©Operative Dentistry, 2014, **39-3**, E128-E136

Reinforcement of Teeth With Simulated Coronal Fracture and Immature Weakened Roots Using Resin Composite Cured by a Modified Layering Technique

RS Seyam • EH Mobarak

Clinical Relevance

Reinforcement of teeth with coronal fractures and immature weakened roots with resin composite that was cured by the modified layering technique could be a promising approach for practitioners.

SUMMARY

Objective: The purpose of this study was to evaluate the strengthening effect of resin composite, cured by a modified layering protocol, for teeth with simulated coronal fracture and weakened immature roots.

Methods: Fifty maxillary teeth were decoronated and their apices sectioned to standardize the length to 12 mm. Prepared teeth were equally distributed into five groups. Group 1VF root apices were flared with Pesso drills up to size 6. The roots were flared until a dentin thickness of only 1 ± 0.2 mm remained. Root ends were filled with mineral trioxide aggregate. The canals were backfilled with Vertise Flow following a modified layering protocol using two light-transmitting posts size 6 and 3. Next, a DT light post size 2 was cemented using the same material. Groups 2TS/MF and 3ED/PF were prepared and cured in the same way as group 1VF but filled with Clearfil Tri-S Bond/Majesty Flow and ED Primer II/Panavia F2.0 respectively. Group 4UF was similarly prepared but left unfilled (control). In group 5NW, roots were unflared but similarly filled as in group 3ED/PF. After 24 hours of storage, the fracture load was measured. The degree of cure for each tested material was indirectly measured using microhardness at

Reham S Seyam, BDS, MDS, DDSc, Department of Endodontics, Faculty of Oral and Dental Medicine, Cairo University, Cairo, Egypt

*Enas H Mobarak, BDS, MDS, DDSc, Restorative Dentistry Department, Faculty of Oral and Dental Medicine, Cairo University, Cairo, Egypt

*Corresponding author: 14 ElZahra St. Dokki, Cairo University, PO Box 12311, Giza, Egypt; e-mail: enasmobarak@hotmail.com

DOI: 10.2341/12-525L

different root levels (cervical, middle, and apical). Data were analyzed using one-way analysis of variance followed by Newman-Keuls post hoc test.

Results: Fracture load results revealed that groups 1VF and 2TS/MF had no statistically significant difference from group 5NW ($p>0.05$). For each tested material, no significant difference was found among microhardness values at different root levels.

Conclusion: It may be possible to reinforce the teeth with coronal fracture and immature weakened roots to be comparable with unweakened ones when composite is applied and cured by the modified layering technique.

INTRODUCTION

Traumatic dental injuries with coronal fracture can lead to pulpal necrosis with cessation of root formation, resulting in an immature root.[1] The immature root can have an open apex coupled with thin dentinal walls, which create endodontic and restorative challenges.[1,2] For management of open apices, mineral trioxide aggregate (MTA) apical barrier has been recommended.[3-5]

Even when treatment of the open apex has been successful, the thin dentinal walls of immature teeth remain a restorative problem because of the high susceptibility to fracture from normal forces of mastication.[1,6] Therefore, when restoring such teeth, it would be advantageous to reinforce the roots in hopes of increasing their resistance to fracture. Researchers have tested the reinforcing effect of different materials including glass ionomer cements, hybrids of glass ionomer cements, and resin composites with different post systems including metal or fiber posts.[1,7,8] Fiber posts have further extended the application of adhesive dentistry in endodontics and have been advocated because of their advantages of corrosion resistance, esthetic appeal, single-visit office placement, and easier removal for endodontic retreatment.[9] In addition, posts with a resin composite that bonds to dentin have surpassed other approaches in increasing the resistance to fracture.[1] Nevertheless, multistep adhesives present with technique sensitivity, difficulty in material application as well as curing effectiveness, and a high C-factor (ratio of bonded to unbonded surfaces) in the root canal. This makes bonding to root dentin a real challenge.

