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Effects of Auxiliary Fiber Posts on Endodontically Treated Teeth With Flared Canals

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Clinical Relevance

Macro-Lock post combined with auxiliary fiber posts could increase the fracture resistance of endodontically treated roots with over-flared canals. However, an effect of the auxiliary fibers on retention strength was not observed.

SUMMARY

This study investigated the fracture resistance and retention of endodontically treated roots with over-flared canals restored with different post systems, including one cast metal post and four fiber posts with/without auxiliary fiber posts. One hundred endodontically treated incisor roots were experimentally flared using a tapered diamond bur. The roots were restored using one of the five post systems: Ni-Cr cast metal post (CM), D.T. Light glass fiber post (DT), Macro-Lock glass fiber post (ML), ML+2 Fibercone auxiliary fiber posts (2FC), and ML+5 Fibercone auxiliary fiber posts (5FC). After fabrication of the crowns, half of the specimens (n=50) were subjected to a fracture failure test—loading with an incremental static force at an angle of 45 degrees to the long axis of the root. The other 50 samples underwent a pull-out test. Fracture failure strength and pull-out strength were measured and analyzed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test (α=0.05). After the tests were completed, all specimens displayed oblique root fractures or cracks, initiating from the palatal cervical margin and propagating in a labial-apical direction. The order of the fracture failure strength was as follows: 5FC=CM=2FC>ML>DT. Cast metal posts demonstrated the highest pull-out strength ($p<0.05$). No significant differences in pull-out strength were found in the ML, 2FC, and 5FC groups. Within the limitations of this study, it was concluded

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that the application of an auxiliary fiber post could significantly increase the fracture resistance of over-flared roots; however, no beneficial effects in enhancing retention were observed.

INTRODUCTION

The restorations of endodontically treated teeth commonly present a challenge to dentists, especially in cases of extensive crown-root destruction.[1,2] This situation occurs with significant loss of coronal tooth structure, fractures, or over-prepared root canals for previous post-retained restorations.[3] Excessive root canal flaring can result in a weak root canal wall and an insufficiently retentive morphology for a post.[4]

Cast metal posts have been used traditionally in these situations to provide necessary retention for the subsequent restoration.[3,5,6] However, these metallic posts have been considered to have biomechanical disadvantages, such as high modulus of elasticity and root fracture potentiality.[7-9] Recently, application of fiber-reinforced composite (FRC) posts in endodontically treated teeth has increased in popularity because of their purported favorable biomechanical properties,[10,11] esthetic appeal, easier removal for endodontic retreatment, and single visit placement.[12] Based on theoretical considerations and finite element analyses, FRC posts are more flexible than cast metal posts and allow better distribution of forces, resulting in fewer root fractures.[10,13] Clinical studies have reported a success rate of 95% to 99% for teeth restored with FRC posts, with no occurrence of root fracture during the study periods.[14,15] However, controversial conclusions were reported by some *in vivo* and *in vitro* studies. Some authors have indicated that the fracture resistance of teeth restored with FRC posts is equal to or greater than that of teeth restored with metal posts.[16,17] Other authors have reported that endodontically treated teeth restored with fiber posts showed decreased fracture resistance compared with teeth restored with metal posts.[18,19] It has been suggested that the inconsistency in these outcomes might be related to factors related to the amount of remaining healthy tooth structure,[20,21] as well as to characteristics of the post, such as material composition,[22] modulus of elasticity,[23] diameter,[24] and length.[25] Therefore, for roots with extreme crown-root destruction, the fracture susceptibility of different post systems needs to be further investigated.

Despite these somewhat conflicting findings, *in vitro*[26,27] and *in vivo*[28-30] studies showed that the most common cause of post-core restoration failure was not the fracture, but rather the pull-out of the cement-post-restoration assembly. Debonding occurred between post-cement and/or cement-root canal dentin interfaces as a result of inadequate bonding strength.

