REVIEW

The ferrule effect: a literature review

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Abstract

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Literature review A ferrule is a metal ring or cap used to strengthen the end of a stick or tube. It has been proposed that the use of a ferrule as part of the core or artificial crown may be of benefit in reinforcing root-filled teeth. A review of the literature investigating this effect is presented. The literature demonstrates that a ferrule effect occurs owing to the artificial crown bracing against the dentine extending coronal to the crown margin. Overall, it can be concluded that a ferrule is desirable, but should not be provided at the expense of the remaining tooth/root structure.

Keywords: dental prosthesis design, ferrule, post and core, tooth.

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Introduction

Successful restoration of root-filled teeth requires an effective coronal seal, protection of the remaining tooth, restored function and acceptable aesthetics. A post-retained crown may be indicated to fulfil these requirements. However, one mode of failure of the post-restored tooth is root fracture. Therefore, the crown and post preparation design features that reduce the chance of root fracture would be advantageous.

A ferrule is a metal ring or cap intended for strengthening. The word probably originates from combining the Latin for iron (ferrum) and bracelets (viriola) (Brown 1993). A dental ferrule is an encircling band of cast metal around the coronal surface of the tooth. It has been proposed that the use of a ferrule as part of the core or artificial crown may be of benefit in reinforcing root-filled teeth. A protective, or 'ferrule effect' could occur owing to the ferrule resisting stresses such as functional lever forces, the wedging effect of tapered posts and the lateral forces exerted during the post insertion (Sorensen & Engelman 1990).

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A literature search was conducted using the Medline database to find papers that have examined the ferrule effect or made reference to it. Papers were found by searching for the word 'ferrule'. Those pertaining to dentistry were then obtained and read to see whether they contributed in examining the ferrule effect. Some of the references used in these papers provided further articles of interest.

Laboratory-based investigation of the ferrule effect

Most research investigating the ferrule effect has been conducted in the laboratory. The complexity of the oral environment prevents clear extrapolation owing to the simplicity of the experiments.

Studies without use of artificial crowns

The concept of an extracoronal 'brace' has been proposed (Rosen 1961) and defined as 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. It is an extension of the restored crown which, by its hugging action, prevents shattering of the root."

Rosen & Partida-Rivera (1996) tested this concept using 76 extracted maxillary lateral incisors that had the crown sectioned to a level 1 mm coronal to the cementoenamel junction. Half of the teeth were further prepared with a bevelled shoulder 2 mm high and 0.25 mm wide at the base, having an angle of convergence of 6°. A gold casting, which represented the collar portion of a crown, was then cemented onto these teeth. Screw posts were then inserted and tightened with incremental torque until the root or post fracture occurred. The collar significantly reduced the incidence of root fracture. However, the rotational application of force in a continuous manner would be rarely present in the mouth, and implies independent movement of the post and collar.

Buccal dentine thickness

The influence of dentine thickness (buccal to the post space) on the resistance to root fracture has been investigated (Tjan & Whang 1985). This study used 40 extracted maxillary central incisors divided into four groups. The control group had 1 mm of remaining buccal dentine. One of the test groups also had 1 mm of remaining buccal dentine and a 60° bevel. The other two test groups had 2 and 3 mm of remaining buccal dentine, and no bevel. Cast post and cores were cemented into the test teeth, but no crowns were placed.

The teeth then underwent compressive loading until they failed. The incorporation of a bevel produced a core that provided a metal collar. The authors concluded from their study that the incorporation of the metal collar did not increase resistance to root fracture. No significant differences were noted between the varying dentine wall thickness, although both the groups with only 1 mm of dentine all failed owing to fracture rather than cement failure. This is of particular interest as different modes of failure may be easier to manage, i.e. a loose post *versus* a fractured root.