In coronal restorations, to overcome the problems of multistep adhesives and their technique sensitivity, adhesive application steps were simplified, resulting in the most recent single-step self-adhering resin composite.[10] Also, the use of a layering technique was found to increase curing effectiveness,[11] to help in volumetric shrinkage compensation,[12] and to decrease the C-factor.[13]

In root canals, plastic light-transmitting posts and, recently, the newer versions of fiber posts were developed to help in light transmission to increase the depth of resin cure.[14] However, it was reported that light curing from the top of post spaces is insufficient to optimally polymerize light-curing adhesives and resin cements in the apical part of the canal.[15] The use of prolonged curing time was reported to aid in the effective curing of the apical part and thus in obtaining homogenous bonding throughout the canal length.[16] Also, the additional use of the light-transmitting posts in successive sizes to apply resin material in layers to control the C-factor while achieving effective curing presents an attractive solution to bonding to weakened root canals. Previous work highlighted the success of this approach to achieve proper bonding to different root levels.[17] The effect of this approach to reinforce weekend roots has not yet been investigated.

The degree of cure has been tested using different approaches, among them the surface microhardness testing that was used in numerous previous studies,[18-20] since it was found to be a good indicator for the degree of conversion.[21-23]

Thus, the purposes of this study were 1) to compare the fracture load of immature roots restored using different resin materials when applied using a modified layering technique with the aid of successive light-transmitting posts and 2) to indirectly test the efficacy of using the modified layering technique in curing the tested materials by measuring their microhardness at different root levels.

MATERIALS AND METHODS

Tooth Selection and Standardization

Intact human maxillary incisors were collected, cleaned, and disinfected and then stored in saline until use.[24] Root length, mesiodistal, and buccolingual diameters at the cemento-enamel junction (CEJ) of the collected teeth were measured with a digital caliper (Mitutoyo digital caliber, Mitutoyo Corp, Kawasaki, Japan).[8] Teeth (n=50) with similar root sizes and lengths were selected (Figure 1A). The overall ranges of root dimensions of all selected teeth measured at the CEJ were 5 (±1) mm mesiodistally

