The Effect of Ferrule Designs on the Fracture Resistance of Endodontically Treated Premolars

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Abstract

This study evaluated the effect of different ferrule designs on fracture resistances and failure modes of endodontically treated mandibular premolars restored with post-core and crown. Fifty mandibular premolars were randomly divided into five groups (n=10). Group 1 had a 2 mm circumferential ferrule. Group 2 had a 2 mm ferrule on the buccal side. Group 3 teeth had a 2 mm ferrule on the lingual side. Group 3 had a 2 mm ferrule on the mesial side. Group 5 had a 2 mm ferrule on the distal side. All the teeth were endodontically treated and restored with fibre posts and composite core build up followed by non-precious metal crowns. A compressive load at a crosshead speed of 0.5 mm/min, 25° to the long axis of the tooth and 2 mm from the central fossa towards the buccal cusps was applied. Failure loads and modes were recorded. Group 3 has significantly higher fracture resistance than group 2. The mean fracture resistances were not statistically significant among the rest of the groups. There was no significant association between ferrule designs and failure mode. In conclusion, Teeth with lingual ferrule alone have better fracture resistance compared to those with buccal ferrule alone.

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Introduction

Endodontically treated teeth are generally weaker and prone to fracture compared to teeth that have not been root-filled. This is mainly due to substantial loss of tooth structure from previous caries, pre-existing restorations and/or endodontic treatment.[1] It has been suggested that the fracture resistance of endodontically treated teeth is directly related to the remaining tooth structure. [2]

In cases of severe hard tissue loss of endodontically treated teeth, restoring such teeth is usually performed by utilizing a post and core system in order to prevent further destruction and to provide the necessary retention and resistance before the placement of a crown or a fixed partial denture. [3, 4]

Cast posts and cores have been used to restore teeth. Nowadays a fabricated fibre reinforced post in combination with a composite core has become the most popular approach. [5] In general, posts made of metal alloys resist greater forces compared to posts of other types.[6] However, the potential danger in using these posts is increased risk of non-restorable failures.[7, 8] On the other hand, fibre reinforced posts show favourable biomechanical properties, stress distributions, and fracture resistances when compared with metal posts.[7, 9] Therefore, their clinical failure rates were also found to be lower.[10] A study reported a success rate of around 95% using fibre reinforced posts to restore endodontically treated teeth. [11]

A preserving radicular tooth structure has been shown to increase the fracture resistance of restored teeth. [12] Researchers also reported that the greater the amount of preserved radicular tooth structure, the better the fracture resistance of a tooth. Therefore, preserving as much as possible of the remaining tooth structure is an essential element to reduce root fractures. [13, 14, 15]

A ferrule is defined as the vertical band of tooth structure at the gingival aspect of the crown preparation. The ferrule effect is described as a 360° metal crown collar apical to the core, and it

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provides resistance to root fracture.[16] Therefore, preserving an adequate dentine above the cement enamel junction (ferrule) height is a critical factor in enhancing the fracture resistance of post restored teeth.[17] Ferrules provide the advantage of load redistribution to the dentine collar that surrounds the coronal portion of the post instead of concentrating it on the post and core.[18]

The ferrule length of 2.0 mm or more showed significantly higher fracture resistance than that of 1.0 or 1.5 mm of fibre or ceramic posts restored teeth.[19, 20] However, a 2 mm circumferential ferrule is difficult to achieve clinically. Therefore, in cases of severe hard tissue damage, using different ferrule designs is beneficial. The aim of this in-vitro study was to compare severely compromised endodontically treated mandibular premolars restored with post-core and crown and the effect of different ferrule designs on fracture resistances and failure modes.

Materials and methods

Specimen preparation: Freshly extracted mandibular lower premolars were selected and stored in a 0.1% chloramine solution for one week. Teeth with previous endodontic treatment and those with large carious lesions and fracture lines in the roots were excluded in the study. An ultrasonic scaler (Peizon® Master 400, Switzerland) was used to remove soft tissues, calculus and necrotic debris from the teeth. The samples were stored in normal saline at 37°C to prevent dehydration before and during the experimental procedures. Teeth dimensions were measured using a digital calliper (Mitutoyo, Tokyo, Japan); teeth with a tooth length of 21.5±1mm, root length of 14±1mm, buccolingual width of 8±1mm and mesiodistal width of 6±1mm were selected. Pre-operative radiographs were then taken to exclude teeth with two canals and teeth with internal resorption. Sixty teeth were selected for the study samples. The teeth were randomly and equally divided into six groups.