Modified collar

The effect of a cervical metal collar was re-examined (Barkhordar *et al.* 1989). This study was based on that of Tjan & Whang (1985) but used a modified collar design. Twenty extracted maxillary central incisors were divided into two groups; those with and those without a collar. Both the groups had 1 mm of buccal dentine, but the test group had a 2-mm collar preparation with approximately 3° of wall taper, and a total convergence of 6°. Cast post and cores were then cemented but no crowns were used. The teeth then underwent compressive loading until root fracture. Barkhordar *et al.* (1989) found that a metal collar significantly increased resistance to root fracture. They also observed different fracture patterns in the collared teeth compared to those without collars. The collared group predominantly underwent patterns of horizontal fracture whereas the teeth without collars mainly exhibited patterns of vertical fracture (splitting).

Modified collar and buccal dentine thickness

The effectiveness of a cervical collar with a thicker buccal dentine wall was investigated (Joseph & Ramachandran 1990). Forty extracted maxillary central incisors were divided into four groups; 1 and 2 mm of buccal dentine, with and without 60° bevels. The subsequent testing was similar to that used by Tjan & Whang (1985). The authors concluded that the use of a 2-mm collar increased the resistance of the tooth to root fracture. The authors noted there was no significant difference between the mean failure load of the two groups with cervical collars, regardless of the amount of remaining buccal dentine.

Collar with resin teeth

The effect of a cervical collar was investigated using photoelastic stress analysis on resin teeth resembling canines (Loney *et al.* 1990). Resin was necessary to conduct the photoelastic analysis but it must be emphasized that resin has a stiffness between a sixth to a quarter that of dentine. Eight teeth were duplicated from a mould of a master tooth. The master tooth was prepared with 2-mm incisal reduction, 1.5-mm buccal reduction and an angled shoulder, and a 0.5-mm lingual chamfer. The master tooth was then reduced another 4 mm to form a flat plane for the core. Four of the resin teeth replicated this preparation; the other four had a 1.5-mm bevel around the flat plane. Cast post and cores were cemented in all the teeth. Crowns were not placed. Each tooth was then placed under a 400-g load at 152° to its long axis, sectioned and then examined at five points. The shear stresses were less varied in the collared group, however, the teeth without collars exhibited significantly lower shear stresses at the three of the five points examined. From their findings, Loney *et al.* (1990) concluded that the used of a core collar did not produce a ferrule effect.

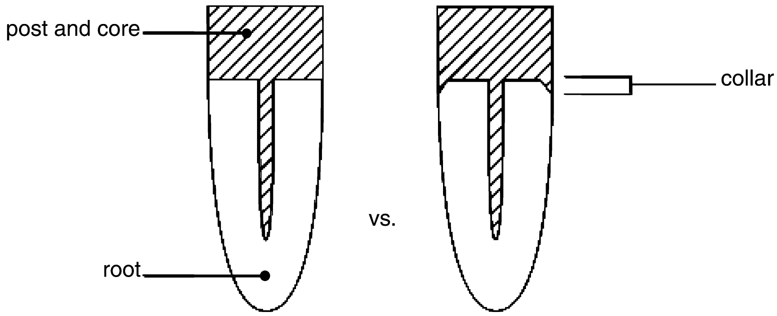

Figure 1 The provision of a cervical collar as part of the core without an artificial crown. Although a bevelled collar/ferrule has been depicted, a butt finish or chamfer could also be used.

Bonded posts and broken down teeth

The influence of a metal collar on the structurally compromised teeth, with and without resin reinforcement has been examined (Saupe *et al.* 1996). Forty extracted maxillary central incisors were divided into two categories: resin reinforced and non-reinforced. These were further divided into roots with and without collars. The collar design was similar to that used by Barkhordar *et al.* (1989), having a 2-mm collar with 3° of taper on the root wall. All the teeth were prepared to simulate structurally compromised roots, with only 0.5–0.75 mm of dentine at the cementoenamel junction. The resin-reinforced roots were prepared using a visible light-cured resin composite bonded to the internal root surface. Cast post and cores were cemented in all teeth using a resin cement. All the other *in vitro* studies (without crowns) reviewed used zinc phosphate as a luting cement. Prior to loading the teeth, the roots were coated with rubber to simulate the periodontal ligament, then embedded in resin. The teeth were loaded until failure, which was detected by a sudden release of the load on the test tooth. Resin reinforcement significantly increased the resistance to failure, but the use of the collar in the resin reinforced group was found to be of no benefit.