Specialized drills accompanying the FRC post systems are developed to improve the adaptation of the posts to the root canals. Nevertheless, the prefabricated FRC posts could not ideally match the root canal in full work length, especially in cases of excessive root canal flaring, thus resulting in a large, conical, and insufficiently retentive post.[4,31,32] In these cases, high bonding strength and adequate retention are indispensable when FRC posts are applied.[33] Recently, a new product, Fibercone (RTD Inc, St Egreve, France), was introduced in dentistry. It was developed as an auxiliary post simultaneously applied with a "master" post. Generally speaking, the auxiliary posts could increase the adaptation of FRC posts in cases of flared or oval canals, thus minimizing polymerization shrinkage and preventing decementation.

However, no consensus is evident in the literature about the feasibility of using fiber posts to restore over-flared root canals. And no scientific data are available related to the clinical application of auxiliary fiber posts. Therefore, the purpose of this study was to evaluate the effects of different post systems, including the application of accessory fiber posts, on restoring over-flared roots. The null hypothesis was that fracture resistance and retention do not vary as a function of the post system.

MATERIALS AND METHODS

The study protocol was reviewed and approved by the Ethics Committee of the School and Hospital of Stomatology, Wuhan University. One hundred sound human maxillary central incisors, extracted for periodontal reasons, were involved in this study. Patients who donated their teeth were informed of the purposes of the research, and written informed consents were obtained prior to teeth extraction. Dental plaque, calculus, and periodontal tissues were removed, and teeth were stored in 0.9% saline solution at 37°C. The teeth were examined using a microstereomicroscope (Stemi SV11 Apo, Carl Zeiss Micro Imaging Inc, Thornwood, NY, USA) at 6× magnification to verify the absence of caries and cracks. And canal morphology was verified from standardized periapical radiographs. Teeth with large root canals or roots with apex dilacerations, fissures, or surface defects were excluded. To verify the mean dimensions of the teeth, root lengths (from

