Nikolai Stankiewicz

Peter Wilson

The Ferrule Effect

Abstract: When the supra-marginal dentine of a root-filled tooth is engaged by a crown, it may create a stronger tooth/restoration complex. This has been termed the ferrule effect. This paper reviews the current evidence for this effect and examines the influence various post and core materials have on it. Means of achieving a ferrule are discussed and the importance of planning for failure is considered.
Clinical Relevance: Provision for the ferrule effect when restoring root-filled teeth with a post-retained crown may optimize the strength of the restored tooth.

Fractured posts, cores and roots of crowned root-filled teeth are disappointing clinical outcomes (Figure 1). Root-filled teeth that require a crown are inherently compromised owing to a loss of coronal dentine, instrumented canals and therefore increased flexure in response to occlusal forces.[1] The dentist must attempt to reduce failure when restoring these teeth by employing design principles, materials and techniques that address such risks.

It has been proposed that an important design principle of crown preparation is the provision of a ferrule. This is achieved by '...the parallel walls of dentine extending coronal to the shoulder of the preparation.'[2] (Figure 2). It is possible that this extension of dentine, when encircled by a crown, provides a protective effect by reducing stresses within a tooth; the 'ferrule effect'.

Evidence of the ferrule effect

Most published papers that

Figure 1. A split root-filled tooth that has lost its coronal restoration.

consider the ferrule effect are laboratory investigations. The methodology employed must be considered in assessing the clinical relevance of any laboratory study. Testing the load capacity of post-retained crowned teeth may include two tests reflecting different clinical conditions:

■ Static load tests which simulate single high force application that might occur with trauma or as a result of parafunctional habits. This approach is limited as it does not consider time-related factors, eg fatigue stress, corrosion.[3] Furthermore, the teeth failure mode may not be reflective of what is seen clinically;[4] or

■ Dynamic testing which seeks to redress this by simulating chewing and is more representative of normal oral function.

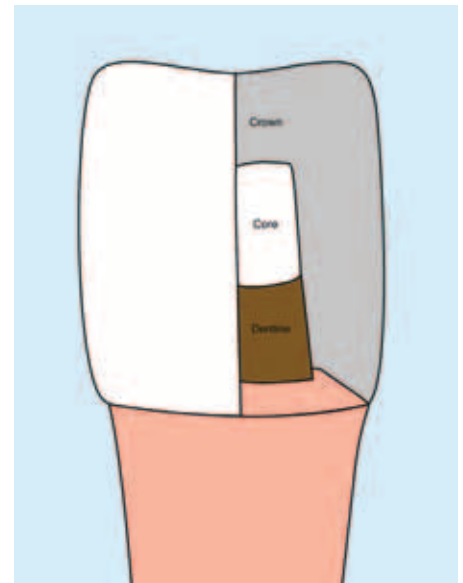Another problem with the laboratory studies of the ferrule effect is a lack of uniformity between studies that

Figure 2. Parallel walls of dentine (shaded) extending coronal from the margin provide a ferrule that, when encircled by a crown, produces the 'ferrule effect'.

makes direct comparisons between various outcomes limited.

It is the aim of this paper to review the predominantly laboratory studies of the influence of the ferrule effect.

Cast post and cores

Where cast post and cores have

Nikolai Stankiewicz, BDSc(Melb), MFGDP(UK), General Dental Practitioner, Bath, UK and **Peter Wilson**, PhD, MDS, MS, FDS RCSEd, DRD RCSEd, Grd Dip Hlth Admn, Associate Professor and Head of Restorative Dentistry Section, University of Melbourne, Australia.
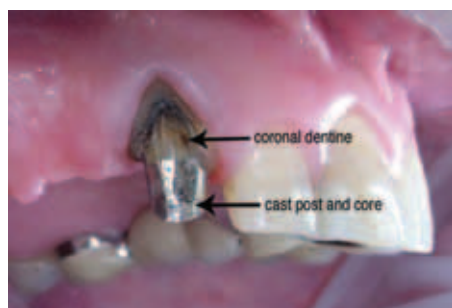
Figure 3. Tooth 3/ demonstrates dentine coronal to the preparation margin.

been used and the test teeth subjected to static loading, coronal dentine extending 1.5 mm to 2 mm has been demonstrated to improve fracture resistance significantly[2,5,6] (Figure 3).

When a cast post and core is used, a 2 mm ferrule seems to be desirable, but this might not always be clinically possible. Tan *et al* [7] investigated the effect of an incomplete ferrule and its influence on resistance to tooth fracture under a static load. Whilst an incomplete ferrule provided by 2 mm of labial and palatal dentine and 0.5 mm proximally provided significant resistance to fracture compared with the teeth without coronal dentine, the complete ferrule was significantly more resistant to tooth fracture. The clinical significance of this difference is not clear.