Torsion

The use of a cervical collar on a post was found to be of particular benefit in increasing the resistance of the post and core to torsional forces (Hemmings *et al.* 1991). Where a very tapered bevel of 45° was used, an increase in resistance to torsional forces 13 times that of the control group was seen. The study did not use crowns over the cores. The authors made the important point that a metal cervical collar may be aesthetically unacceptable where the metal is visible at the gingival margin.

Summary of studies without use of artificial crowns

These studies give mixed results as to the effectiveness of a cervical collar in producing a ferrule effect (Fig. 1). Even so, the results of these studies should be interpreted with caution, as none of them used artificial crowns on the cores. This was noted by Loney *et al.* (1990), who felt that such tests were still valid, as they helped to determine an optimal post and core form. They believed this would be of importance in crowns that had lost cement or become loose, resulting in the post and core being placed under increased forces.

Despite the confusion over the usefulness of a cervical collar, cores that are made with a ferrule create technical problems. The design requires increased casting expansion at the ferruled part of the core, and a decrease in casting expansion in the post. In a comparison of casting techniques, it was demonstrated that this could not be achieved to a clinically acceptable level, despite the authors trying five different casting techniques (Campagni *et al.* 1993). Their results raise concern about the findings in the studies which did employ a core with a ferrule, as the technical problems encountered with casting may have influenced the outcomes of testing.

Studies with artificial crowns

Sixty extracted maxillary incisors were used to investigate the effect of six different tooth preparation designs on the resistance to failure (Sorensen & Engelman 1990). All the teeth had post and cores cemented, over which a crown was then cemented. Each tooth was loaded at 130° to its long axis until it failed which encompassed either displacement of the crown or post, or fracture of the root or post.

One design was a 130° sloped shoulder from the base of the core to the margin. Whereas this design has a ferrule between the crown and margins and also between the core and tooth, it did not increase resistance to failure or fracture.

Two groups had a 90° shoulder without any coronal dentinal extension, and one of these groups also had a 1-mm-wide 60° bevel finish line. The placement of a bevel at the crown margin in these groups did not increase fracture resistance. This was in accordance with the findings of Tjan & Whang (1985).

Two groups had a significantly different mean failure load compared with the other four groups. These two designs had a 90° shoulder and a 1-mm-wide 60° bevel finish line. One of the groups had a 1-mm coronal dentinal extension. The other had a 2-mm-wide coronal dentinal extension and a 1-mm-wide 60° contrabevel at the tooth–core junction. As failure threshold was not significantly different between these two groups, it may be inferred that the contrabevel is of no benefit. Furthermore, and most importantly, the coronal extension of dentine above the shoulder is the design feature which increases the resistance to failure, and thus imparts a ferrule effect.

Sorensen & Engelman (1990) advised that as much coronal tooth as possible should be preserved, and a butt-joint margin between the core and tooth be used, i.e. minimal taper. They went on to suggest that the ferrule effect be defined as "... a 360° metal collar of the crown surrounding the parallel walls of the dentine extending coronal to the shoulder of the preparation. The result is an elevation in resistance form of the crown from the extension of dentinal tooth structure."

An investigation of root fracture related to the post selection and crown design also considered the influence of the ferrule effect (Milot & Stein 1992). Forty-eight resin maxillary central incisors were divided into three groups. One of the groups had a cast post and core, the other two groups used a direct post system with a cermet cement core. Half the teeth in each group had a 1-mm concave bevel apical to the margin. Although the dimensions of the tooth preparations were not disclosed, the illustrations indicated that in all teeth there was dentine extending coronal to the margin. Therefore, the ferrule effect would have been expected in both the control and test groups in this experiment.

