Published online: 2019-09-25

On the ferrule effect and the biomechanical stability of teeth restored with cores, posts, and crowns

John S. Mamoun[1],

Correspondence: Dr. John S. Mamoun
Email: mamounjo@gmail.com

[1]DMD, Private Practice, Manalapan, NJ USA

ABSTRACT

An abutment for a fixed partial denture may not contain enough tooth structure, such that the abutment does not provide an adequate 'ferrule effect'. A crown or bridge dental prosthesis that is cemented onto such an abutment/s may undergo biomechanical failure. Here, the tooth, core, and post complex, on which the crown is cemented, may fracture off from the abutment, causing the crown to separate from the abutment, while the cement that bonds the crown to the tooth, core, and post complex remains intact, such that the tooth, core, and post complex remains inside the crown when the crown separates from the abutment. This article reviews the dentistry literature on the ferrule effect, and presents alternative definitions for terms such as ferrule, the ferrule effect, and the ferrule tooth structure. The article also explains how the use of a surgical operating microscope, or high magnification binocular surgical loupes of ×6-8, or greater magnification improve the ability of a dentist to assess how much ferrule tooth structure an abutment contains, compared to the use of unaided vision.

Key words: Crown, dentistry, ferrule, microscopes, prosthodontics

INTRODUCTION

A ferrule[1,2] has been defined as 'a 360 degree metal collar of the crown surrounding the parallel walls of the dentine extending coronal to the shoulder of the preparation';[3] 'a subgingival collar or apron of gold which extends as far as possible beyond the gingival seat of the core and completely surrounds the perimeter of the cervical part of the tooth';[4] and a cast restoration that 'encircles the remaining parallel walled tooth structure with a metal band'.[5]

Placing a ferrule (such as a crown) around a preparation creates a protective 'ferrule effect', which has been claimed to 'prevent shattering of the root'' of the abutment[4] and aid in 'providing resistance to dislodgment and preventing fracture.the actual bracing of the complete crown over the tooth structure constitutes the ferrule effect, i.e. the protection of the remaining tooth structure against fracture'.[5] An abutment is most resistant to fracture if the abutment provides substantial amounts of tooth structure, that is of a height of 1.5-2.0 mm above the projected ferrule margin, for the ferrule or crown to grab onto.[5-10]

Alternative definition of ferrule effect

Alternatively, the 'ferrule effect' may be defined as the effect whereby cementing a 'ferrule', or 360 degree metal (or porcelain) band, around a tooth, prevents independent flexure of tooth and/or core and/or post structures that are located within the supra-ferrule-margin volume of the tooth, such that if a force is applied to the tooth, the entire supra-ferrule-margin tooth, core, and post complex works as one unit to resist the force; as long as the cement that lutes or bonds the ferrule to the supra-ferrule-margin tooth, core, and post complex is intact, the ferrule effectively 'transfers' the location, within the tooth volume, that resists a force on the tooth, from multiple possible (and unpredictable) fracture planes to (theoretically) a single fracture plane, that consists of the (approximately) horizontal

How to cite this article: Mamoun JS. On the ferrule effect and the biomechanical stability of teeth restored with cores, posts, and crowns. Eur J Dent 2014;8:281-6.

DOI: 10.4103/1305-7456.130639

cross section of the tooth, core, and post structure that is located at the level of the apical margin of the ferrule.

The bond strength, of the cross section, that forms the interface between the sub-ferrule-margin and the supra-ferrule-margin tooth, core, and post complex, consists additively of several possible bond strengths: the bond strength of any luting cement or composite resin bond within the cross section; and the bond strengths, respectively, of the intermolecular forces that bond the sub-ferrule-margin core material with the supra-ferrule-margin core material, the sub-ferrule-margin post material with the supra-ferrule-margin post material, and the sub-ferrule-margin tooth structure with the supra-ferrule margin tooth structure. A fracture plane at this interface may involve a fracture of a luting or bonding cement that was binding two different materials, and/or a fracture of a chemical bond within a material that was spanning this interface, such as a fracture of tooth structure or a fracture of a post at an internal post fracture plane.

The preceding definition of the 'ferrule effect' is simplistic because the abutment on which a ferrule is cemented can fracture at any fracture plane, and not necessarily at a fracture plane that is approximately parallel with the plane that is circumscribed by the ferrule margin. However, for purposes of defining the 'ferrule effect', a simplified assumption is made that the fracture plane is (theoretically) located at the ferrule margin.

