IN VITRO EVALUATION OF THE FERRULE EFFECT AND POST MATERIAL ON FAILURE LOAD AND MODE IN ENDODONTICALLY TREATED TEETH

by

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Dedication

To my mother,

To my sister,

And my nieces.

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Signed Statement

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person except when due reference has been made in the text. I gave consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

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Penilaian secara *in-vitro* kesan ferul dan bahan pasak keatas kegagalan beban dan mod pada gigi yang menerima rawatan endodontik

Abstrak

Masih terdapat kontroversi berkenaan kesan ferul dan pasak prefabriksi terikat yang lebih baik pada kekuatan gigi yang menerima rawatan endodontik. Tujuan kajian ini adalah untuk membandingkan kesan ferul dan dua jenis bahan pasak terikat keatas kegagalan beban dan mod kegagalan pada gigi yang menerima restorasi selepas rawatan endodontik.

Enam puluh lapan gigi insisor tengah maksila yang telah dicabut dipotong sepanjang 15 $\pm$ 0.1mm koronal kepada apek akar menggunakan pemotong tisu keras (Exakt, Germany) dan hanpis berkelajuan tinggi. Mereka kemudiannya dirawat secara endodontik menggunakan teknik “step-back” dengan kikir apikal utama bersaiz 45 dan diobturat dengan “gutta percha” (Meta Dental Co. Ltd, Korea) dan bahan pengap AH 26 (Dentsly Mailefer, Germany) menggunakan teknik pemadatan lateral. Ruang untuk pasak kemudiannya disediakan menggunakan alat berputar Gates-Glidden dengan pembuangan “gutta percha” dengan meninggalkan hanya 5mm panjang dari apeks, diikuti penebuk Tenax (Coltene Whaledent, USA) sehingga saiz 1.3mm untuk meluaskan kanal. Sampel-sampel dibahagikan secara rawak kepada 4 kumpulan dengan 17 sampel setiapnya dimana . Kumpulan A dipasang dengan pasak titanium (Tenax post, Coltene Whaledent, USA) tanpa penyediaan ferul; Kumpulan B dipasang dengan pasak titanium dan penyediaan 2mm ferul; Kumpulan C dipasang dengan pasak komposit diperkuat gentian kaca (Tenax fiber white post, Coltene Whaledent,

USA) tanpa penyediaan ferul dan Kumpulan D dipasang dengan pasak komposit diperkuat dengan gentian kaca dan penyediaan 2mm ferul. Semua pasak disimen menggunakan Panavia F (Kuraray Medical Inc., Japan), sebelum teras dibina dengan Paracore (Coltene Whaledent, USA) dan saiznya disamakan dengan menggunakan "paraform coreformer #1". Korona kemudiannya difabrikasi mengguräkan Ni-Cr dimana panjang setiap sampel dengan korona dalam kedudukannya adalah 23 ±0.1mm, diperiksa menggunakan kaliper digital. Korona disimen dengan Ketac-Cem (3M ESPE, Germany). Empat blok besi digunakan untuk memegang spesimen semasa ujian mekanikal. Setiap blok mempunyai lubang selinder yang ditebuk dengan diameter berbeza (5.5mm, 6.5mm, 7.5mm dan 8.5mm) supaya dapat disesuaikan kepada kelebaran spesimen yang berbeza dengan bahan impresi silikon getah dimasukkan untuk mengsimulasi ligamen periodontal. Mesin ujian universal (Instron 3366, USA) telah digunakan untuk ujian mekanikal dengan memberi beban tekanan pada kelajuan gerak silang 1mm/min pada sudut 135° kepada paksi panjang sampel sehingga ianya gagal.

Median kegagalan beban untuk kumpulan A, B,C dan D adalah 253.10N (76.6), 256.40N (279.7), 203.10N (68.7) dan 251.75N (69.2) secara berturut. Ujian Kruskal - Wallis menunjukkan bahawa median kegagalan beban tidak signifikan secara statistik diantara semua empat kumpulan (p>0.05). Mod kegagalan mod pula diklasifikasikan sebagai samada kegagalan memuaskan (kegagalan restorasi sahaja) atau kegagalan tidak memuaskan (kegagalan restorasi dan struktur penyokong gigi). Kumpulan C mempunyai frekuensi tertinggi kegagalan memuaskan (87.5% kegagalan memuaskan dan 12.5% kegagalan tidak memuaskan). Kumpulan A mempunyai (37.5% kegagalan memuaskan dan 62.5% kegagalan tidak memuaskan). Kumpulan B dan D mempunyai

(0% kegagalan memuaskan dan 100% kegagalan tidak memuaskan). Ujian Chi-square untuk ketakbersandaran menunjukkan perbezaan signifikan dalam mod kegagalan antara kumpulan ($p<0.05$).

Kesan ferul dan bahan pasak tidak memberi kesan yang signifikan ke atas kegagalan beban pada gigi yang dirawat secara endondontik, tetapi gigi yang telah dipasang dengan pasak komposit diperkuat gentian kaca mempunyai mod kegagalan yang lebih memuaskan dari gigi yang dipasangkan dengan pasak titanium bila kesan ferul tidak disediakan.

In vitro evaluation of the ferrule effect and post material on failure load and mode in endodontically treated teeth.

Abstract

There are still controversy regarding the ferrule effect and a better bonded prefabricated posts on strength of endodontically treated teeth. The aim of this study was to compare the effect of ferrule and two types of bonded post material on failure load and failure mode of restored endodontically treated teeth.