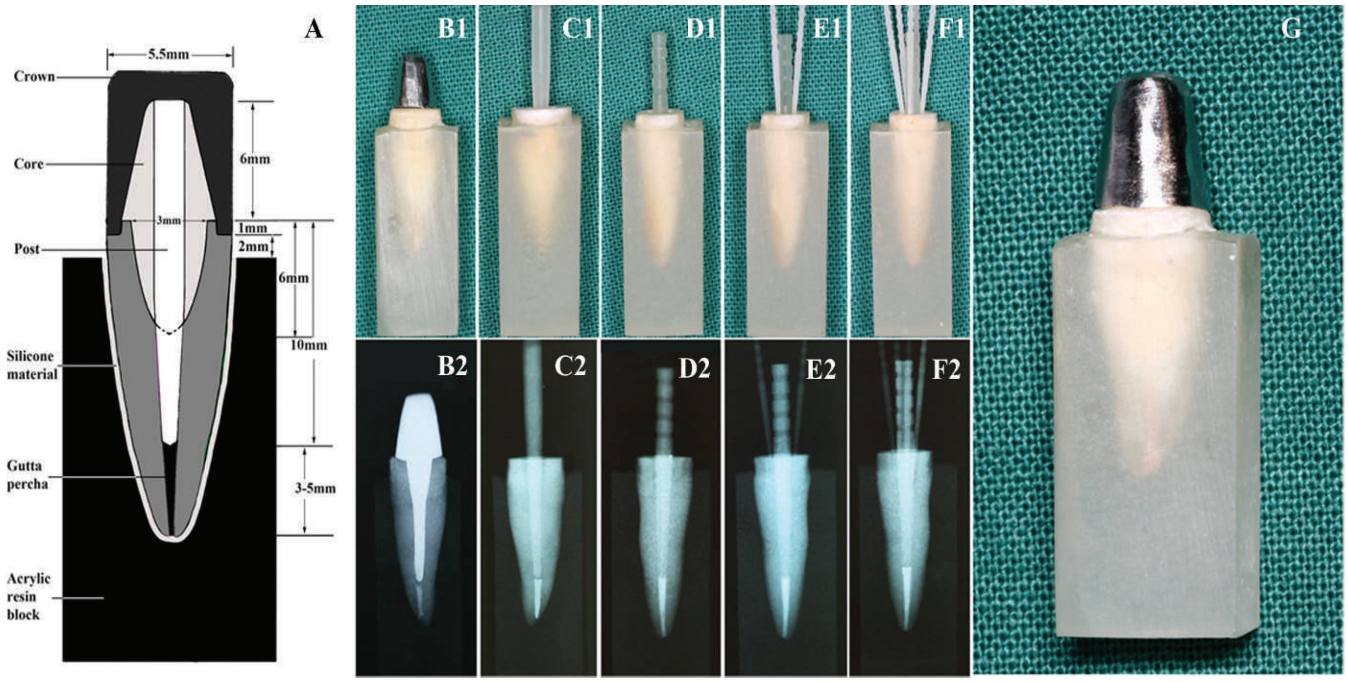

Figure 1. *Schematic diagram of the preparation of a specimen. (A): Criterion for specimen fabrication. (B1, B2): Group CM and x-ray photograph. (C1, C2): Group DT and x-ray photograph. (D1, D2): Group ML and x-ray photograph. (E1, E2): Group 2FC and x-ray photograph. (F1, F2): Group 5FC and x-ray photograph. (G): Specimen with a full metal crown.*

the root apex to the buccal midpoint of the cementoenamel junction [CEJ]) and buccolingual and mesiodistal dimensions (at the level of the cervical margin) were measured using a caliper (LA-6, Dentsply, York, PA, USA). Overall, the mean of root length was 14.7±1.6 mm, while the means of buccolingual and mesiodistal dimensions were 7.1 ± 0.6 mm and 6.3 ± 0.5 mm.

Preparation of Over-flared Root Canals

Anatomical crowns were transversely sectioned at 1.0 mm coronal to the CEJ of the buccal aspect using a diamond low-speed rotary cutting instrument (SP1600, Leica Microsystems GmbH, Wetzlar, Germany). The section surface was flattened to be perpendicular to the longitudinal axis of the tooth using SiC sand paper (600-grit). Afterward, the root canals were endodontically treated and obturated with gutta-percha (Lexicon Gutta Percha Points, Dentsply, Tulsa, OK, USA). After storage in 0.9% saline solution at 37°C for 72 hours, the entrance of the root canal was enlarged using a taped diamond bur (with a taper of 0.5) with a length of 6 mm.

Restorative Procedures: Fabricating the Post-cores and Crowns

The prepared roots were restored with one of five post systems as follows (n=10): Ni-Cr alloy cast metal post (Bego, Bremen, Germany) (group CM), D.T. Light FRC post (Bisco Inc, Schaumburg, IL, USA) (group DT), Macro-Lock FRC post (RTD Inc) (group ML), Macro-Lock plus 2 Fibercone FRC posts (group 2FC), and Macro-Lock plus 5 Fibercone FRC posts (group 5FC). The post space of the root canals was prepared using respective drills recommended by each post system. A schematic diagram of the root canal preparation is shown in Figure 1 and Table 1. To simulate the periodontal ligament (only for the fracture failure test), the root surface of 50 specimens was coated with a thin layer of polyvinyl-siloxane impression material (Examixfine, GC Inc, Tokyo, Japan). Finally, the roots were embedded in acrylic resin blocks (Uni-Fast II, GC Inc) parallel to the long axis of the teeth at a level 2 mm below the CEJ of the buccal aspect. Parallelism among the post, the canal, and the acrylic resin block was obtained by using a parallel grinding instrument (CL-MF2002S, Heraeus-Kulzer Inc, Hanau, Germany).

For group CM, Ni-Cr alloy metal post cores were casted and cemented using conventional glass ionomer cement (Fuji, GC Inc). The coronal portion was 6 mm in height with a 1-mm height, 0.5-mm width ferrule end (Figure 1).

For FRC post groups, the canals were etched with 37% phosphoric acid (Ultra-Etch, Ultradent, South Jordan, UT, USA) for 15 seconds, rinsed with