Without this metal band encircling the tooth, a variety of force vectors contacting the tooth surfaces cause a variety of different tooth, core, and post structures to flex, such as to put stress on various different potential fracture planes within the tooth root or coronal structure, some of which resist fracture better than others, potentially causing a fracture at any one of multiple fracture planes. Such independent flexure of supra-gingival tooth, core and post structure in the nonferruled tooth can also induce stress planes in furcations and roots, and potentially cause root or furcation fracture, particularly with posterior teeth that are missing marginal ridges or transverse ridges that, if present, help to bind the buccal and lingual halves of a nonferruled posterior tooth. When a tooth is ferruled, the forces that would be generated in multiple flexure stress planes in the nonferruled tooth are instead distributed over a wide area, located at the ferrule margin. Hence, a ferrule can potentially improve the biomechanical stability of a tooth, by 'shifting' the interfaces that resist stresses, from weak tooth, core, and post interfaces, to a strong tooth, core, and post interface that is located at the ferrule margin.

If, hypothetically, a supra-ferrule-margin tooth, core, and post complex is divided into infinite horizontal cross sections, some of those cross sections may not contain enough natural tooth structure to provide enough resistance against fracture at a fracture plane located at one of these cross sections [Figure 1]. Experiments suggest that natural tooth structure, more than core or postmaterials, provides the strongest bond strength for resisting shear-off forces.[5,11] Therefore, it is assumed, for simplicity of argument, that the cross-sectional area of the natural tooth structure within these horizontal cross sections, multiplied by the bond strength per unit area of the natural tooth structure (a quantity that is difficult to predict clinically) is the most important factor for determining how much force an abutment can resist before the crown shears off at the level of the crown margin. Therefore, the most catastrophic fracture, of a horizontal cross section located at a ferrule margin, is one where the natural tooth structure contained within the cross-section fractures [Figure 2].

If apical to the most apical aspect of a volume of tooth, core, and poststructure, that contains too many cross sections that lack enough natural tooth structure to resist shear-off forces, there exists a 1.5-2.0 mm high volume of tooth, core, and post structure that contains enough cross sections, that contain enough natural tooth structure, to resist shear-off forces, then placement of the apical margin of the ferrule at the apical aspect of this stronger 1.5-2.0 mm volume of tooth, core, and post structure can improve the

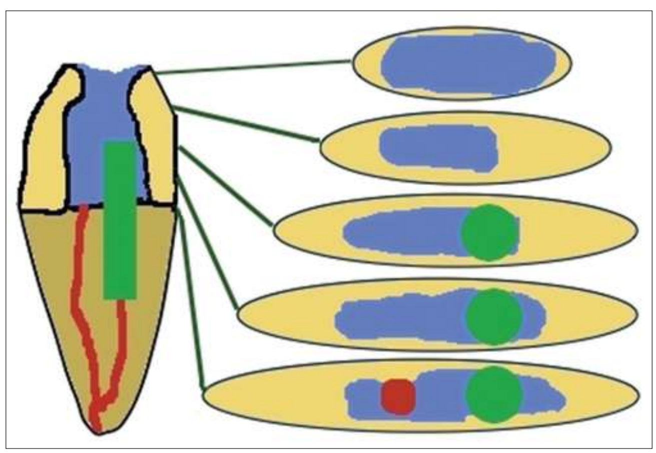

Figure 1: Various cross sections at different levels of a tooth/core/post abutment complex shows how much cross-sectional area consists of gutta percha (red), post material (green), core material (blue), and natural tooth structure (yellow)

Figure 2: The cantilever on this bridge increased torque forces on the bridge and contributed to the bridge separation from the abutments. The premolar abutment shows catastrophic fracture of ferrule tooth structure approximately at the level of the abutment margin. In the mouth, the canine abutment debonded due to extensive caries

biomechanical stability of the tooth when it is ferruled or crowned. The amount of dentin[6] in these cross sections is more important than the amount of enamel in determining the tensile strength of these cross sections or the tensile strength of the volume of tooth structure that is formed by infinite numbers of these horizontal cross sections.