Sixty eight extracted maxillary central incisors were sectioned 15 ± 0.1mm coronal to the root apex using hard tissue cutter (Exakt, Germany) and high speed handpiece. They were then endodontically instrumented using step-back technique with master apical file size 45 and obturated with gutta percha (Meta Dental Co. Ltd, Korea) and sealed with AH 26 (Dentsply Maillefer, Germany) using lateral condensation technique. Post spaces were then prepared using Gates-Glidden rotary instrument to remove gutta percha leaving 5mm from the apex, followed by Tenax drills (Coltene Whaledent, USA) up to size 1.3mm in diameter to enlarge the canals. Samples were randomly divided into four groups of 17 where Group A was placed with titanium post (Tenax post, Coltene Whaledent, USA) without ferrule preparation; Group B placed with titanium post and 2mm ferrule preparation; Group C placed with glass fiber reinforced composite post (Tenax fiber white post, Coltene Whaledent, USA) without ferrule preparation and Group D placed with glass fiber reinforced composite post and 2mm ferrule preparation. All posts were cemented using Panavia F (Kuraray Medical Inc., Japan), before the core was built with Paracore (Coltene Whaledent, USA) and standardise the size using paraform coreformer #1. Crowns were then fabricated using Ni-Cr where the length of each sample with the crown in place was

23 ± 0.1mm, checked using a digital calliper. Crowns were cemented using Ketac-Cem (3M ESPE, Germany). Four metal blocks were used to hold the specimens during mechanical testing. Each block had a drilled cylindrical hole with a different diameter (5.5mm, 6.5mm, 7.5mm and 8.5mm) so as to accommodate to different specimens' widths with rubber silicon impression material injected to simulate the periodontal ligament. A universal testing machine (Instron 3366, USA) was used for the mechanical testing by applying a compressive load at a crosshead speed of 1mm/min at an angle of 135º to the long axis of the sample until failure.

The medians of failure load for groups A, B, C and D were 253.10N (76.6), 265.40N (279.7), 203.10N (68.7) and 251.75N (69.2) respectively. Kruskal-Wallis Test indicated that the medians of failure load were not statistically significant across the four groups ($p > 0.05$). Failure mode was classified as either favorable failure (failure of the restoration only) or unfavorable failure (failure of the restoration and the supporting tooth structure). Group C had the highest frequency of favorable failures (87.5% favorable and 12.5% unfavorable failures). Group A had (37.5% favorable and 62.5% unfavorable failures). Group B and D had (0% favorable and 100% unfavorable failures. Chi-square test for independence indicated a significant difference in failure mode between the groups ($p < 0.05$).

The ferrule effect and post material did not significantly affect the failure load of endodontically treated teeth, but those restored with glass fiber reinforced composite posts had a more favorable failure mode than those restored with titanium posts when the ferrule effect was not present.

Chapter 1

INTRODUCTION

1.1 Background

Restoration of endodontically treated teeth is one of the oldest fields in restorative dentistry. Morgano and Brackettt credit the concept of using the root of a tooth for retention of a crown to Pierre Fauchard in the middle of the 18^{th} century. Fauchard inserted wooden dowels in canals of teeth to aid in crown retention, where the wood would expand in the moist environment thus enhancing the retention of the dowel overtime. Unfortunately, the root would often fracture vertically (Morgano and Brackett, 1999). The use of wooden dowels continued through the 19^{th} century however; in 1878 the Richmond crown was introduced which incorporated a threaded tube in the canal with a screw retained crown. They were later modified as a 1-piece dowel and crown by eliminating the threaded tube. One-piece dowel-crowns were not practical when divergent paths of insertion of the post-space and remaining tooth structure existed. Removal and replacement of crowns was another problem. These difficulties led to development of a post-and-core restoration as a separate entity with an artificial crown cemented over a core and remaining tooth structure (Morgano and Brackett, 1999).

The advent of scientific endodontic therapy in the 1950s increased the challenges in restorative dentistry. Endodontics replaced extraction being accepted as a treatment for severely damaged teeth and a satisfactory restorative solution was necessary. Cast posts and cores became the routine methods of restoration (Morgano and Brackett, 1999). Cast post and core has the tendency to transfer the occlusal forces to the remaining dentine causing tooth fractures. To counter this, the concept of an extracoronal ‘brace’ has been proposed by Rosen in 1961 (cited by (Stankiewicz and Wilson, 2002) which being 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’’. Eissman and Radke (cited by (Morgano, 1996) used the term *ferrule effect* to describe this 360° ring of cast metal and recommended extension of the definitive cast restoration at least 2mm apical to junction of the core and remaining tooth structure.

The introduction of all-ceramic crown restoration led to the development of posts which are white and/or translucent. Metal posts are visible through the more translucent all-ceramic restorations and even with less translucent restorations may cause the marginal gingiva to appear dark. Thus, posts made of zirconia and other ceramic materials were developed to fulfil these esthetic requirements (Schwartz and Robbins, 2004).

Carbon fiber reinforced posts gained popularity in the 1990s. Their main proposed advantage was that they were more flexible than metal posts and had approximately the same modulus of elasticity (stiffness) as dentin. When bonded in place with resin cement, it was thought that forces would be distributed more evenly in the root, resulting in fewer root fractures. Other types of fiber reinforced posts were also introduced, including quartz fiber, glass fiber and silicon fiber reinforced posts. They are claimed to offer the same advantages as the carbon fiber reinforced posts, but with better esthetics. Because they are newer, there is less research available on them than carbon fiber reinforced posts (Schwartz and Robbins, 2004).