Table 1: *Post Systems and Materials Tested in This Study*

Group	Post System	Canal Preparation		Core	Manufacturer	Batch
		Apex	Entrance			
CM	Cast metal post-core	GG drill #1-4		Cast Ni-Cr	Bego, Bremen, Germany	70-98
DT	D.T. Light (3#)	#1-3		PermaCem	Bisco Inc, Schaumburg, L, USA	0600004198
ML	Macro-Lock (4#)	#1-4	Diamond bur with a taper of 0.5		RTD Inc, St Egreve, France	106160903
2FC	Macro-Lock (4#)+2 Fibercone	#1-4				102440902
5FC	Macro-Lock (4#)+5 Fibercone	#1-4				

distilled water for 30 seconds, and dried with absorbent paper points. Adhesive resin was applied (Adper Single Bond 2, 3M ESPE, St Paul, MN, USA) and light polymerized for 20 seconds using a halogen light-polymerizing unit (ESPE Elipar Trilight, 3M ESPE). All FRC posts and auxiliary FRC posts were cemented with a resin cement (PermaCem, DMG Inc, Hamburg, Germany) and were light-cured for 40 seconds. The FRC posts were cut, leaving 6 mm out of the root canal entrance to retain composite cores. Ten polyester trays, replicated from the specimens in group CM, were fabricated using a heat/vacuum tray-forming machine (Ultra-form, Ultradent). Core build-up composite resin (Luxa-Core, DMG Inc, Hamburg, Germany) was filled into these trays and was used to build the cores for the FRC post groups. Finally, all cores and roots were prepared in keeping with the criteria mentioned previously.

For the standardization of applying loading during the mechanical tests, full metal crowns were made for all specimens. The crowns were airborne particle abraded with 50 μm aluminum-oxide powder, and were cemented using a conventional glass ionomer cement. The specimens were then stored in 100% relative humidity, at 37°C, for a period of 72 hours.

Thermomechanical Aging

Specimens were subjected to thermomechanical aging before the fracture and pull-out tests were performed.[34] Mechanical aging was applied with a universal testing machine using a stainless steel spherical antagonist (with tip 3 mm in diameter) contacting on the lingual surface, 2 mm below the incisal edge of the crowns. A 45-degree oblique load of 49.0 ± 0.7 N was applied in 60,000 cycles with a crosshead speed of 10 mm/s downward and 70 mm/s upward. Load frequency was 1.7 Hz, and load cycle duration was 0.6 second. Thermocycling aging was performed with 12,000 cycles at 5°C to 50°C with a dwell time of 70 seconds. Finally, the specimens were randomly divided into two halves, and each half was subjected to a fracture failure test or a pull-out test (n=50).

Fracture Failure Tests

A total of 50 specimens were subjected to fracture failure tests using the universal testing machine (Model 8841, Instron, Norwood, MA, USA). A custom-fabricated jig was used to standardize the position of specimens at the base of the apparatus, so that loading was applied at an angle of 45 degrees in relation to the long axis of the roots (Figure 2). A compressive force was applied on the lingual surface (2 mm below the incisal edge) at a crosshead speed of 0.5 mm/min until fracture occurred. Modes of fracture were observed using x-ray photographs. Fracture modes were classified into three categories as follows: root fracture, post fracture, invisible fracture. With respect to fracture location, the fracture modes were classified as follows: a-cervical, b-middle, and c-apical.

Pull-out Tests

The remaining 50 specimens were subjected to a pull-out test using the universal testing machine mentioned previously. The acrylic resin block and the crown were fitted to dynamometer clamps