Definition of the ferrule tooth structure

The 'ferrule tooth structure' is the tooth structure that extends 1.5-2.0 mm in the occlusal direction from the projected ferrule margin, and will be encircled by the apical 1.5-2.0 mm of the intaglio surface of the crown or ferrule margin. The ferrule tooth structure, compared to post, core, cement, or resin bond materials, adds most substantially to the ability of a tooth, core, and post complex, after a ferrule or crown is placed on it, to resist fracture at the level of the ferrule margin, and also adds most to reducing the forces that a post places on a root after a crown is placed on a tooth, core, and post complex. The 'ferrule tooth complex' is the complex of tooth structure, and/or core material and/or post material that exists within the volume encircled by the apical 1.5-2.0 mm of the ferrule margin.

To more precisely define 'ferrule tooth structure', imagine if a tooth was prepared into a cylinder shape, with a feather margin that had no horizontal component such as a chamfer or shoulder. This cylinder-shaped abutment theoretically contains the maximum amount of the ferrule tooth structure, since the perimeter at the gingiva of this cylinder feather-edge abutment encircles the greatest amount of cross-sectional surface area, since this perimeter has not been drilled into, in an axial direction, to make a horizontal marginal component. An infinite number of parallel axes, all of the same angle, originating respectively from an infinite number of points on the perimeter and base of the cylinder, define the cylinder and the dimensions of this 'ideal' abutment. A point on the abutment, that is located 1.5-2.0 mm or less occlusal distance from the base (or margin) of this perfect cylinder abutment, is a part of the ferrule tooth structure, if it is part of a continuous line of tooth structure that extends to the level of the margin of the abutment, such that this line of tooth structure is parallel with the infinite number of parallel lines that defines the dimensions of the ideal cylinder shape of this abutment.

The average height of all of these continuous lines of tooth structure emanating from the level of the ferrule margin is the average height of the ferrule tooth structure. The volume of the ferrule tooth structure is the average height of the ferrule tooth structure, multiplied by the cross-sectional area of the ferrule tooth structure at the level of the ferrule margin. Also, the height of the ferrule tooth structure that originates from the floor of a pulp chamber of an endodontically treated tooth is essentially zero, since the chamber floor is essentially located at the gingival level, and superior to the chamber floor is empty space.

Clinically, abutments are not perfect cylinders, but are tapered. To assess the amount of ferrule tooth structure in a tapered abutment, the dentist imagines what would be the dimensions of an ideal cylinder shape of this tapered abutment, and then imagines what aspects of tooth structure are located within 1.5-2.0 mm occlusal distance from the margin, and would also be located on lines of continuous tooth structure that are parallel to the imaginary parallel lines of the imaginary cylinder.

Some parts of tooth structure can be located within 1.5-2.0 mm occlusal distance from the projected ferrule margin, and yet not be part of the ferrule tooth structure, because such tooth structure may not be part of a continuous line of tooth structure that extends to the gingiva and that is also parallel to the axes of an ideal cylinder shape of that abutment. An example is height-of-contour tooth structure, which tapers apically toward the axial direction, and therefore has no tooth structure directly apical to it. Other examples include: the 'soffit', or tooth structure that is located along the perimeter of a pulp chamber at the occlusal aspect of a pulp chamber,[6] that 'curls' toward the center of the pulp chamber; or tooth structure at the CEJ, that overhangs slightly over the root structure directly apical to it. Also, if a tooth has been damaged by caries such that after the carious material is removed, the tooth structure has the shape of an arch that rises vertically from the gingiva and curls axially, that part of the tooth that forms the curling arch at the occlusal aspect is also not part of the ferrule tooth structure [Figure 3].

Some tooth structure helps us to prevent a nonferruled posterior tooth from splitting apart into separate buccal and lingual halves, along a fracture line that goes from the mesial to the distal. Examples of this are the oblique ridge of a maxillary molar, and the tooth structure located superior to the roof of a pulp chamber of a posterior tooth. If such buccal-to-lingual binding tooth structure is also connected, in a continuous line that is parallel with the imaginary axes of a cylinder preparation of that abutment, to tooth structure that is located at the ferrule margin, the apical 1.5-2.0 mm of this tooth structure adds to the ferrule tooth structure. If not, then this tooth structure only contributes to preventing a nonferruled tooth from splitting apart into separate buccal and lingual pieces; it is not part of the ferrule tooth structure. In addition, after a ferrule or crown is placed on a tooth, the ferrule or crown binds the buccal and lingual halves of the tooth as much as does the natural buccal-to-lingual binding tooth structure. This makes the binding function of this buccal-to-lingual tooth structure irrelevant in the ferruled tooth.