Recently, single tooth implants are being proposed as an alternative to endodontic treatment. This issue is controversial, however Iqbal and Kim (2008) concluded that endodontic treatment of teeth represent a feasible, practical, and economical way to preserve function in a vast array of cases and that dental implants serve as a good alternative in selected indication in which the prognosis is poor.

1.2 Statement of Problem

Restoration of endodontically treated teeth using cast metal posts advocate the use of the ferrule effect to reduce the susceptibility of fracture of the remaining tooth structure. Even though few studies found that ferrule effect is important, however the importance of it is not clear with recent advancements like bonded titanium posts and fiber reinforced composite posts which using adhesive luting cements. The debate about which post material can sustain higher failure loads (thus, longer clinical service) and express more favourable failure modes (thus allow re-restoration) is also still unsolved in literature.

1.3 Justification of The Study

Nowadays, several newly developed bonded posts were available in the market. This study was done to help in better understanding the relationship between ferrule effect and titanium and fiber reinforced composite posts.

This may give dental clinicians an idea in selecting better treatment option, which at the same time may improve the prognosis of endodontic treatment, make it easier, less time consuming and also more cost effective.

The study could also provide manufacturers of dental materials with information which are necessary to develop new materials or improve the properties of those already existed.

Chapter 2

LITERATURE REVIEW

2.1 Endodontically Treated Teeth

Endodontics was defined by Walton and Torabinejad, (2002) as "That branch of dentistry concerned with the morphology, physiology, and pathology of the human dental pulp and periradicular tissues. Its study and practice encompass the basic and clinical sciences including biology of the normal pulp, the etiology, diagnoses, prevention, and treatment of diseases and injuries of the pulp and associated periradicular tissues."

Endodontic treatment was defined by Mosby's Medical Dictionary, (2009) as “that aspect of endodontics dealing with the treatment of diseases of the dental pulp, consisting of partial (pulpotomy) or complete (pulpectomy), extirpation of the diseased pulp, cleaning and sterilization of the empty root canal, enlarging and shaping of the canal to receive sealing material, and obturation of the canal with a non irritating hermetic sealing agent”.

Endodontically treated teeth eventually need to be restored, which may range from simple direct restoration to indirect crown restoration. They may also be utilized as abutments in fixed dental prosthesis or removable denture prosthesis. The physiological changes in endodontically treated teeth due to loss of vitality of dentine like dehydration and collagen fibres cross-linking changes may further complicate the restoration procedures, especially when posts are indicated (Gutmann, 1992).

2.2 Restoration of Endodontically Treated Teeth

Restorations of endodontically treated teeth aim to restore them into a healthy state biologically, functionally and esthetically by replacing the missing and protecting the remaining tooth structure from future diseases or fracture.

The final configuration of the restored endodontically treated tooth may include maximum of five components (Wagnild and Mueller, 2002)

1. The residual tooth structure and its attachment mechanism.
2. The apical endodontic seal.
3. The post.
4. The core.
5. The final coronal restoration.

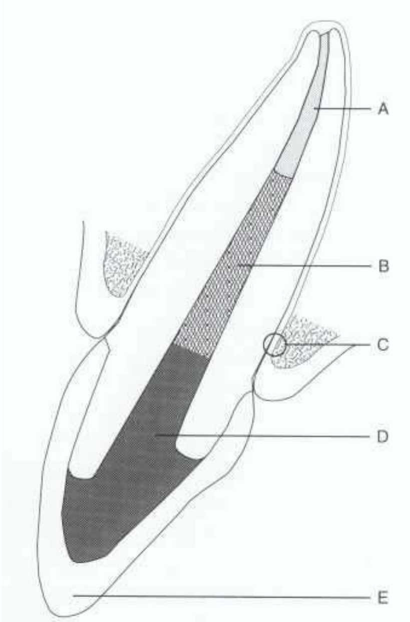

Figure 1: The final configuration of a restored endodontically treated tooth (A) The apical endodontic seal (B) The post (C) The residual tooth structure and its attachment mechanism (D) The core (E) The final coronal restoration (Wagnild and Mueller, 2002).

Anyway, not all endodontically treated teeth need post or crown. Some need only an access seal for the coronal restoration, others may need core and crown only, and some need all three components of post, core and crown.

2.2.1 The residual tooth structure and its attachment mechanism

Residual tooth structure is the factor mostly affects the treatment plan for restoration of endodontically treated teeth. It is also the factor that the clinician has less control over the other factors. Two aspects should be considered: the amount of residual tooth structure and the position of the tooth in the dental arch.

The loss of coronal tooth structure due to caries, trauma and previous dental procedures is the major contributor to the reduced strength observed in endodontically treated teeth when compared to healthy teeth. Access to pulp chamber and instrumentation of pulp canal also reduce the strength of endodontically treated teeth but to a lesser extent than loss of coronal tooth structure (Reeh *et al.*, 1989). Apically, the loss of vitality of the endodontically treated tooth also affects the composition of its dentine leading to dehydration and changes in collagen fibres cross-linking which further affecting the tooth strength (Gutmann, 1992).

Position of the tooth in the dental arch (incisor, canine, premolar and molar) also affects the treatment plan. The magnitude of occlusal forces is higher on posterior teeth than anterior teeth (Kohn, 2002). The direction of occlusal forces on posterior teeth is vertical while it is oblique on anterior teeth. The esthetic requirements for anterior teeth are usually more in consideration compared to posterior teeth.

The restoration of an endodontically treated tooth should be designed to preserve the tooth attachment mechanism of junctional epithelium and periodontal ligament. The restoration should not violate the biological width and a supragingival finishing line for crowns is preferable.