One group of sound teeth was used as control and received no restoration. Each tooth was decoronated 16 mm from the apex of the root towards the crown by means of a horizontal cut; the cutting was perpendicular to the long axis of the root. All root canals of the specimens were prepared using the step-back technique with K-files (Dentsply/Maillefer, Switzerland). The master apical file used was size 40. The canals were repeatedly irrigated with 3.0 ml of a 1% sodium hypochlorite solution (NaOCl) (Clorox (M) Industries Sdn Bhd, Malaysia) after each filing. The teeth were obturated with gutta-percha cones (Dentsply/Maillefer, Switzerland) using the lateral condensation technique and a resin-based canal sealer (AH-plus Dentsply).

Post space preparation:

Gates-Glidden drills sizes 1 and 2 (Dentsply/Maillefer, Switzerland) were used to further removed gutta percha to 2/3 root length (10 mm), leaving 5 mm of gutta percha apically. A matching drill (size 1) of (RelyX Fibre Post, 3M ESPE, US) was used to complete dowel space preparation. For tooth mounting, a thin layer of light-body silicone-based impression material (Aquasil Ultra XLV Dentsply) was applied around the root surface to simulate the periodontal ligament. Each tooth was embedded in cold-cure epoxy resin (Mirapox 950-230 A and B, Miracon Sdn Bhd, Kuala Lumpur, Malaysia) using a silicone mould, leaving 2 mm of root surface exposed to simulate the biological width.

Ferrule designs preparation:

Group 1: 2 mm circumferential all the teeth.
Group 2: 2 mm ferrule only on the buccal side.
Group 3: 2 mm ferrule only on the lingual side.
Group 4: 2 mm ferrule only on the mesial side.
Group 5: 2 mm ferrule only on the distal side.

Post cementations:

Before post cementation, the root canals were flushed with 1% sodium hypochlorite. Then, the canals were promptly rinsed with distilled water and dried with paper points (Dentsply/Maillefer, Switzerland). Each post was cemented with self-adhesive resin cement (RelyX™ Unicem, 3M/ESPE) and immediately seated into the cement-filled canal using moderate finger pressure for five minutes to allow the cement to auto-polymerize. Then, a light cure was applied for 40 seconds to complete the setting of the cement.

Core build up:

A matrix band was placed around each tooth to ease the core build up procedure. The composite resin was applied into the matrix to form the core until the desired height of 5 mm from the cemento-enamel junction level covering the coronal end of the post was achieved. The occlusal surface was light-cured for 40 seconds. The matrix band was then removed and an additional 40 seconds of polymerization was subsequently performed on the surfaces around the core to ensure complete setting of the core material.

For crown preparation and cementation, each specimen was prepared to receive a metal crown. In order to standardize the preparation convergence angle, a diamond bur (998FG021 round ended, tapered with guide pin, NTI-Kahla GmBH, Germany) was attached to a high-speed rotary hand piece, which was fixed to a paralleling device (custom-made at the Engineering Department, University of Malaya). A guide pin at the tip of the bur produced a standardized depth of the chamfer margin of 1 mm. By using a digital calliper (Mitutoyo, Tokyo, Japan), the core height of 6 mm from CEJ was marked. Occlusal reduction was done using a high-speed diamond bur (S811-314-037-7-ML, SwissTec, Switzerland) until the marking line. A one step impression technique was used to take the impression of the preparation specimens using Impregum soft polyether (3M/ESPE). The crowns were fabricated using a non-precious alloy. The axial and occlusal thicknesses of the crowns were standardized to 1 mm and 2 mm respectively using a crown calliper and tungsten carbide burs. A small indentation measuring 3 mm diameter and 1 mm depth was made on the buccal cusp 2 mm from the central fossa of each crown. The crowns were cemented using self-adhesive resin cement (Rely XU 200 3M/ESPE).