A ferrule can be placed on any nonundercut abutment, even if the abutment has a feather edge margin with no horizontal component. When a dentist cuts axially into a feather-edge preparation to create a margin with a horizontal component, such as a shoulder margin,[6] the dentist reduces the volume and cross-sectional area of the ferrule tooth structure, and reduces the biomechanical stability of the resulting abutment.

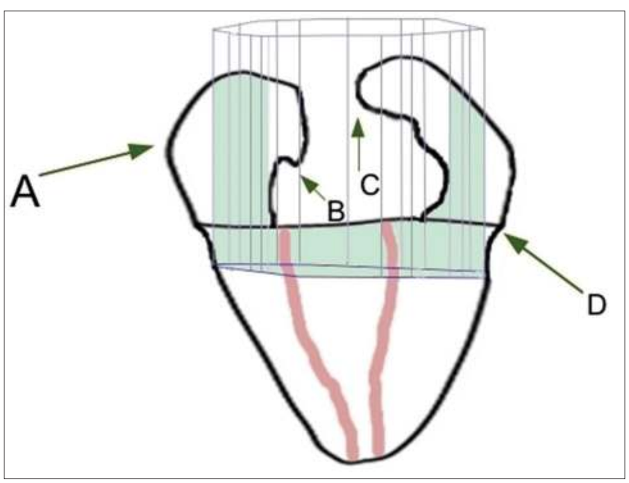

Figure 3: Longitudinal cross section of an unprepared, endodontically treated tooth (before core placement) shows the imaginary axes (in blue) of an 'ideal' cylinder preparation of this tooth and also shows the ferrule tooth structure, highlighted in green. Tooth structure that is not part of ferrule tooth structure is indicated as: (A) height of contour tooth structure; (B) the soffit; (C) occlusally arching tooth structure; (D) CEJ overhang material

Biomechanical failures due to inadequate ferrule effect

A crown made for an abutment, that does not contain enough ferrule tooth structure to provide a substantial ferrule effect, may undergo various forms of biomechanical failure. These failures are due to the abutment's lack of bond strength to resist fracture of the tooth, core, and post complex located at the level of the crown margin, or due to there not being enough ferrule tooth structure to reduce forces that a post places on a root. Specific examples of such failure include: the tooth, core, and post complex, on which the crown is cemented, shears off the abutment at a horizontal fracture plane that is located at the level of the crown margin, but the cement that lutes the crown to the supra-crown-margin tooth, core, and post complex remains intact, such that the crown separates from the abutment, with the tooth, core, and post complex still being embedded inside the crown [Figure 4]; the cement layer luting a post to a root fractures, resulting in the crown separating from the abutment root with the tooth, core, and post complex embedded in the crown, with or without damaging the root [Figure 5]; if a crown, tooth, core and post complex had previously sheared off an abutment at the level of the crown margin, and the dentist simply re-cemented the complex onto the abutment, the weak cement layer may fracture soon after, resulting in the crown separating from the

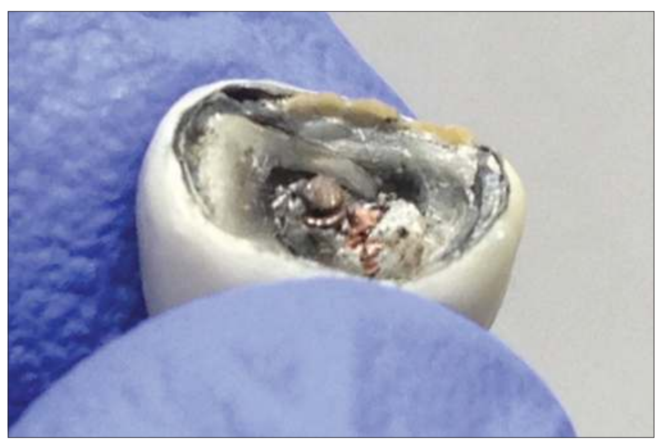

Figure 4: A crown has fractured off at the level of the crown margin. The fracture interface combines fractures of a cement interface binding dissimilar materials, and chemical bonds within tooth, post and core materials spanning the interface between the sub-crown-margin and supra-crown-margin tooth, core, and post complex

Figure 5: This maxillary central incisor crown initially failed due to fracture of the ferrule tooth structure around the post, even though the cement luting the crown to the supra-crown-margin tooth structure did not fail. The crown, post, and core was then re-cemented as is, without ferrule tooth structure; a few months later the cement apical to the crown margin failed, while also fracturing the root

abutment; if a crown is cemented on a tooth and core complex where the core material extends apically beyond the crown margin, forming a convex bulge of core material apical to the crown margin, the natural tooth structure of the abutment consists of a root tip with a concave, subgingival margin, or a 'reverse ferrule' abutment; the cement layer is likely to fracture soon.