2.2.2 The apical endodontic seal

Proper endodontic treatment is important before placing the restoration. There should be no signs and symptoms such as active inflammation, exudate, fistula or sensitivity. If doubts remain, the tooth should be observed until there is evidence of success.

Endodontic sealing success will depend on the materials used and the technique applied. A study by Nixon *et al.* (1991) which compared the sealing capabilities of 3, 4, 5, 6, and 7mm of apical gutta-percha, found that the greatest leakage occurred when only 3mm of gutta-percha was retained. Therefore 4 to 5mm of gutta-percha should be retained apically when posts are needed to ensure an adequate seal. Information from literature search regarding resin-based root filling materials recommendation with posts is lacking.

Endodontic sealer can also affect restoration of endodontically treated teeth. The setting process of dental resins occurs by free-radical addition polymerization, and this process can be inhibited by phenolic compounds, such as eugenol (2-methoxy-4-allyphenol) (Morgano and Brackett, 1999). Thus eugenol free sealers are indicated when resin cements are planned to be used to bond the posts.

Vertical condensation technique of obturation is more convenient for the dentist than lateral condensation when posts are recommended; after the gutta percha is vertically condensed to 5mm apically the posts can be cemented, while in lateral condensation technique the root canal should be obturated completely and then the gutta percha is removed during post space preparation (Ingle *et al.*, 2002). Lateral condensation is also more likely to produce undesirable stress concentrations than is vertical condensation (Ingle *et al.*, 2002). However the effect of post preparation on the apical seal of endodontically treated teeth is not significantly affected by the obturation technique (De Nys *et al.*, 1989).

2.2.3 The post

Post is a relatively rigid restorative material placed in the root of an endodontically treated tooth that had suffered significant damage and has insufficient coronal tooth structure for retention of the core and the crown. The post itself does not strengthen the tooth; in fact the tooth may be weakened if dentin is sacrificed to place a large diameter post. Thus, the purpose of placing a post is to provide retention for the core and coronal restoration (Goodacre and Kan, 2002).

The indication of post placement in anterior teeth depends on the residual coronal tooth structure. In maxillary lateral incisors and mandibular incisors the remaining tooth structure is usually insufficient to retain and support the core and the crown, thus a post is needed. In maxillary central incisors and canines the crown preparation was done first and the remaining tooth structure is judged whether it could retain the core and the crown, otherwise the post will also be required (Robbins, 2001; Goodacre and Kan, 2002).

Posts are indicated in posterior teeth if the remaining coronal tooth structure does not provide adequate retention for the core and crown. When residual coronal tooth structure is adequate, other more conservative retention and resistance features (pulp chamber retention, amalgam pins and threaded pins) can be used to retain the core and the crown (Robbins, 2001).

Posts can be classified as either prefabricated or custom made (cast post and core). Posts also can be classified according to morphology as either parallel (cylindrical shape) or tapered (conical shape). Posts also can be classified according to their material such as metal, ceramic and fiber reinforced composite posts.

Prefabricated posts are versatile, can be used with direct restorative materials cores or cast metal cores, some have their own prefabricated cores. Technique simplicity is another advantage of using prefabricated posts. Metal prefabricated posts also have more suitable physical properties as compared to custom-made cast posts. Custom-made posts are used when the root canals have noncircular cross section or extreme taper, when the angle of the core in relation to the root must be altered, when a small tooth such as a mandibular incisor requires a post and core or when multiple post and core restorations are planned in the same arch (Robbins, 2001).

Parallel posts are more retentive than tapered ones and they seem to distribute stresses more evenly along their length thus less likely to cause root fractures (Goodacre and Kan, 2002) However, parallel posts require removal of more tooth structure than tapered ones and, therefore, may not be suitable for roots with thin walls. Tapered posts allow for minimal dentin removal since most roots themselves are tapered. Unfortunately, the stresses absorbed by these posts are concentrated in the apex, creating a wedging effect and increasing the risk of vertical root fracture (Goodacre and Kan, 2002).

2.2.4 The core

The core consists of restorative material placed in the coronal area of a tooth which replaces carious, fractured or otherwise missing coronal tooth structure and retains the final crown if indicated (Wagnild and Mueller, 2002).

Core material could be built by direct restorative material (dental amalgam, dental composite resin, glass ionomer) especially when prefabricated posts were indicated or as the sole restorative materials when crowns are not indicated. Core material could also be built from cast metal like the custom fabricated post and core.

Glass ionomer cements have natural colour, are easy to manipulate, biocompatible, corrosion resistance and release fluoride. However they have low fracture toughness which makes propagation of cracks more susceptible, limiting their use as core material to low stress situations (Robbins, 2001).

Composite resin as a core material has many advantages for example, ease of use and variability of curing methods (light-cure, autocure and dual-cure). Its tooth-coloured property makes it suitable to be used for both tooth-coloured (all ceramic, zirconia, indirect composite resin) and metal-based crowns. Mechanically, the composite resin has adequate fracture toughness and compressive strength under static loading, but performed poorly under dynamic loading (Robbins, 2001).

Dental amalgam as a core material has adequate strength both under static and dynamic loading and with custom cast cores, it is the material of choice in high stress situations (Robbins, 2001). However, all ceramic crowns may not be placed with amalgam cores for esthetic reasons.

2.2.5 The final coronal restoration

Coronal restorations is the component of the restoration that re-establish function and isolate the dentin and endodontic restorative materials from microleakage, they also distribute functional forces and protect the tooth against fracture. The crowns may also provide a ferrule effect when the crown margins are extended beyond the core to encircle the tooth structure (Wagnild and Mueller, 2002).