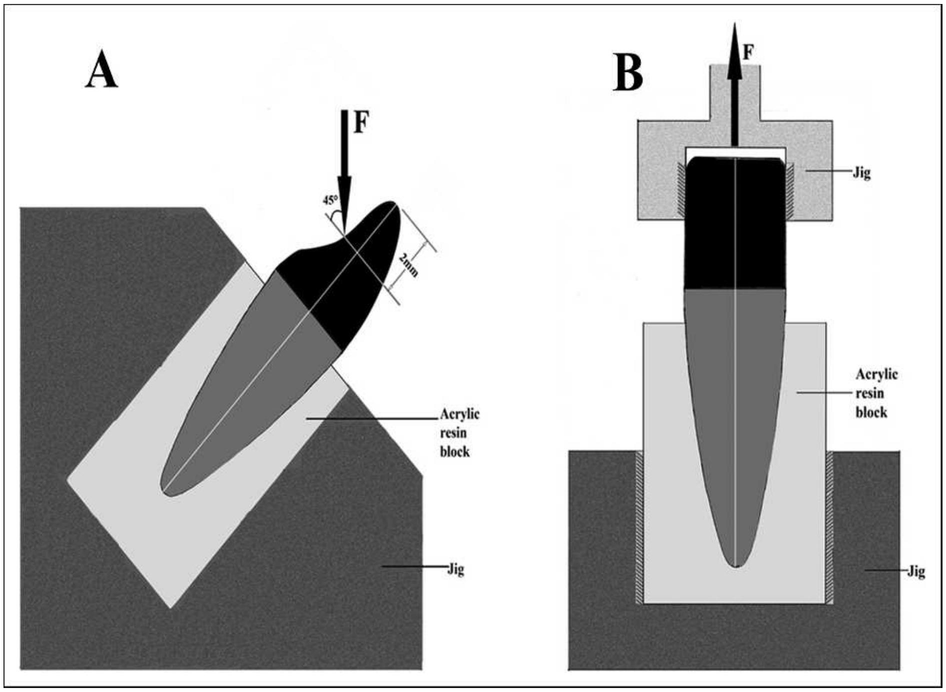

Figure 2. *Schematic drawing of the setup for fracture failure testing and pull-out testing of the post. (A): Fracture failure testing. (B): Pull-out testing.*

(Figure 2). A 0.5 N preload was applied to maintain the specimens in tension and to allow for self-alignment before testing. A force was applied on the full metal crowns at a crosshead speed of 0.5 mm/min until detachment occurred. Pull-out strength values were recorded. The pulled out post fragments were collected and observed with the microstereomicroscope at 1× and 4× magnifications.

Statistical Analysis

The means of fracture failure strength and pull-out strength were calculated. The data were analyzed using one-way analysis of variance (ANOVA) with the post system setting as the variable. Tukey's post hoc test was performed to evaluate differences among the post systems. All analyses were performed using the Statistical Package for the Social Sciences (SPSS) statistical package (SPSS 13.0 for Windows, SPSS Inc, Chicago, IL, USA). The level of significance was set at 0.05.

RESULTS

All specimens remained intact after 60,000 cycles of dynamic loading and 12,000 thermal cycles.

Evaluation of the Fracture Failure Tests

The means of fracture failure strengths (N) and standard deviations are presented in Table 2. The fracture failure strength of group DT was the lowest. No statistical difference in fracture strength was noted among the groups CM, 2FC, and 5FC.

The results of the fracture modes are presented in Table 3. Almost all samples encountered root fracture, except for four specimens with invisible fracture. All root fractures occurred opposite the area where the force was applied. No post fracture occurred in the groups CM and 5FC. The percentages of post fracture were 50%, 30%, and 30% in the groups of DT, ML, and 2FC, respectively. With respect to root fracture location, most fractures happened in the cervical region of the roots in which the fiber post systems were used, whereas 50% of root fractures were located in the middle of the roots in group CM. Representative x-ray photographs of fractures are shown in Figure 3.

Analysis of Pull-out Tests

Table 4 shows the means of pull-out strengths (N) and Tukey's post hoc analysis results. In group CM, debonding failure strength was significantly greater than that of the fiber post groups ($p<0.05$). No statistical differences in pull-out strength were noted among groups ML, 2FC, and 5FC ($p>0.05$). The lowest value of pull-out strength appeared in group DT ($p<0.05$). Figure 4 presents the representative pulled out post fragments. A rough surface

Table 2: *Means and Tukey's Post Hoc Comparisons of Fracture Failure Strength, N*

Group	n	Mean, N	SD	Minimum, N	Maximum, N	Tukey's Interval[a]		
CM	10	511.09	91.95	300.26	638.17	a		
DT	10	305.73	76.34	227.98	466.25		b	
ML	10	449.50	113.18	317.13	597.05			c
2FC	10	490.17	83.27	389.13	602.32	a		
5FC	10	550.25	62.84	458.29	640.63	a		

[a] *For Tukey's intervals, the same letter means no significant difference within groups.*

with a thin layer of glass ionomer was detected in group CM. In group DT, the separation presented at the interface of the post-cement layer, and no cement remained on the post surface. A residual cement layer was obvious on post-fragment surfaces in most of the specimens of groups ML, 2FC, and 5FC. A thin layer of residual cement was observed in the serrations and the passive threading cut in the Macro-Lock post surface.