Testing procedure:

Each specimen in the resin block was fixed in a customized metal holder in a testing machine (Shimadzu, Autograph, Japan) 25° to the crown. Compressive load was applied using a stainless steel 3 mm diameter round ended loading rod at a crosshead speed of 0.5 mm/min. The load was applied on the buccal cusp 2 mm from the tip of the cusp towards the central fossa. The compressive load was applied until fracture occurred (Figure 1). The fracture pattern of each specimen was recorded. The fracture mode was classified into either restorable or unrestorable. The restorable fracture mode was considered to occur by complete or partial post and core debonding or post-core-tooth complex fracture above the epoxy resin level. The unrestorable fracture mode displayed fracture of the post/core/root below the epoxy resin, vertical root fracture or cracks below the epoxy resin level. The data were analysed using Statistical Package of the Social Sciences (SPSS) Version 12. One-way analysis of variance (ANOVA) was employed to compare the mean fracture loads of the groups as well as the failure modes.

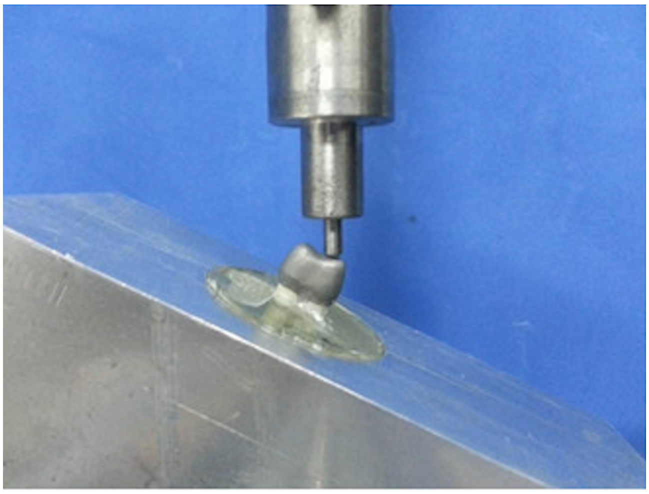

Figure 1. Positioning of a specimen in the universal testing machine for static loading.

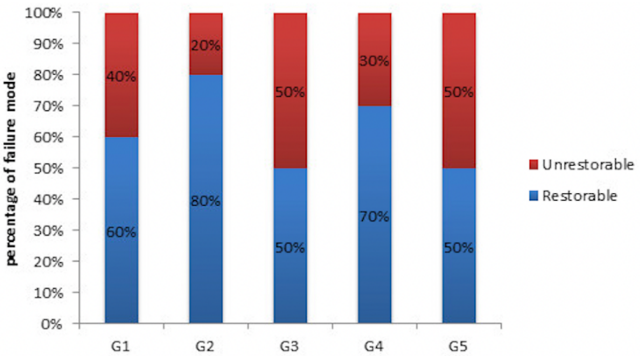

Figure 2. Percentage of Restorable and unrestorable failure modes for all groups.

Results

Shapiro-Wilk test showed the data were normally distributed ($P>0.05$). The means of failure loads of each group are presented in Table 1. The ANOVA test showed significant differences exist among the different groups ($p = 0.003$). The post-hoc multiple pairwise comparisons revealed that group 3 produced significantly higher fracture resistance compared to group 2 ($p = 0.001$).

Table 2 presented the detailed distribution of failure modes for all the specimens. Series of Fisher's exact tests showed different ferrule designs were not significantly associated with failure mode ($p>0.05$). The percentage of specimens with restorable and unrestorable failure modes for each group are presented in Figure 2. Group 3 had a 90% specimens with restorable failure mode followed by 70% for group 1, 60 % for group 5 and 50% for both group 2 and group 4.

Different ferrule designs	n	Mean Failure Loads (N) ± (SD)	F-statistic[a] (df)	*P* value
Group 1	10	591.3 (149.7)		
Group 2[a]	10	472.9 (101.4)		
Group 3[a]	10	723.5 (181.3)	4.7(4)	0.003*
Group 4	10	598.1 (96.4)		
Group 5	10	559.1 (129.5)		

Table 1. (a) indicated significant difference between groups using Tukey post-hoc test.
* Significant value was set at $p < 0.05$

	Failure mode	G1	G2	G3	G4	G5
Restorable failure	Complete post and core debonding			1		
	Partial post and core debonding	5	3	3	1	2
	Post-core-tooth complex fracture above the epoxy resin level	2	2	3	4	4
Unrestorable failure	Fracture of the post/core/root below the epoxy resin	2	3			2
	Cracks below the epoxy resin level		1	3	4	
	Vertical root fractures	1	1		1	2

Table 2. The distribution of failure modes among the groups.