The indication of crowns is highly dependent on the amount of residual coronal dentine. Anterior teeth with favourable loading and largely intact coronal structures can be restored simply by direct restorative material placed in the access opening preparation. Crowns construction should be limited to situations in which esthetic and functional requirements cannot be adequately achieved by other more conservative restorations (Scurria *et al.*, 1995).

Endodontically treated posterior teeth are subject to greater loading than anterior teeth, have occlusal interdigitation with the opposing teeth that place expansive forces on the cusps which could lead to fracture. Therefore crowns should be placed on endodontically treated posterior teeth. However, in certain posterior teeth which do not have substantive occlusal interdigitation of a nature that attempts to separate the cusps, they can be restored with direct restorative material (Scurria *et al.*, 1995).

Crowns for restoration of endodontically treated teeth can be fabricated from either metal or ceramic. Cast metal ceramic crowns fulfill the requirements of coronal restorations of endodontically treated teeth and can be used with any type of post material. High strength all ceramic crowns are more esthetic than metal ceramic ones, but they need to be used with tooth coloured posts as carbon fiber reinforced posts and metal posts may shine through the ceramic crowns affecting their esthetic appearance.

2.3 The Ferrule Effect

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). 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 (Stankiewicz and Wilson, 2002). Ferrule effect was studied extensively in literature (Table 1), and many methodologies were used such as static loading, dynamic loading, stress simulation techniques, or clinical *in vivo* studies as mentioned below (Stankiewicz and Wilson, 2002).

Table 1: Summary of literature regarding the ferrule effect

The study	Method of testing	The ferrule effect
Tjan and Whang (1985)	Static loading	No significant improvement of fracture resistance
Barkhordar *et al.* (1989)	Static loading	Significantly improved fracture resistance
Loney *et al.* (1990)	Photoelastic models	Significantly improved stress distribution
Sorensen and Engelman (1990)	Static loading	No significant improvement of fracture resistance
Hemmings *et al.* (1991)	Static loading	Significantly improved fracture resistance

Table 1: Summary of literature regarding the ferrule effect (cont.)

The study	Method of testing	The ferrule effect
Milot and Stein (1992)	Static loading	Significantly improved fracture resistance
Libman and Nicholls (1995)	Dynamic loading	Significantly improved fracture resistance
Torbjorner *et al.* (1995)	Clinical trail	Significantly lower failure rate
Saupe *et al.* (1996)	Static loading	No significant improvement of fracture resistance
Isidor *et al.* (1999)	Dynamic loading	Significantly improved fracture resistance
Gegauff (2000)	Static loading	No significant improvement of fracture resistance
al-Hazaimeh and Gutteridge (2001)	Static loading	No significant improvement of fracture resistance
Pierrisnard *et al.* (2002)	Finite element analysis	Significantly improved stress distribution
Zhi-Yue and Yu-Xing (2003)	Static loading	Significantly improved fracture resistance
Akkayan (2004)	Static loading	Significantly improved fracture resistance
Tan *et al.* (2005)	Static loading	Significantly improved fracture resistance
Aykent *et al.* (2006)	Static loading	Significantly improved fracture resistance
Naumann *et al.* (2007)	Dynamic loading	Significantly improved fracture resistance
de Oliveira *et al.* (2008)	Static loading	No significant improvement of fracture resistance
Hinckfuss and Wilson (2008)	Static loading	Significantly improved fracture resistance
Al-Amro and Wilson (2009)	Dynamic loading	No significant improvement of fracture resistance
Dorriz *et al.* (2009)	Dynamic loading	Significantly improved fracture resistance
Eraslan *et al.* (2009)	Finite element analysis	Significantly improved stress distribution
Ma *et al.* (2009)	Dynamic loading	Significantly improved fracture resistance
Meng *et al.* (2009)	Static loading	No significant improvement of fracture resistance
Lima *et al.* (2010)	Static loading	Significantly improved fracture resistance
Mancebo *et al.* (2010)	Clinical trail	Significantly lower failure rate
Schmitter *et al.* (2010)	Finite element analysis	Significantly improved stress distribution

2.3.1 Ferrule effect evaluation using static loading

Multiple studies had used static loading to test ferrule effect, where an increasing load is applied to the test specimens at an identified direction and crosshead speed of the testing machine. The failure load of the specimens is recorded and can be used for comparison between different experimental groups. Failure mode sometimes can also be evaluated. Some of these studies found that ferrule effect improved the failure load significantly (Barkhordar *et al.*, 1989; Hemmings *et al.*, 1991; Milot and Stein, 1992; Zhi-Yue and Yu-Xing, 2003; Akkayan, 2004; Tan *et al.*, 2005; Pereira *et al.*, 2006) and other studies found no significant advantage for the ferrule effect (Tjan and Whang, 1985; Sorensen and Engelman, 1990; Saupe *et al.*, 1996; Gegauff, 2000; al-Hazaimeh and Gutteridge, 2001; Aykent *et al.*, 2006).

Brakhordar and colleagues (1989) compared the effect of a 2mm, 3° tapered metal ferrule on the strength of a cast post and core in endodontically treated anterior teeth to those with no ferrule effect. There was a statistically significant difference ($p < 0.05$) and the types of fractures in the metal ferrule group suggested that the teeth required a higher force to cause failure, while another study by Hemmings *et al.* (1991) investigated the resistance of various post and core designs to torsional forces. All the antirotational features tested such as keyway form, coronal flare form, auxiliary pin form, and cervical collar form (Figure 2) elevated resistance to torque. The cervical collar was the most favourable design embracing resistance and reducing tooth fractures.