Direct post and cores

Whilst cast post and cores have their advantages, direct post and cores also have a place in the restoration of root-filled teeth. Unlike cast posts, direct posts have the advantage of only needing one appointment, reducing the risk of root filling contamination, no laboratory costs, and a wider choice of materials.

The influence of the post and core colour on the aesthetic outcome of the restored tooth and the elasticity of the post material have been driving forces behind the development of new direct post systems. Various fibre-reinforced and zirconia systems are suggested by manufacturers for cases where all ceramic crowns are used and the detracting optical properties of a metal post and core are to be avoided. Many of these posts are completely opaque (Figure 4).

The aesthetic posts tend to be more flexible than metal posts (Table 1). The rationale behind the use of a more flexible post is controversial. On one side of the argument: a post that more closely matches the elasticity of the root is less likely to lead to root fracture; on the other hand, flexibility may lead to movement of the stiff crown away from the margin and opening at the crown margin or fracture of the post.

Metal posts

Zhi-Yue and Yu-Xing[6] found no significant difference between teeth with a cast post and core without a ferrule and the teeth with a direct post and core with a 2 mm ferrule. They did not test specimens restored with a direct post and core and no ferrule.

With a static load test, Pereira *et al* [8] found increasing ferrule length increased resistance to fracture when a stainless steel post and composite resin core was used. There was significantly greater resistance to fracture when a 3 mm ferrule was placed compared with no ferrule.

The study by Pereira *et al* [8] tested posts and cores without coronal dentine. The direct posts tended to fail due to core fracture, whereas the cast posts failed due to root fracture. A fractured core may be a retrievable situation; a fractured root is probably not. Therefore, in the absence of a ferrule, the clinician may need to consider whether to opt for the stronger cast post, with root fracture likely in the event of higher load failure, or the weaker stainless steel post that may be salvageable following failure, but fail at a lower load.

Without a ferrule, the cast post and core provided significantly greater resistance to failure than the direct post and core. The clinical significance is, however, questionable as the authors do note that the forces required to induce failure were all well above normal intra-oral forces. Statistical significance does not infer clinical significance and subsequently both the modes of testing and the forces that are required for failure must be evaluated before extrapolating clinical recommendations from the results.

Non metallic posts

Under static loading, Akkayan[9]

Material	Modulus of Elasticity
dentine	15–19 GPa
quartz fibre	20 GPa
glass fibre	30 GPa
cast gold	75–110 GPa
titanium	100 GPa
carbon fibre	120 GPa
zirconia	200 GPa
stainless steel	200 GPa

Table 1. The modulus of elasticity of dentine and various post materials.

evaluated the effect that the ferrule length had on the fracture resistance of maxillary canines restored with four different aesthetic post types; quartz fibre, glass fibre, zirconia, and combined glass fibre and zirconia. Regardless of the post type, a 2 mm ferrule resulted in the highest fracture resistance. The teeth with quartz fibre posts were the most resistant to fracture regardless of ferrule length. The zirconia posts proved to be the weakest amongst the materials tested. The author expressed concern that these posts would prove difficult to remove if they fractured *in vivo*.

Ng *et al* [10] also investigated the influence of a ferrule on resistance to fracture of maxillary central incisors restored with quartz fibre posts and composite resin cores. They found that a 2 mm ferrule significantly increased resistance to fracture when compared with teeth restored without a ferrule. The mode of failure in the teeth with a ferrule was mainly root fracture, whereas the group without a ferrule mainly failed as a result of debonding.

Goto *et al*[11] compared a cast gold alloy post and core and direct posts of titanium alloy and glass fibre-reinforced resin, both with composite resin cores. The preparations all included a 1.5 mm ferrule. The specimens underwent cyclic loading until the crown's luting cement underwent preliminary failure (cracking). The teeth that had the glass fibre-reinforced resin posts performed the best, followed by the titanium alloy post.

The performance of the glass fibre posts was attributed to the resin luting

Figure 4. A metal direct post alongside a glass fibre post.

cement used and its ability to withstand horizontal shearing forces better than the zinc phosphate cement that was used for the metal posts. The use of a composite core bonded to the dentine with the titanium post may have resulted in better performance with this post when compared with the cast post. Even in the presence of a ferrule, there are other variables that will influence the performance of the restored tooth. This may include both the type of post and core used and the luting cement(s) used.