DISCUSSION

Based on these findings, the null hypothesis that fracture resistance and retention do not vary as a function of the post system was rejected.

It is difficult to standardize the extensively destroyed root canals in a laboratory study. In the present study, the over-flared root was achieved using a diamond drill to enlarge the root entrance. Furthermore, a relatively shorter and narrower ferrule with a height of 1.0 mm and a width of 0.5 mm was set as the criterion of the tooth preparation. This was done because of the extensive coronal structure loss of specimens used in the present study.

Static compressive loading is usually used to assess the fracture resistance of pulpless teeth. However, most failures of post-retained restorations were not caused by a static compress, but by a fatigue fracture of ordinary chewing force. So thermomechanical aging is vitally important before the effects of post-retained pulpless teeth can be evaluated. In the present study, all teeth suffered from 60,000 cycles of dynamic loading and 12,000 thermal cycles before initial testing.

Research has demonstrated that ordinary chewing force in adults ranges from 7 kg to 15 kg.[35] In the present investigation, the fracture failure strength of all specimens was beyond normal chewing forces. However, the clinical significance of these results should be questioned. In a clinical situation, the failure of a post-and-core restoration is a complex result of cyclic loading, materials fatigue, and microleakage. So the restoration can be expected to fail with less loading than was applied in this study. Moreover, a continuous ferrule was set in the present study, which could probably increase the fracture resistance of the roots. Thus, fracture failure strengths were given only for comparison among groups.

No significant difference was found among the groups of CM, 2FC, and 5FC, and fracture failure strengths of groups 2FC and 5FC were greater than that of group ML. These findings might be explained by the fact that increasing diameter of the FRC post using auxiliary fiber posts has a positive effect on stress distribution.[11] X-ray photographs showed that the fracture mode of the FRC post groups was cervical fracture or crack, nevertheless 50% of the fractures in group CM were located at the middle of the roots. It could be assumed that the fiber posts were able to transmit partial loading stresses to the prepared root canals, thus distributing the load over a bigger surface area of the tooth structure.[23,36] However, either of the middle or cervical root fractures could be considered as an "unfavorable" fracture. Therefore, results indicate that once fracture failure had occurred in extensively flared roots, it was nonrepairable whether cast metal posts or FRC posts were used.

A push-out test was performed and was recommended for evaluation of the bonding strength of post-retained restorations.[37] However, in the pre-

Table 3: *Modes of Fracture Observed by Visual Inspection Using X-ray Photographs*[a,b]

Sample No.	CM			DT			ML			2FC			5FC		
	Load, N	Type	Location	Load, N	Type	Location	Load, N	Type	Location	Load, N	Type	Location	Load, N	Type	Location
1	300.26	RF	a	282.74	RF PF	a a	597.05	RF	a	487.09	RF	a	525.48	RF	a
2	638.17	RF	a	466.25	RF	a	317.13	RF	a	487.02	RF	a	558.46	RF	a
3	484.29	RF	b	360.77	RF PF	a a	392.89	RF	a	449.69	RF	a	489.15	RF	a
4	484.45	RF	a	227.98	RF	a	594.88	invisible fracture		393.24	invisible fracture		486.81	RF	a
5	526.35	RF	b	385.33	RF PF	a a,b	372.03	RF	a	538.19	RF	a	587.32	RF	a
6	489.98	RF	a	241.2	RF PF	a a	487.02	RF	a	392.35	RF	a	612.08	RF	a
7	478.22	RF	b	288.19	invisible fracture		586.27	RF PF	a c	389.13	RF PF	b b	618.6	RF	a
8	567.53	RF	a	302.65	RF	a	470.12	RF	a	575.26	RF PF	a a	640.63	RF	a
9	539.37	RF	b	263.23	RF PF	a b	356.27	RF PF	a a	602.32	RF	a	525.67	RF	a
10	602.32	RF	b	238.98	RF	a	321.32	RF PF	a a	587.39	RF PF	a c	458.29	invisible fracture	