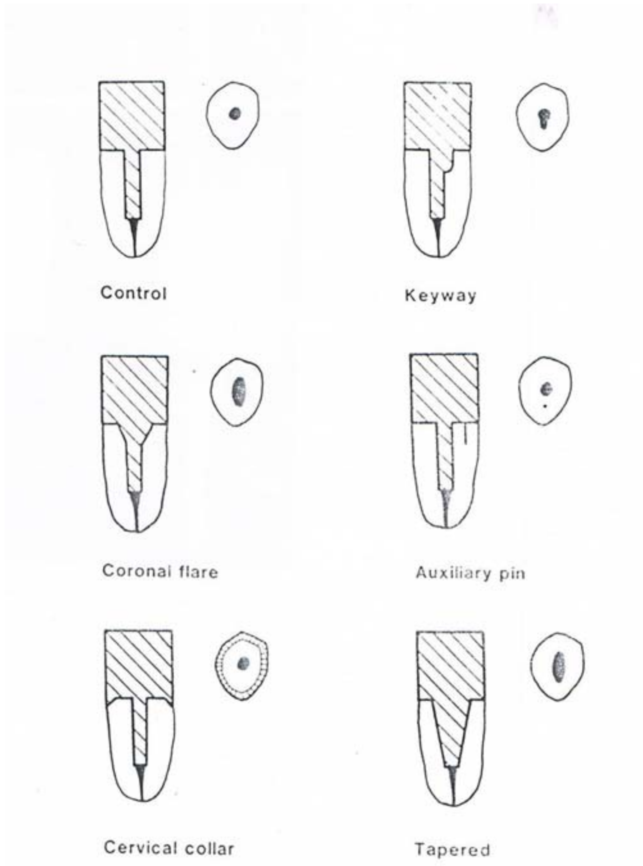

Figure 2: Study groups of Hemmings *et al.* (1991)

Not only extracted teeth were used in the evaluation of the ferrule effect, but standardized plastic analogues simulating an endodontically treated maxillary central incisor root were also used to investigate the resistance to root fracture in endodontically treated teeth. This study showed that beveled preparations with a concomitant final restoration provided a significant increased resistance to root fracture. Furthermore, vertical fracture occurred twice as often with non-beveled preparations (Milot and Stein, 1992).

Zhi-Yue and Yu-Xing (2003) did an *in vitro* study of the effects of post-core design and ferrule on the fracture resistance of root canal treated human maxillary central incisors restored with metal ceramic crowns. Not all of the post-core structures tested improved the strength of the endodontically treated teeth. Those prepared with a 2mm dentin ferrule more effectively enhanced the fracture strength of restoration with custom cast post-core of endodontically treated maxillary central incisors.

Akkayan (2004) compared the effect of three different ferrule lengths on the fracture resistance and fracture patterns of crowned endodontically treated teeth restored with four different esthetic dowel systems. Teeth prepared with 2mm ferrules demonstrated significantly higher fracture thresholds for all four dowel systems when compared to teeth prepared with a 1mm ferrule length. Increasing the ferrule length of the endodontically treated teeth from 1mm to 1.5mm in specimens restored with quartz fiber and glass fiber dowels did not produce significant increases in the failure loads. There was no significant difference in fracture resistance detected between glass fiber and glass fiber plus zirconia dowels with 1.5mm and 2mm ferrules. There were also no significant differences in fracture patterns between the four dowel systems.

Tan *et al.* (2005) investigated the resistance to static loading of endodontically treated teeth with uniform and nonuniform ferrule configurations. The results demonstrated that central incisors restored with cast dowel/core and crowns with a 2mm uniform ferrule were significantly more resistant to fracture compared to central incisors with non-uniform (0.5 to 2mm) ferrule heights. Both the 2mm ferrule and non-uniform ferrule groups were more fracture resistant than the group that lack of ferrule.

Another study compared the fracture strengths of endodontically treated teeth using posts and cores and variable quantities of coronal dentin located apical to core foundations with corresponding ferrule designs incorporated into cast restorations. This study showed that an increase amount of coronal dentin significantly increases the fracture resistance of endodontically treated teeth (Pereira *et al.*, 2006).

Hinckfuss and Wilson (2008) evaluated the fracture resistance of bovine teeth restored with one-piece cast core/crowns and no ferrule, compared to teeth restored with amalgam cores and full coverage crowns, with and without a dentine ferrule. The study found that the maximum load resistance was significantly enhanced by a 2mm ferrule compared with teeth with no ferrule and teeth restored with one-piece cast core/crowns. Teeth restored with one-piece cast core/crowns were significantly more resistant to loading than teeth restored with amalgam cores and crowns without a ferrule (Hinckfuss and Wilson, 2008).

A recent study by Lima and colleagues (2010) evaluating the effect of ferrule preparation on the fracture resistance of endodontically treated teeth, restored with composite resin cores with or without glass fiber posts, found that the ferrule preparation increased the fracture resistance of endodontically treated teeth. However, the use of glass fiber post showed no significant influence on the fracture resistance.

Not all studies found a significant advantage for the ferrule effect. The earliest study to investigate the ferrule effect using static loading was done by Tjan and Whang in 1985. The purposes of this study were to compare the resistance to fracture under horizontal force and the failure characteristics of dowel channels on maxillary central incisors with various thickness of remaining buccal dentin and to study the effect of a metal collar on the resistance of roots to fracture. No statistically significant differences have been found among the means of failure load and the addition of a metal collar did not enhance the resistance to root fracture.