Naumann, Preuss and Frankenberger[12] tested whether there was a difference in fracture resistance between teeth restored using a glass fibre post or a titanium post. When a 2 mm ferrule was provided, the post material did not result in significantly different resistance to fracture. Where a ferrule was provided and the titanium post used, all failures were catastrophic. Unlike Goto et al,[11] resin cement was used for both post types in this study and it was found that, when a ferrule was present, there was no significant difference between the post types in fracture resistance under static loading.

Hu et al[13] investigated the roles of several variables on fracture resistance and the mode of failure in structurally compromised teeth. A cast post and core, composite resin as both post and core, and a carbon fibre post with a composite resin core were tested. A 1 mm ferrule was tested against the absence of a ferrule. All the samples were thermocycled, then half were subjected to a static load test until initial tooth cracking. The other half underwent cyclic fatigue testing.

The ferrule was shown to be significant in improving resistance to fracture for all post types. The teeth restored with carbon fibre posts outperformed the cast post and cores. The authors noted that the modulus of elasticity of the post may therefore be of importance in resisting specific types of loading. For a sudden impact, the cast post and core is more effective, but under the daily repetitive forces of chewing and normal function, a more flexible material might be desirable.

Under cyclic fatigue testing, the teeth with cast posts and those with carbon fibre posts all failed owing to vertical root fracture. The provision of a ferrule did not change the mode of failure. Regardless of a ferrule being present or absent and the mode of testing, the composite post and core restored teeth failed on the inside of the core without root fracture.

The modes of failure observed led the authors to recommend the use of the composite resin post and core over the other two systems, despite the others demonstrating better resistance to fracture. The emphasis on the choice was placed upon the mode of failure and the ability to repair the tooth following failure, versus extraction.

Naumann, Preuss and Rosentritt[14] questioned '...what extent the degree of dentine preservation influences the success of the ferruled anterior restoration.' Maxillary incisors were prepared with 2 mm of ferrule interrupted at the facial, palatal and proximal segments and compared against a control with a complete ferrule. Glass fibre posts with a composite core were used.

In contrast with the results of Tan et al,[7] who tested cast post and cores, the teeth with a complete ferrule did not give the greatest resistance to fracture. The teeth that had only facial dentine providing a ferrule had the greatest fracture resistance. The relative weakness of the complete ferrule was attributed to a lessened area for adhesion of the core material. This suggests that the pursuit of a ferrule at the expense of tooth loss may not always be favourable. The authors noted that, except for the specimens with a proximal interrupted ferrule, the median fracture values were greater than 400 N, which is greater than what might be encountered *in vivo*.

Finite element analysis

Computer simulation using finite element analysis has been employed to investigate the ferrule effect.

Pierrisnard et al[15] simulated a cast nickel chromium post and core, a nickel chromium post with a composite core and a carbon fibre post with a composite core. Preparations with a 2 mm ferrule and without a ferrule were simulated. Cement was not considered in the analysis as the authors considered its mechanical impact to be insignificant. This may be at variance with the results of Goto et al[11] as discussed earlier.

The models underwent simulated static loading. The lack of a ferrule was identified as the 'most significant contributory factor in increasing the risk of fracture'. The results revealed that a ferrule influenced the degree of stress at the cervical section of tooth restored with a post-retained crown. Cervical stresses significantly increased in the absence of a ferrule, and were highest when a metal post was used. The composite resin core and nickel chromium post generated more stress than the cast post and core when there was no ferrule. When a ferrule was present, no significant difference in cervical stress was found between the teeth restored with cast or direct metallic posts. The provision of a ferrule had no effect on the cervical stresses of the model restored with a carbon fibre post.

Finite element analysis was used by Ichim et al[16] in their investigation of the effect of ferrule length on both the mechanical resistance of the crown and stress distribution within the root of a maxillary central incisor restored with a post-retained crown.

Their analysis predicted that a ferrule influences the displacement of the crown when subjected to palatal loading. A ferrule of at least 1.5 mm resulted in maximum resistance to axial rotation/displacement. Ferrule height was most efficient when greater than the rotation radius of the crown. Furthermore, a reduced ferrule will still '...reduce the axial arm of rotation force...' and thereby reduce the bending force on the post. Stress analysis predicted differences in root dentine stress, depending upon the presence or absence of a ferrule. This may account for the different modes of failure seen *in vitro*.

Clinical studies

A systematic review of clinical trials investigating posts found only two randomized controlled clinical trials that compared failures with different post types.[17] The studies included did not consider the presence of a ferrule. Furthermore, the review was unable to conclude whether metal cast posts or carbon fibre posts were preferable in the restoration of root-filled teeth.