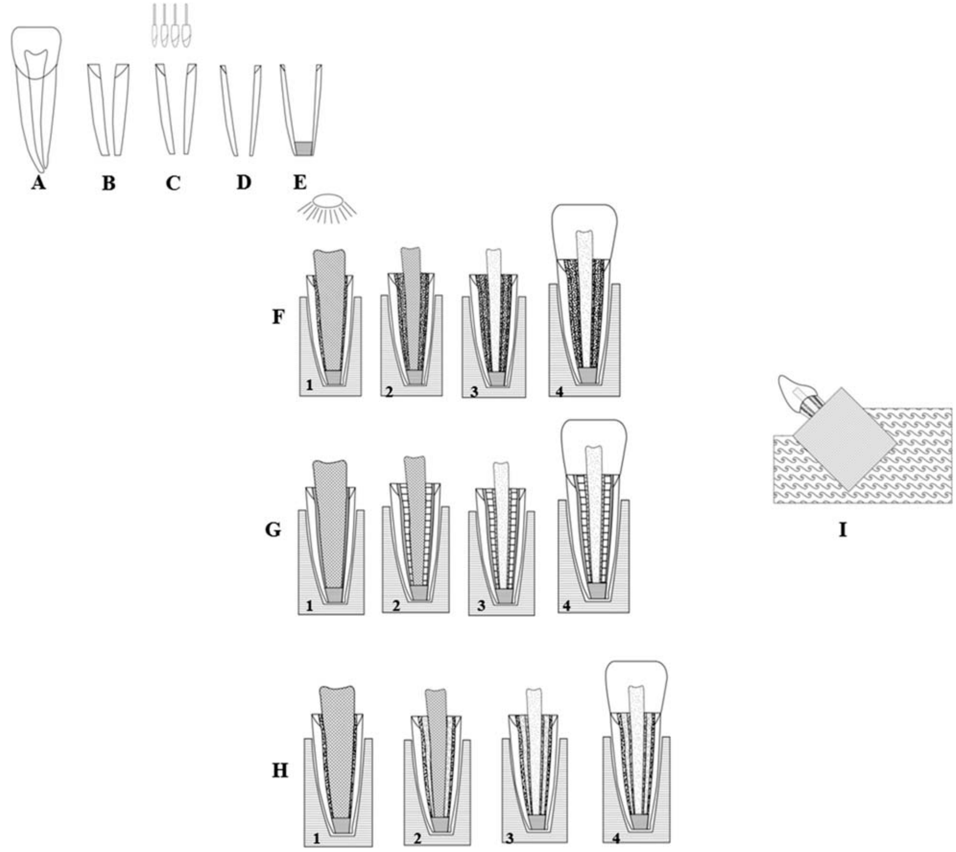

Figure 1. *Schematic drawing illustrating tooth preparation with simulated coronal fracture and weakened immature root (A, B, C, and D). Root end was filled with 3 mm mineral trioxide aggregate apical plug (E). Group 1VF specimens were reinforced by Vertise Flow (VF) in three layering applications (F1, 2, 3, and 4). Group 2TS/MF specimens were reinforced by Clearfil Tri-S Bond (TS) and flowable resin composite Clearfil Majesty Flow (MF) in three layering applications (G1, 2, 3, and 4). Group 3ED/PF specimens were reinforced by dual-cure self-etch primer adhesive/cement ED Primer II(ED)/Panavia F2.0 (PF) in three layering applications (H1, 2, 3, and 4). For each specimen, core buildup was constructed with Filtek Supreme using a former (Figures 1F4, 1G4, 1H4). Each specimen was placed in a specially fabricated jig, subjected to 45° load using a universal testing machine at a crosshead speed of 0.5 mm/min to the palatal surface of cores of all specimens (I).*

and 6 (±1) mm buccolingually. The root length was approximately 15 (±1) mm.

Tooth Preparation and Immature Weakened Canal Simulation With Coronal Fracture

To simulate the worst case scenario of an immature tooth with weakened canal walls and coronal fracture, the anatomical crowns of the teeth were sectioned perpendicular to the long axis of the roots, leaving 2 mm coronal to the CEJ of the buccal surfaces using a saw (Isomet, low-speed saw, Lake Bluff, IL, USA) under water coolant. The root length was standardized to 12 mm by sectioning the root apices (Figure 1B). Forty teeth were flared to simulate the immature root canal walls. Apically, the canals were enlarged to a depth of 12 mm using Peeso reamers (Dentsply Maillefer, Ballaigues, Switzerland) of ascending sizes from size 3 (1.1 mm diameter) to size 6 (1.7 mm diameter; Figure 1C). The canal spaces were flared throughout the canal length using high-speed tapered diamond burs (Dentsply Maillefer), leaving approximately 1 ± 0.2 mm of dentin thickness between the internal prepared root canal wall and the external root surface at the cervical margin (Figure 1D).[25] The remaining thickness was confirmed with a digital caliper (Mitutoyo digital caliber, Mitutoyo Corp).[25] After flaring, buccolingual and mesiodistal radiographs were taken to ensure the homogeneity of root flaring. The other 10 teeth were prepared in the same way apically but without the coronal flaring.[6]

After preparation, each tooth was irrigated using 2 mL NaOCl 5.25% (Clorox, Alexandria Detergent of Chemicals Company, Alexandria, Egypt). Pro-Root MTA (Dentsply Dental, Tulsa, OK, USA) was mixed according to the manufacturer's instructions and used to form a 3-mm apical plug (Figure 1E). A Messing gun (EndoGun, Medidenta, Woodside, NY, USA) was used to place the material as close to the

Table 1: *Materials Descriptions, Manufacturers, Compositions, and Batch Numbers*