Sorensen and Engelman (1990) examined the effect of various ferrule designs and amounts of coronal tooth structure (Figure 3) on fracture resistance of endodontically treated anterior teeth. The study concluded that one millimeter of coronal tooth structure above the crown margin substantially increased the fracture resistance of endodontically treated teeth, whereas a contrabevel at either the tooth core junction or the crown margin was ineffective measure.

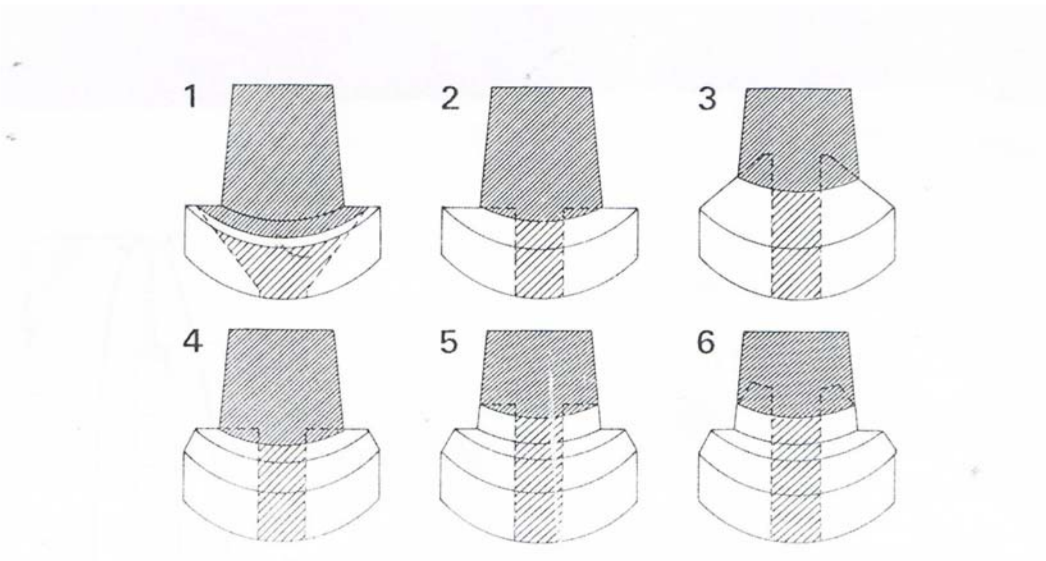

Figure 3: Study groups of Sorensen and Engelman (1990), Group 1: 90° shoulder and no coronal dentinal extension and 1mm of axial tooth structure at the shoulder, Group 2: 90° shoulder and no coronal dentinal extension, Group 3: 130° sloped shoulder, Group 4: 90° shoulder and a 1mm wide 60° bevel finish line with no coronal dentinal extension, Group 5: 90° shoulder and a 1mm wide 60° bevel finish line with 1mm coronal dentinal extension, Group 6: 90° shoulder and a 1mm wide 60° bevel finish line with 2mm coronal dentinal extension and contrabevel at tooth-core junction.

A study to determine the combined effect of crown lengthening and placement of a ferrule on the failure resistance to static load of mandibular second premolar analog teeth found that the combination resulted in a reduction of static failure load (Gegauff, 2000).

Another study by Meng *et al.* (2009) also evaluated the effect of ferrule preparation length on the fracture resistance after simulated surgical crown lengthening and forced tooth eruption of endodontically treated teeth restored with a carbon fiber reinforced post and core system. The study found that increased apical ferrule preparation lengths resulted in significantly increased fracture resistance for simulated forced tooth eruption, but not for simulated crown lengthening.

While investigating the validity of intraradicular reinforcement, Saupe and colleagues. concluded that when a bonded resin reinforcement and dowel cementation was used on structurally weakened roots, there was no statistically significant difference between post and core restorations that used a ferrule and those without ferrule (Saupe *et al.*, 1996).

The value of the ferrule preparation with prefabricated post and cores utilizing composite resin cement and core materials were further investigated by Alhazaimeh and Gutteridge in 2001. This *in vitro* study investigated the effect of a ferrule preparation on the fracture resistance of crowned central incisors incorporating a prefabricated post (Parapost) cemented with Panavia-Ex and with a composite resin core. The additional use of a ferrule preparation on a crowned tooth incorporating a prefabricated post and composite resin core restoration provided no statistically significant improvement in the fracture resistance.

Aykent *et al.* (2006) evaluated the effects of two dentin bonding agents and a ferrule preparation on the fracture resistance of crowned mandibular premolars incorporating prefabricated dowel and silver amalgam cores. The study found that a ferrule preparation or a bonding agent designed for silver amalgam core–dentin bonding can each increase the fracture strength for teeth receiving cast crowns after endodontic therapy and dowel and amalgam core restorations. The presence of 1mm of coronal dentin above the shoulder significantly increased the fracture strength of teeth restored with a prefabricated post and amalgam core. If a tooth has lost all coronal structure and a ferrule preparation cannot be created, the use of one of the dentin bonding agents tested (Superbond D-Liner and Panavia F) with a silver amalgam core may be used as an alternative to increase the fracture strength of crowned teeth and the success of the restoration.

Oliveira and colleagues (2008) evaluated the fracture resistance of endodontically treated teeth restored with prefabricated carbon fiber posts and varying quantities of coronal dentin. The study results suggested that the amount of coronal dentin did not significantly increase the fracture resistance of endodontically treated teeth restored with prefabricated carbon fiber post and composite resin core.