Crowns were cemented on all the teeth, which were then loaded with a compressive force until they fractured. The force was applied at 120° to the long axis of each tooth. The teeth with the bevel had an increased resistance to root fracture. Milot & Stein (1992) proposed that the bevel produced a ferrule effect and the gingival extension of the metal collar provided support at the point of leverage. The use of a cermet/glass-ionomer cement as a core material, as in this study, is not recommended owing to its lack of strength (McLean 1998). The authors noted some cracking and crazing of the cement cores prior to crown placement, but did not report any significant differences in fracture resistance between the teeth with cast and cermet cement cores.

Ferrule length

Based on the effective ferrule demonstrated by Sorensen & Engelman (1990), the influence of ferrule length on resistance to preliminary failure was investigated (Libman & Nicholls 1995). The authors defined preliminary failure as the propagation of a crack in or around the luting cement of the crown. Twenty-five extracted maxillary central incisors were split into five groups; a control group and four test groups. The test groups had ferrule lengths of 0.5, 1, 1.5 and 2 mm. The teeth were prepared with 1-mm-wide shoulders. The test teeth had cast post and cores cemented and the control group did not. All the teeth were restored with cast crowns. The teeth were subjected to cyclic loading until preliminary failure was detected, using a strain gauge. The control group and the teeth with 1.5- and 2-mm ferrules were found to be significantly better than the teeth with 0.5- and 1-mm ferrules in resistance to preliminary failure. The authors concluded that 1.5 mm should be the minimum ferrule length when restoring a root-filled maxillary central incisor with a post- and core-retained crown.

Libman & Nicholls (1995) paid particular attention to the shortcomings of some methods of *in vitro* testing. The use of cyclic loading in their study was based upon the rationale that failure within the dental complex was associated with repeated fatigue loads rather than a single fracture-inducing load. The authors also acknowledged that their study did not duplicate the deformability of the periodontal ligament. Furthermore, the ferrule height in the study was constant around the circumference of the tooth, which may differ from the clinical situation where the finish line follows the morphology of the interproximal gingivae.

The conclusions of Libman & Nicholls (1995) were based on rigid parameters (Gegauff 2000). Their study used short (8-mm long) and narrow (1.25-mm diameter) posts and there was no simulation of periodontal support. Their finding of a 1.5-mm minimum effective ferrule may not be the case clinically.

Cyclic loading was adopted in an investigation of the influence of post and ferrule length on resistance to failure (Isidor *et al.* 1999). Using 90 extracted bovine teeth, they studied three post lengths (5, 7.5 and 10 mm) and two ferrule lengths (1.25 and 2.5 mm). Bovine teeth were selected in an attempt to reduce variability. The teeth were restored with prefabricated titanium posts and resin composite cores. The teeth were all crowned, then subjected to cyclic loading until the crown or post dislodged or the post or root fractured. The fracture resistance of the specimens increased with the ferrule length, but was not enhanced by increased post length. The authors note that this is of particular significance in re-evaluating studies which have investigated post length and design without a crown in their experiment methodology. Furthermore, it would suggest that an increase in post length, to achieve an increase in retention does not decrease resistance to failure.

Type of post and core

Most of the studies investigating the ferrule effect have used cast post and cores. Milot & Stein (1992) used direct posts with cermet cores, but found no significant difference in fracture resistance compared with the teeth they restored with cast post and cores. The posts were all cemented with zinc phosphate cement. Al-Hazaimeh & Gutteridge (2001) investigated the effect of a ferrule on central incisors when a direct post and composite resin core was used. The prefabricated posts and composite resin cores were placed in 20 central incisor teeth. The posts and crowns were luted with a resin cement. Ten of the teeth had a 2-mm ferrule, the others had no ferrule. Analysis following compressive loading until failure demonstrated no significant difference between the two groups. The authors proposed that the strength afforded by the resin may have masked any benefit provided by the ferrule.