Material (Manufacturer)	Description	Composition and batch number
Clearfil Tri-S Bond: Kuraray Medical Inc, Tokyo, Japan	Light-cure single-step self-etch adhesive system	MDP, Bis-GMA, HEMA, photoinitiators, ethanol, water, silanated colloidal silica (061232)
Clearfil Majesty Flow: Kuraray Medical Inc, Tokyo, Japan	Light-cure flowable resin composite	TEGDMA, silanated barium glass filler, silanated colloidal silica, hydrophobic aromatic dimethacrylate, di-camphorquinone (00308A)
Vertise Flow: Kerr Corp, Orange, CA, USA	Light-cure self-adhering flowable resin composite	Matrix: GPDM and methacrylate co-monomers fillers (70wt%): prepolymerized filler, barium glass, nano-sized colloidal silica, nano-sized ytterbium fluoride (3358782)
Panavia F2.0: Kuraray Medical Inc, Osaka, Japan	Dual-cure single-step self-etch resin cement	ED Primer II; Liquid A: HEMA (30%-50%), MDP, N-methacryloyl-5-aminosalicylic acid, water, accelerator (61185); ED primer II liquid B: N-methacryloyl-5-aminosalicylic acid, accelerator, water, sodium benzene sulfinate (61185); Paste A: hydrophobic aromatic and aliphatic dimethacrylate, hydrophilic aliphatic dimethacrylate, sodium aromatic sulfinate (TPBSS), N,N-diethanol-p-toluidine, surface-treated (functionalized) sodium fluoride <10%, silanated barium glass (61185); Paste B: MDP, hydrophobic aromatic and aliphatic dimethacrylate, hydrophilic aliphatic dimethacrylate, silanated silica, photo initiator, dibenzoylperoxide (61185)

Abbreviations: Bis-EMA: ethoxylated bisphenol A glycol dimethacrylate; Bis-GMA, bisphenol-A glycol dimethacrylate; GPDM: glycerol phosphate dimethacrylate; HEMA, 2-hydroxy ethyl methacrylate; MDP, 10-methacryloyloxydecyl dihydrogen phosphate; TEGDMA, triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate.

apex as possible. A hand plugger and the thick end of moistened paper points (Dentsply Maillefer) were used to condense the material to the apex. Radiographs were taken to ensure proper placement and increment thickness. Teeth were then stored at 37°C and 100% humidity for at least 24 hours. Aluminum foil was wrapped around the roots of each specimen up to 2 mm below the CEJ to act as a spacer.[26] The roots were then centrally embedded in polyester (polyester #2121, Hsien, Taiwan) along their long axis following the methodology described by Mobarak and others.[27] After the setting of the resin, the foil was replaced by polyether light impression material (Examix NDS, GC Corporation, Tokyo, Japan) to simulate the periodontal ligament. In each canal, the smear layer was removed using 5 mL of 17% EDTA followed by 5 mL of 5.25% NaOCl as an irrigant. Final irrigation was accomplished with 10 mL of distilled water,[28] then air dried with high-pressure airflow for five seconds.

Specimen Grouping

The embedded specimens (n=50) were equally divided into five groups according to the preparation and reinforcing material used. Materials used in the present study are presented in Table 1. The tested groups were as follows.

Group 1VF—Ten flared specimens received Vertise Flow (VF) material (Kerr Corp, Orange, CA, USA), a light-cure self-adhering flowable resin composite, in three layering applications. A light coat of VF was first agitated onto the canal walls using a disposable microbrush applicator (Microbrush International Co., Grafton, WI, USA). A light-transmitting plastic post size 6 (Luminex, Dentatus USA Ltd, New York, NY, USA) was then inserted centrally in the root canal at the level of the apical MTA, leaving approximately 0.5 mm thickness of VF resin composite material circumferentially (Figure 1F1). Curing was done on top of the light-transmitting post for 80 seconds using Elipar S10 (3M ESPE Dental Products, St Paul, MN, USA). The light-curing unit had an intensity >800 mW/cm^2 that was checked using a radiometer (Demetron LED Radiometer, Kerr Corp). After curing, the light-transmitting plastic post was removed. A second layer of VF was then applied and cured with the aid of a size 3 light-transmitting plastic post (Luminex, Dentatus USA Ltd) to obtain a circumferential resin composite with thickness of less than 2 mm (Figure 1F2). This layer was also cured for 80 seconds in the same way as the first layer. After curing, the light-transmitting post was removed. The remaining space was then filled with VF, then a DT light post (size 2, Bisco Inc, Schaumburg, IL, USA) was placed slowly and cured for an additional 80 seconds (Figure 1F3). All posts were mounted so the long axis of the post coincided with the long axis of the root. The posts were standardized to a length of 11 mm, and the tip of the curing unit was positioned on top of the post.