2.3.2 Ferrule effect evaluation using dynamic loading

Some studies investigated ferrule effect using dynamic loading by assuming it more simulating the clinical situation. In these studies, a constant load is applied to the test specimens until failure and the number of load cycles is recorded and used to compare between experimental groups. The dynamic loading is expensive and time consuming. The results concluded from these studies do not differ much from those using static loading.

The first study using dynamic loading to evaluate ferrule effect was done by Libman and Nicholls in 1995. This research investigated maxillary central incisors restored with cast posts and cores and complete cast crowns with four different ferrule lengths of 0.5mm, 1mm, 1.5mm and 2mm. The results of this study showed that the 0.5mm and 1mm ferrule lengths failed at significantly lower number of cycles than the 1.5mm and 2mm ferrule lengths and control teeth.

Isidor *et al.* (1999) evaluated the influence of post and ferrule length on the resistance to cyclic (fatigue) loading of teeth with prefabricated titanium posts (ParaPost, Coltene Whaledent, USA) and crowns. The result found that ferrule length was more important than post length in increasing fracture resistance to cyclic loading of crowned teeth.

Another study had used a combination of dynamic and static loading during investigation of the influence of the rigidity of different post materials (titanium versus glass fiber reinforced composite) on the fracture resistance of endodontically treated teeth. They found that fracture resistance of endodontically treated teeth is not influenced by the rigidity of the post material. The combination of ferrule preparation and endodontic post results in higher load resistance after thermomechanical loading than any other build-up design (Naumann *et al.*, 2007).

Ma and friends studied the failure of the crown cement for an all-ceramic crown cemented with resin cement using different ferrule lengths. Teeth with a 0.5mm and 1.0mm ferrule lengths showed a significant increase in the number of fatigue cycles over the teeth without the ferrule preparation (Ma *et al.*, 2009).

Some studies were not supportive of the ferrule effect; recently Al-Amro and Wilson (2009) carried out a study on the effect of a ferrule on the strength and fracture resistance of bovine teeth and found that fracture resistance was not enhanced by 2mm ferrule height.

Another study compared the fracture resistance of endodontically treated teeth restored with different post and core systems in combination with complete metal crowns in teeth with no coronal structure. The researchers found that bonding cast posts to the tooth structure has a significant effect on compensating for the lack of a ferrule on endodontically treated teeth, and concluded that either a ferrule preparation or bonding with the use of an opaque porcelain layer can increase the fracture resistance of teeth with little remaining tooth structure that are restored with cast crowns following endodontic therapy (Dorriz *et al.*, 2009).

2.3.3 Ferrule effect evaluation using stress simulation techniques

Photoelastic models and finite element analysis were used by some researchers to investigate stress concentration areas within the complex structure of endodontically treated teeth.

The effect of a metal collar on stress distribution with cast post and cores was studied by using three dimensional photoelastic models of maxillary canine teeth of average dimensions. It appeared that the collar had a slight, but significant effect on stress distribution. This finding might validate the concept that a ferrule helps to unite different portions of the tooth (Loney *et al.*, 1990).

In 2002, Pierrisnard studied the effect of different corono-radicular reconstruction methods on stress transmission to dental tissues. The study software performed stress analysis of complex structures by finite element analysis. The absence of a cervical ferrule was found to be a determining negative factor, giving rise to considerably higher stress levels. When no ferrule was present, the Ni-Cr post/ composite resin core combination generated greater cervical stress than cast post and cores. Nevertheless, the peripheral ferrule seemed to cancel the mechanical effect of the reconstruction material on the intensity of the stresses. With a ferrule, the choice of reconstruction material had no impact on the level of cervical stress (Pierrisnard *et al.*, 2002).

In another study also using the finite element stress analysis method, the effect of ferrule with different post materials on the stress distribution of dentin and the restoration-tooth complex were compared. The stress values observed with the use of a 2mm ferrule were lower than with no ferrule design for both the glass fiber-reinforced and zirconium oxide ceramic post systems. The stress values observed with zirconium oxide ceramic were higher than that of glass fiber-reinforced post system (Eraslan *et al.*, 2009).

Results of a recent study that combines the advantages of an *in vitro* tests and finite element analysis (FEA) by Schmitter found that increased ferrule height and resin bonding of the crown resulted in significantly higher fracture loads. FEA confirmed these results and provided information about stress and force distribution within the restoration. Based on the findings of an *in vitro* tests and computations the authors concluded that crowns, especially those with a small ferrule height, should be resin bonded (Schmitter *et al.*, 2010)

2.3.4 Ferrule effect evaluation using clinical *in vivo* studies

Few clinical studies were conducted exclusively to investigate the ferrule effect, one study noted that all post fractures showed a similar pattern of a lack of ferrule effect of the metal collar at the crown margin area and a sharp interface between post and core (Torbjorner *et al.*, 1995).

In a recent three year clinical trial investigating the effect of tooth type and ferrule on the survival of pulpless teeth restored with fiber posts, results showed a statistically significant lower failure rate in teeth with ferrule compared to teeth without ferrule (Mancebo *et al.*, 2010).

2.4 Post Material

Post material could be categorized into three categories which are metallic, ceramic and fiber reinforced composites. In the previous two decades all posts were metallic, either from precious alloy, semi precious alloy, nickel chrome, titanium, titanium alloy or stainless steel. Ceramic posts were introduced in the late 80’s as the need for new esthetic post which is compatible with all ceramic crowns emerged. They were