Discussion

The main challenge of using human teeth is the difficulty to obtain standardization due to variations in physical and mechanical properties, the morphology of the pulp, the ageing of the teeth and the presence of micro cracks in the dentine.[5,21] To standardize the specimens, teeth dimensions were measured using a digital calliper (Mitutoyo, Tokyo, Japan).

In the present study, a 5 mm length of gutta percha was preserved apically to imitate the true clinical situation. Studies showed that an apical seal could still be achieved if 4 to 5 mm gutta percha remained apically.[22, 23]

There are various post and core systems. The two basic types are a metal post and core that is custom cast as a single piece and a two element design, which includes a prefabricated post cemented into a root canal followed by an amalgam or composite core.[24] A prefabricated fibre post and direct resin composite as the core is one of the treatment options for management of moderately to severely compromised endodontically treated teeth. [25]

Prefabricated fibre posts and composite resin cores were chosen due to their increasing popularity among clinicians, especially when restoring teeth in the aesthetic zone. The procedure can be done in one visit and the structure can be bonded to dentine using resin cements forming the so-called monobloc. This monobloc form helps the whole assembly to act as a single compound entity that will flex slightly with the tooth structure under load [26], thus facilitating a restorable stress distribution to the root structure and consequently reducing the possibility of unrestorable root fractures.[27, 28, 29] Freedman and Pegoretti et al. found that composite core buildup, resin luting agents and fibre reinforced composite posts can be used to achieve this monobloc assembly. [27, 30]

The 10 mm post length is approximately equal to two thirds of the root length. This has been recommended by several studies [31, 32] and increases the retention and resistance of the post. In the present study, the load was applied in the buccal cusp 2 mm from the central fossa using a 3 mm round end rod as suggested in other studies.[33, 34] The force was loaded on the buccal cusp 25° to the long axis of the tooth to simulate a worst-case scenario with the presence of non-working side interference.[34]

The results of this study demonstrated that the fracture resistances of these teeth were similar to the control group regardless of the design of the ferrule. However, the lingual ferrule alone has significantly better fracture resistance compared to that of the buccal ferrule alone.

Researchers studied the effects of four types of ferrule design on mean fracture resistance using central incisor teeth. They showed that mean fracture resistance was greater in the group which had a facial ferrule than it was in other groups when force was applied on the palatal side. [35, 36] In the present study, the force was applied towards the buccal cusp of the lower premolars, and the results showed that the buccal ferrule demonstrated the lowest fracture resistance. This is comparable with the study by Izadi et al.,[36] which found that the lowest fracture resistance was demonstrated by the group with a ferrule on the opposite side of the direction of the force. Although group 3 has the highest mean fracture resistance, there was no significant difference among groups 1,3, 4 and 5 and this is in accordance with results of other studies. [37,38]

The failure mode for every intra radicular restorative technique should be taken into consideration when evaluating fracture resistance.[7] The present study showed that majority of the specimens in all the groups had restorable failure mode (70–80%). This could be attributed to use of fibre posts and composites core systems that have the same modulus of elasticity as those of dentine that may result in a mechanically homogenous unit with superior biomechanical performance.[28]

Similarly, Salameh et al. reported that fibre posts improved the fracture mode. Their results demonstrated that the percentage of restorable fractures in teeth restored with fibre posts was 93%.[39] Sterzenbach et al. concluded that, in cases of severely compromised teeth with two or fewer remaining cavity walls and a 2 mm ferrule, teeth restored with self-adhesive luted prefabricated posts achieve a high long-term survival rate irrespective of the post material and its rigidity. [40]

Conclusions

Under the limitations of this in-vitro study:

1. Teeth with half surface ferrule demonstrated comparable fracture resistance to those with a circumferential ferrule.
2. The ferrule in the surface opposite to the applied force could enhance the mean fracture resistance compared to that of the circumferential or ferrule at the same surfaces of applied force.

Declaration of Interest

All authors have no conflict of interest

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