Research and the ferrule effect

Research shows that the presence of a 1.5-2.0 mm height of tooth structure above the gingiva is more important for preventing fracture than use of a post,[11,12] although some authors suggest that the bond strength of a resin bonded post reduces the need for a ferrule effect.[13-18] Beyond 3 mm of ferrule tooth structure height, there is little improvement in abutment fracture resistance.[19,20] When an abutment has a post, a retentive ferrule causes forces placed on a crown to transmit to the cemento–enamel junction (CEJ) area; here, if the abutment fails, it tends to fail via a horizontal fracture. However, if an abutment has a post but has no retentive ferrule, the post puts more forces on the root and less at the CEJ; here, if the abutment fails, it tends to fail via root fracture.[21-25] If the cervical tooth structure height is too short, crown lengthening surgery may reveal more tooth structure for the ferrule to encircle. [17,26] The tooth walls that the ferrule encircles should be at least 1 mm thick to be strong enough to contribute to the ferrule effect, although the tooth walls do not have to completely encircle the abutment, [5,11,12] if a partial encirclement contains enough tooth structure to create a substantial ferrule effect.

With maxillary anterior teeth, occlusal forces tend to contact the lingual surfaces, putting the cingulum areas of these teeth under tensile force, and the facial areas of these teeth under compressive force.[27-29] In maxillary anterior teeth, it is important to preserve ferrule tooth structure that is part of the cingulum, since this provides resistance to tensile forces.[12]

Abutments that are not in occlusion, or that are opposed by denture teeth (which have 20-25% of the chewing force[30,31] of natural teeth), require less ferrule tooth structure to be biomechanically stable. Cantilevered abutments, abutments that have to close wide interproximal spaces, or single abutments that are thin in cross section at the gingiva, such as premolars or mandibular incisors, will be under higher torque forces, and require more ferrule tooth structure.

Caries located at a crown margin damages the ferrule tooth structure, reducing the biomechanical stability of the abutment. Sometimes, it is difficult to determine how much ferrule tooth structure is left in a crowned abutment that has developed cervical caries, without removing the crown and directly observing the abutment. Also, if a dentist leaves gutta percha or cotton in a root canal chamber, and builds a core over this weak foundation, the ferrule tooth, core, and post complex may flex more than if the core was stiffer.

Using microscopes to evaluate ferrule tooth structure

Microscope-level magnification of ×6-8 or greater, combined with co-axial illumination, facilitates visually distinguishing between ferrule tooth structure and nonferrule tooth structure, such as the soffit, occlusally arching tooth structure, or height-of-contour tooth structure. Microscopes facilitate verifying that the outer perimeter of a preparation margin ends on ferrule tooth structure, instead of ending on the height-of-contour tooth structure, or on a marginal overhang consisting of the core build-up material or natural tooth structure.

CONCLUSION

The amount of ferrule tooth structure that an abutment contains determines how resistant is a crown or bridge to the form of biomechanical failure where the fixed prosthesis separates from the abutment due to the tooth, core, and post complex on which the abutment is cemented fracturing from the abutment, such that the tooth, core, and post complex remains inside the crown or bridge when the crown or bridge separates from the abutment, with the cement that binds the crown or bridge to the tooth, core, and post complex remaining intact. The most catastrophic form of crown separation failure involves fracture of the natural tooth structure within the abutment, particularly if such fracture involves the root structure or ferrule tooth structure.