The authors observed a high mean failure load for both groups, which they attributed to the resin luting cement. Although there was no difference between the two groups' resistance to failure, the modes of failure differed. The group with a ferrule underwent oblique fracture, whereas the group without a ferrule largely underwent vertical root fracture.

Summary of studies with artificial crowns

These studies showed that coronal extension of dentine above the shoulder increases the resistance to failure (Fig. 2). This ferrule effect may be significantly enhanced when the coronal extension of dentine is at least 1.5 mm. This effect has been demonstrated in teeth restored with cast post and cores. A ferrule in teeth restored with direct posts and resin cores may not offer any additional benefit.

In all the *in vitro* studies, both with and without crowns, only single rooted teeth have been investigated. The influence of the ferrule effect on multi-rooted teeth remains an area for further research.

The ferrule effect *in vivo*

There appear to be no reports of prospective clinical investigations of the ferrule effect. A retrospective study of the survival rate of two post designs was conducted by Torbjörner *et al.* (1995). Their study involved reviewing the records of 638 patients, with a total of 788 posts; the patients were not examined. Seventy-two of the posts failed. Most (46 cases) failed owing to the loss of retention. It was observed that all the post fractures (six cases) occurred in teeth with a "... lack of a ferrule effect of

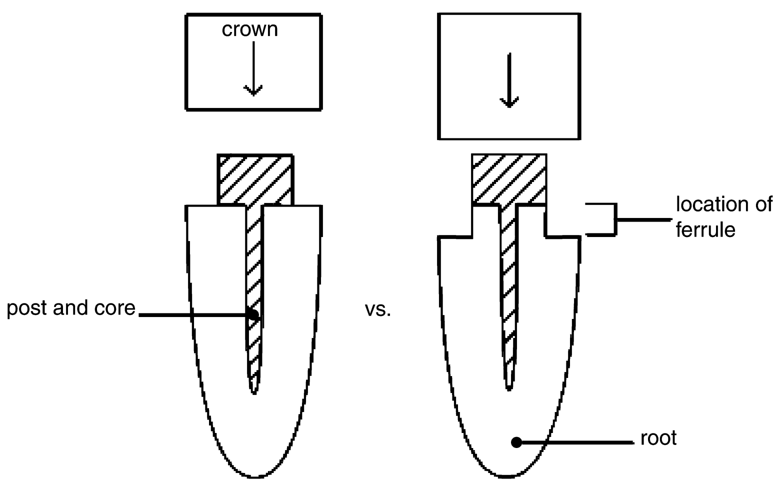

Figure 2 Coronal extension of dentine above the shoulder provides an effective ferrule.

the metal collar at the crown margin area . . .". The remainder failed owing to root fracture. Their study did not state how many crowns surveyed had a ferrule. From the work of Sorensen & Engelman (1990) and Libman & Nicholls (1995) it has been shown that the position and length of the ferrule is of significance. Torbjörner *et al.* (1995) did not indicate whether these design features were recorded in the patients' files. Furthermore, radiographs do not allow assessment of the amount of tissue remaining under a crown with a metal substructure. Therefore, it would be prudent for future studies to make some record of the ferrule, or even consider keeping dies.

A classification of the single-rooted pulpless teeth based upon the amount of remaining supragingival tooth structure has been recommended (Kurer 1991). Five classes of pulpless tooth were described; class I has sufficient coronal tissue for a crown preparation, II has coronal tissue but requires a core, and III has no coronal tissue. The classes IV and V refer to the complications of intraosseous fracture and periodontal disease. However, this classification does not account for a minimum effective ferrule length. It would perhaps be of value to add a further subclassification of ferrule length to the Class II type of pulpless tooth. A suitable distinction would be *less than* or *at least* 2 mm-ferrule length.