[a] *Fracture type was classified into three categories as follows: root fracture (RF), post fracture (PF), and invisible fracture.*
[b] *With respect to location, fractures were classified according to the root or post in which they occurred: a-cervical, b-middle, or c-apical*

liminary study, the weak dentin wall, especially in the cervical region, was not strong enough to support the push-out force. Moreover, the section of cast post might potentially destroy the bonding surface. Therefore, the pull-out test was performed in this study. Tukey's multiple comparisons showed that the order of pull-out strength values was CM>ML=2FC=5FC>DT. As expected, the cast post fit the canal space better than the FRC posts. Therefore, the cement layer was thinner and more uniform in group CM, which might contribute to the higher retention of cast posts compared with fiber posts. With respect to the FRC post groups, two interfaces were used: the dentin-cement layer and the cement-layer post. Investigation with micro-stereoscopy showed that most of the debonding occurred in the cement layer-post interface in group DT, and in the dentin-cement layer interface in the ML, 2FC, and 5FC groups. Residual cement materials were found in a series of serrations along with passive threading into the surface of Macro-Lock posts. It was presumed that the design of notches in the Macro-Lock post surface could significantly reinforce the retention of the post-cement interface. Tukey's multiple analysis revealed that no significant differences among the ML, 2FC, and 5FC groups. It indicated that the application of auxiliary posts could not positively increase the retention of flared pulpless roots.

One limitation of the study is that the bonding procedures were performed in vitro. The manufac-

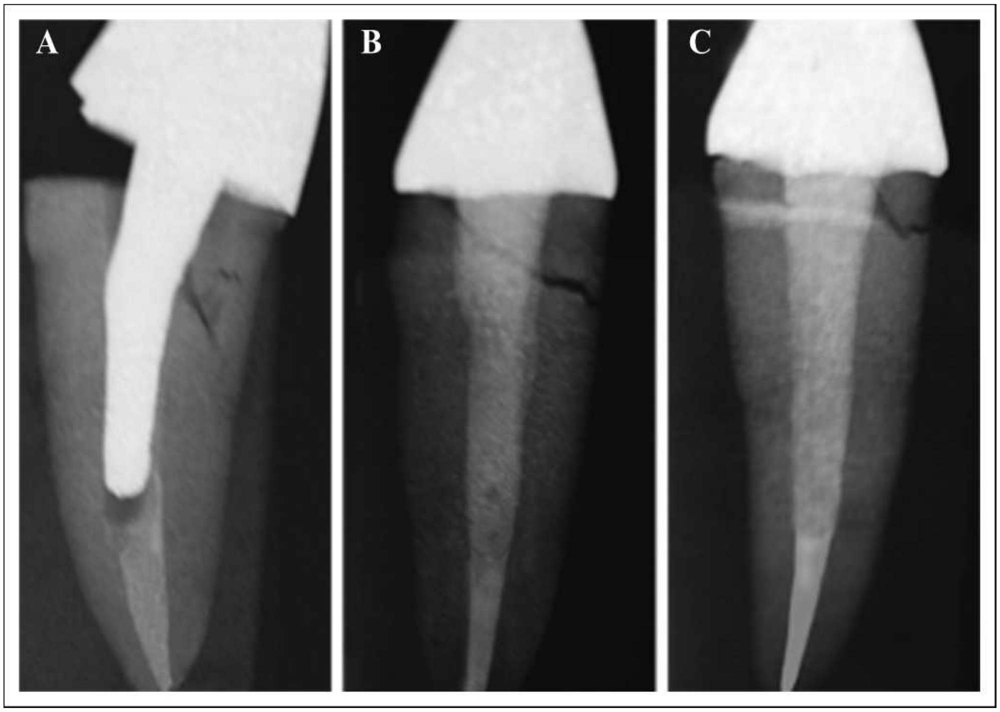

Figure 3. *Representative x-ray photographs of fracture failure testing. (A): Root fracture at the middle region of the root. (B): Root and post fracture at the cervical region of the root. (C): Root fracture at the cervical region of the root.*

turer's recommendations were followed, and the moisture control might not be as ideal, especially in terms of the application of glass ionomer cement. The fracture failure strength and the pull-out strength could not fully reveal the clinical status of endodontically treated roots under chewing forces. Other properties of the materials and the effects of material aging should be investigated in future studies.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions were drawn:

1. The Macro-Lock post showed superior retention and fracture resistance compared with the D.T. Light post.
2. The Macro-Lock post combined with the auxiliary fiber posts increased the fracture resistance of the over-flared root.