REFERENCES

1. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE. Fundamentals of Fixed Prosthodontics. 3rd ed. Chicago: Quintessence Publishing; 1997. p. 85-103, 191-2.
2. Rosenstiel SF, Land MF, Fujimoto J. Contemporary Fixed Prosthodontics. 4th ed. St. Louis: Mosby; 2006.
3. Sorenson JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. J Prosthet Dent 1990;63:529-36.
4. Rosen H. Operative procedures on mutilated endodontically treated teeth. J Prosthet Dent 1961;11:973-86.
5. Jotkowitz A, Samet N. Rethinking ferrule--a new approach to an old dilemma. Br Dent J 2010;209:25-33.
6. Clark D, Khademi J. Modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010;54:249-73.
7. Isidor F, Brøndum K, Ravnholt G. The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. Int J Prosthodont 1999;12:78-82.
8. Libman WJ, Nicholls JI. Load fatigue of teeth restored with cast posts and cores and complete crowns. Int J Prosthodont 1995;8:155-61.
9. Stankiewicz NR, Wilson PR. The ferrule effect: A literature review. Int Endod J 2002;35:575-81.
10. Akkayan B. An *in vitro* study evaluating the effect of ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. J Prosthet Dent 2004;92;155-62.
11. Ferrari M, Vichi A, Fadda GM, Cagidiaco MC, Tay FR, Breschi L, *et al*. A randomized controlled trial of endodontically treated and restored premolars. J Dent Res 2012;91(Suppl 7):72S-8S.
12. 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.
13. Coelho CS, Biffi JC, Silva GR, Abrahão A, Campos RE, Soares CJ. Finite element analysis of weakened roots restored with composite resin and posts. Dent Mater J 2009;28:671-8.
14. Mahmoudi M, Saidi A, Gandjalikhan Nassab SA, Hashemipour MA. A three-dimensional finite element analysis of the effects of restorative materials and post geometry on stress distribution in mandibular molar tooth restored with post-core crown. Dent Mater J 2012;31:171-9.
15. al-Hazaimeh N, Gutteridge DL. An *in vitro* study into the effect of the ferrule preparation on the fracture resistance of crowned teeth incorporating prefabricated post and composite core restorations Int Endod J 2001;34:40-6.
16. Sherfudhin H, Hobeich J, Carvalho CA, Aboushelib MN, Sadig W, Salameh Z. Effect of different ferrule designs on the fracture resistance and failure pattern of endodontically treated teeth restored with fiber posts and all-ceramic crowns. J Appl Oral Sci 2011;19:28-33.
17. Meng QF, Chen YM, Guang HB, Yip KH, Smales RJ. Effect of a ferrule and increased clinical crown length on the *in vitro* fracture resistance of premolars restored using two dowel-and-core systems. Oper Dent 2007;32:595-601.
18. Hempton TJ, Dominici JT. Contemporary crown-lengthening therapy: A review. J Am Dent Assoc 2010;141:647-55.
19. 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 Prosthet Dent 2006;95:50-4.
20. Al-Omiri MK, Al-Wahadni AM. An *ex-vivo* study of the effects of retained coronal dentine on the strength of teeth restored with composite core and different post and core systems. Int Endod J 2006;39:890-9.
21. Rosen H, Partida-Rivera M. Iatrogenic fracture of roots reinforced with a cervical collar. Oper Dent 1986;11:46-50.
22. Barkhorder RA, Radke R, Abbasi J. Effect of metal collars on resistance of endodontically treated teeth to root fracture. J Prosthet Dent 1989;61:676-8.
23. Joseph J, Ramachandran G. Fracture resistance of dowel channel preparation with various dentin thickness. Fed Oper Dent 1990;1:32-5.
24. Tjan AH, Whang SB. Resistance to root fracture of dowel channels with various thickness of buccal dentin walls. J Prosthet Dent 1985;53:496-500.
25. Ng CC, al-Bayat MI, Dumbrigue HB, Griggs JA, Wakefield CW. Effect of no ferrule on failure of teeth restored with bonded post and cores. Gen Dent 2004;52:143-6.
26. Gegauff AG. Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns. J Prosthet Dent 2000;84:169-79.
27. 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.
28. 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 Prosthet Dent 2005;93:331-6.
29. Al-Omiri MK, Rayyan MR, Abu-Hammad O. Stress analysis of endodontically treated teeth restored with post-retained crowns: A finite element analysis study. J Am Dent Assoc 2011;142:289-300.
30. Michael CG, Javid NS, Colaizzi FA, Gibbs CH. Biting strength and chewing forces in complete denture wearers. J Prosthet Dent 1990;63:549-53.
31. Haraldson T, Karlsson U, Carlsson GE. Bite force and oral function in complete denture wearers. J Oral Rehabil 1979;6:41-8.

Access this article online	
Quick Response Code:	**Website:** www.eurjdent.com
	Source of Support: Nil. **Conflict of Interest:** None declared