There is clearly a need for robust clinical trials that will help provide an evidence-based approach to the restoration of root-filled teeth. Trials are expensive and demanding of resources, yet the lack of unbiased and high quality data in a routine part of restorative dentistry is cause for concern and should act as a motivating factor for researchers.

Pre-operative assessment and achieving a ferrule effect

When there is less than 1.5–2 mm of supra-marginal dentine for a ferrule effect, the clinician and patient must decide whether this will be an acceptable compromise. In the absence of dentine above the margin, consideration might be given to sub-gingival margin placement, crown lengthening, root extrusion, or accepting absence of ferrule.

Where possible, crowns should be placed at least 2 mm from the alveolar crest to avoid impinging upon the periodontal attachment mechanism. Fugazzotto and Parma-Benfenati[18] advised leaving at least 3 mm to be clear of the attachment mechanism. Therefore, if a ferrule is to be present, at least 4.5 mm of supra-alveolar tooth will be required.

Sub-gingival margins may allow for more dentine, but this may bring with it the technical problems of accurately recording the margins in an impression, and difficulty in removing excess luting cement. Patients might find it difficult to keep the area clean and the opacity of the crown may compromise gingival aesthetics.

In the absence of a ferrule, Aykent et al[19] found that in vitro use of a dentine bonding agent with an amalgam core and a direct stainless steel post provided a significant increase in fracture resistance in extracted premolars. Whilst dentine bonding of the amalgam core did not offer any significant improvement when a 1 mm ferrule was present, this study suggests that there may be a role for dentine bonding of amalgam cores when a ferrule cannot be achieved.

Both crown lengthening and orthodontic extrusion may allow for an increased ferrule, but they add additional cost, discomfort and length of treatment times for the patient. Crown lengthening increases the crown to root ratio. Whilst Ichim et al[16] used finite element analysis to predict that crown lengthening did not alter the levels or pattern of stress within the palatal dentine, Gegauff[20] concluded that crown lengthening could be problematic.

Gegauff[20] investigated whether crown lengthening to achieve a ferrule would affect the static load failure. By placing the finish line further apically, Gegauff postulated that the tooth may be weakened as a result of the resultant decrease in cross-sectional area of the preparation and the increased crown to root ratio. Orthodontic extrusion may avoid this problem as it results in a smaller change in the crown to root ratio.

Core considerations

The purpose of a post in a root-filled tooth is to retain the core, which in turn retains the crown. Cast metal, composite resin and amalgam are favoured core materials. Pilo et al investigated whether the choice of core was significant when a 2 mm ferrule was engaged.[21] Under static loading, no difference was seen in fracture resistance when cores of amalgam, cast metal or composite resin were used with a cast or stainless steel post.

A more recent core material is pressed ceramic, which can be used with a zirconia post. Under dynamic loading, Heydecke et al found no significant differences in fracture strength between the following:
■ Teeth restored with titanium posts and composite resin cores;
■ Zirconia posts and composite resin cores;
■ Zirconia posts and heat pressed ceramic cores; and
■ Cast-ongold post and cores.[22]

The teeth were prepared with facial and palatal ferrule height of 2 mm and proximal height of 1 mm.

Core diameter when composite resin is used may be of importance when metal posts are used, but possibly not with glass fibre posts.[23] The design of the post head has also been cited as a potential factor in core integrity.[24] Delamination of the core from the post is a potential mode of failure that may lead to loss of crown retention.

Figure 5. (a–c) This post-retained crown has had its dentine core fracture, leading to failure. The remaining supra-gingival dentine is limited, and the decision whether to place a new crown or extract the tooth must consider any compromises that may be required. (Source: Dr K Chong.)

Planning for failure

Restorations fail. Clinicians should ask themselves what can be done when the restoration they are placing fails. Many of the papers examined in this review have demonstrated that the mode of failure of a restored root-filled tooth can be affected by several variables, including the mode of testing, the amount of ferrule, the type of post and core used and the type of luting cement used. Some failures are catastrophic and extraction would be the only option following failure. Other modes of failure allow for retrievability, but may be at the expense of resistance to displacement and may allow for leakage, which could prejudice the endodontic treatment.

Furthermore, it should be acknowledged that the teeth being described are seriously damaged.[25] Careful consideration should be given to whether the restoration will give the patient quality and value or a compromised outcome (Figure 5). It is important that clinicians know when to extract a tooth and seek alternative treatment modalities.