Preoperative tooth assessment

In assessing whether a tooth should be restored, the clinician must consider the amount of remaining supragingival tissue. Libman & Nicholls (1995) demonstrated *in vitro* that the minimum effective ferrule should be 1.5 mm of coronal dentine extending beyond the preparation margin. Below this length, there is a significant decrease in resistance to preliminary failure. Without supportive *in vivo* research the clinician is left to question whether satisfactory treatment can still be provided where a ferrule is absent or that is shorter than that advised in this *in vitro* study.

A minimum ferrule length of 2 mm to compensate for the difficulties of intraoral tooth preparation has been recommended (McLean 1998). Citing a paper by Freeman *et al.* (1998), it was noted that even where a 1-mm ferrule was attempted extraorally, it was difficult to achieve. Overcompensation is thus advisable to achieve an adequate length of parallel dentine, to produce an effective ferrule.

The ferrule length that may be obtained will be influenced by the 'biologic width'. This is defined as ". . . the dimension of the junctional epithelial and connective tissue attachment to the root above the alveolar crest" (Sivers & Johnson 1985). If unpredictable bone loss and inflammation is to be avoided, the crown margin should be at least 2 mm from the alveolar crest. It has been recommended that at least 3 mm should be left to avoid impingement on the coronal attachment of the periodontal connective tissue (Fugazzotto & Parma-Benfenait 1984). Therefore, at least 4.5 mm of supra-alveolar tooth structure may be required to provide an effective ferrule.

In those clinical situations where there is insufficient ferrule length, even where margins are placed subgingivally, the clinician may consider surgical crown lengthening or orthodontic extrusion. This allows the distance between the crown margin and alveolar crest to be widened, and increases the potential ferrule length.

Methods to increase ferrule length will reduce the root length and result in more tooth loss, possibly making the crown to root ratio unfavourable. Furthermore, both procedures will add to the cost of restoring the tooth, prolong treatment time and cause discomfort to the patient. The study by Al-Hazaimeh & Gutteridge (2001) suggests that the use of a resin-bonded direct post and resin core may be a preferable alternative where a ferrule can not easily be obtained.

The effect of crown lengthening to establish a ferrule on static load failure was investigated (Gegauff 2000). Using restorative composite resin to make root analogues, two groups of 10 teeth were tested. One group simulated teeth that had received crown lengthening and a ferrule in the preparation; the other group were not crown lengthened and were without a ferrule and no remaining clinical crown. All the teeth had cast post retained cores and crowns cemented prior to testing. Both the alveolar bone and periodontal ligament were simulated in the study. The teeth were subjected to a load by a universal testing machine until failure (peak load). The group that had crown lengthening and a ferrule demonstrated a significantly lower failure load.

Gegauff (2000) noted that the apical relocation of the finish line following crown lengthening resulted in a decrease in the cross section of the preparation. Subsequently, this reduction in tissue combined with an altered crown to root ratio may result in weakening of the tooth. He also pointed out that orthodontic extrusion may be preferable to crown lengthening as it results in a smaller change in the crown to root ratio. The results of that study suggested that the overall importance of a ferrule at the expense of remaining tooth structure was unclear.

A balance between the ferrule length obtained and the remaining root is therefore needed. These considerations are obviously best made prior to root canal treatment. If a suitable ferrule length cannot be obtained, the patient should be informed of the potential compromise.

Conclusions

Laboratory evidence shows in some circumstances that a ferrule effect occurs owing to the crown bracing against the dentine extending coronal to the crown margin. Furthermore, a significant increase in resistance to failure in single rooted teeth is observed where this dentine extends at least 1.5 mm. However, the cost of getting this support in teeth with no coronal dentine is loss of tooth tissue. When assessing a tooth prior to root treatment and subsequent restoration with a crown (if needed), a ferrule would be desirable but not at the expense of the remaining tooth/root structure.

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