.
22. Arunpraditkul S, Saengsanon S, Pakkivvat W. Fracture resistance of endodontically treated teeth: Three walls versus four walls of remaining coronal tooth structure. J Prosthodont 2009;18:49-53.
23. Hemmings KW, King PA, Setchell DJ. Resistance to torsional forces of various post and core designs. J Prosthodont 1991;66:325-9.
24. Poiate IA, Vasconcellos AB, Poiate Junior E, Dias KR. Stress distribution in the cervical region of an upper central incisor in a 3D finite element model. Braz Oral Res 2009;23:161-8.