Conclusion

A body of evidence from *in vitro* studies and computer simulation support the theory that supra-marginal dentine, when engaged by a cast crown, results in a ferrule effect. The ferrule effect acts to protect the underlying tooth and improves the resistance of the restoration to failure. It is, however, part of a system that is also influenced by the type of post and core placed, the luting cements used and the amount of dentine remaining.

References

1. Sedgley CM, Messer HH. Are endodontically treated teeth more brittle? *J Endod* 1992; **18**: 332–335.
2. Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. *J Prosthet Dent* 1990; **63**: 529–536.
3. Naumann M, Sterzenbach G, Pröschel P. Evaluation of load testing of postendodontic restorations *in vitro*: linear compressive loading, gradual cycling loading and chewing simulation. *J Biomed Mater Res B Appl Biomater* 2005; **74**: 829–834.
4. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. *J Prosthet Dent* 1999; **81**: 652–661.
5. Libman WJ, Nicholls JI. Load fatigue of teeth restored with cast posts and cores and complete crowns. *Int J Prosthodont* 1995; **8**: 155–161.
6. Zhi-Yue L, Yu-Xing Z. Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors. *J Prosthet Dent* 2003; **89**: 368–373.
7. Tan PL, Aquilino SA, Gratton DG *et al*. *In vitro* fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. *J Prosthet Dent* 2005; **93**: 331–336.
8. 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**: 50–54.
9. 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**: 155–162.
10. Ng CC, al-Bayat MI, Dumbrigue HB, Griggs JA, Wakefield CW. Effect of no ferrule on failure of teeth restored with bonded posts and cores. *Gen Dent* 2004; **52**: 143–146.
11. Goto Y, Nicholls JI, Phillips KM, Junge T. Fatigue resistance of endodontically treated teeth restored with three dowel-and-core systems. *J Prosthet Dent* 2005; **93**: 45–50.
12. Naumann M, Preuss A, Frankenberger R. Reinforcement effect of adhesively luted fiber reinforced composite versus titanium posts. *Dent Mater* 2007; **23**: 138–144.
13. Hu S, Osada T, Shimizu T, Warita K, Kawawa T. Resistance to cyclic fatigue and fracture of structurally compromised root restored with different post and core restorations. *Dent Mater J* 2005; **24**: 225–231.
14. Naumann M, Preuss A, Rosentritt M. Effect of incomplete crown ferrules on load capacity of endodontically treated maxillary incisors restored with fiber posts, composite build-ups, and all-ceramic crowns: an *in vitro* evaluation after chewing simulation. *Acta Odontol Scand* 2006; **64**: 31–36.
15. Pierrisnard L, Bohin F, Renault P, Barquins M. Corono-radicular reconstruction of pulpless teeth: a mechanical study using finite element analysis. *J Prosthet Dent* 2002; **88**: 442–448.
16. Ichim I, Kuzmanovic DV, Love RM. A finite element analysis of ferrule design on restoration resistance and distribution of stress within a root. *Int Endod J* 2006; **39**: 443–452.
17. Bolla M, Muller-Bolla M, Borg C *et al*. Root canal posts for the restoration of root filled teeth. *Cochrane Database Syst Rev* 2007; **1**: CD004623.
18. Fugazzotto PA, Parma-Benfenati S. Preprosthetic periodontal considerations. Crown length and biologic width. *Quintessence Int Dent Dig* 1984; **15**: 1247–1256.
19. Aykent F, Kalkan M, Yucel MT, Ozyesil AG. Effect of dentin bonding and ferrule preparation on the fracture strength of crowned teeth restored with dowels and amalgam cores. *J Prosthet Dent* 2006; **95**: 297–301.
20. 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**: 169–179.
21. Pilo R, Cardash HS, Levin E, Assif D. Effect of core stiffness on the *in vitro* fracture of crowned, endodontically treated teeth. *J Prosthet Dent* 2002; **88**: 302–306.
22. Heydecke G, Butz F, Hussein A, Strub JR. Fracture strength after dynamic loading of endodontically treated teeth restored with different post-and-core systems. *J Prosthet Dent* 2002; **87**: 438–445.
23. Artopoulou I, O'Keefe KL, Powers JM. Effect of core diameter and surface treatment on the retention of resin composite cores to prefabricated endodontic posts. *J Prosthodont* 2006; **15**: 172–179.
24. Chang WC, Millstein PL. Effect of design of prefabricated post heads on core materials. *J Prosthet Dent* 1993; **69**: 475–482.
25. Morgano SM. Restoration of pulpless teeth: application of traditional principles in present and future contexts. *J Prosthet Dent* 1996; **75**: 375–380.