Table 4: *Means and Tukey's Post Hoc Comparisons of Pull-out Strength, N*

Group	n	Mean, N	SD	Minimum, N	Maximum, N	Tukey's Interval[a]		
CM	10	319.70	66.41	192.66	412.57	a		
DT	10	123.37	26.10	93.91	168.36		b	
ML	10	182.44	44.54	136.86	243.52			c
2FC	10	212.07	52.88	162.09	320.96			c
5FC	10	225.76	72.61	133.50	331.06			c

[a] *For Tukey's intervals, the same letter means no significant difference within groups.*

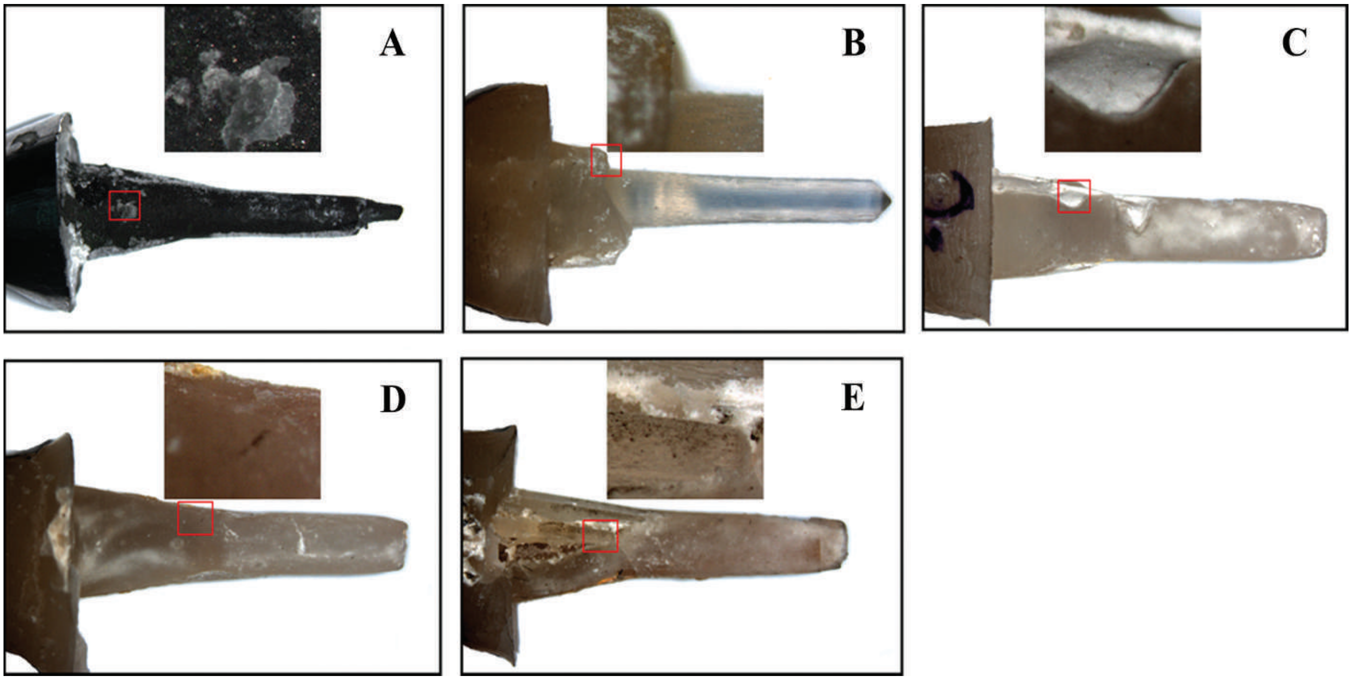

Figure 4. *Photographs of pulled out post fragments observed using a microstereomicroscope at 1× and 4× magnifications. (A): Group CM. (B): Group DT. (C): Group ML. (D): Group 2FC. (E): Group 5FC.*

3. The application of auxiliary fiber posts has no effect on the retention strength of over-flared roots.

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