Group 2TS/MF—Specimens (n=10) were filled similar to group 1VF, but the light-cure single-step self-etch adhesive system Clearfil Tri-S Bond and flowable resin composite Clearfil Majesty Flow (Kuraray Medical Inc, Tokyo, Japan) were used instead. Clearfil Tri-S Bond was applied according to the manufacturer's instructions (Figure 1G1). Light curing through a size 6 light-transmitting plastic post for 80 seconds was done. The canals were then filled with Clearfil Majesty Flow using the other successive light-transmitting posts (Figure 1G1 and 1G2) and finally the DT Light Post (size 2) following the same protocol applied to the VF group (Figure 1G3).

Group 3ED/PF—Specimens (n=10) were filled and cured following the previously mentioned protocol for the VF and TS/MF groups (Figure 1H1, 1H2, 1H3) but using dual-cure primer adhesive/cement ED Primer II/Panavia F2.0 (Kuraray Medical Inc) that was applied according to the manufacturer's instructions.

Group 4UF—In this group, the flared teeth were left unfilled, except at the apical 3-mm MTA barrier (control). A cotton pellet was placed at a level just below the facial CEJ before core buildup using resin composite but without using intraradicular posts.[6]

Group 5NW—Nonflared teeth were used in this group. The post space was prepared with a specific size 2 drill (Bisco Inc) of 1 mm diameter that corresponds to the DT light post size 2. The canal space was then filled with Panavia F2.0 as in group 3ED/PF following the manufacturer's instructions. However, the material was applied in one increment using only size 2 DT light post and cured for 80 seconds.

For each specimen, the core buildup was constructed with Filtek Supreme (3M ESPE Dental Products) using a former (Figures 1F4, 1G4, 1H4)[29] after Clearfil Tri-S Bond adhesive system application. All specimens were stored in distilled water at 37°C for 24 hours before mechanical testing.

Fracture Load Measurement

Each specimen was placed in a specially fabricated jig. Specimens were subjected to a compressive load on the palatal surface of the cores at an angle of 45° to the long axis of the tooth [5] (Figure 1I) using a universal testing machine (Model LRX-Plus, Lloyd Instruments Ltd, Fareham, UK) at a crosshead speed of 0.5 mm/min (Figure 1I). The maximum load required to cause fracture was recorded for each specimen. Failed teeth were examined for failure mode determination and presented as in Chuang and others.[30]

Table 2: *Fracture Resistance (N) Results of Experimental Groups (n=10)*[a]

Experimental Group	Fracture Resistance, Mean (SD)
Group 1VF	313.43 (103.7)[a]
Group 2TS/MF	324.52 (114.8)[a]
Group 3ED/PF	243.47 (81.4)[b]
Group 4UF	169.23 (61.6)[c]
Group 5NW	370.10 (86.6)[a]

[a] *Groups with the same lowercase subscript letter are not statistically significant (Newman-Keuls test, p>0.05).*

Microhardness Evaluation

Three representative teeth from groups 1VF, 2TS/MF, and 3ED/PF were prepared and restored in the same way. After 24 hours, using the Isomet saw, one section (2- ± 0.05-mm thickness) was obtained from each of the cervical, middle, and apical levels. Surface hardness was determined using the Vickers Micro-hardness Tester (Model HVS-50, Laizhou Huayin Testing Instrument Co, Ltd, Laizhou, Shandong, China). A load of 200 g was applied to the surface of the specimens for 10 seconds. Three indentations were done 100 μm apart from each other for each of the different root levels (cervical, middle, and apical) of each specimen, from which a mean Vickers hardness number (VHN) value was calculated.[31]

One-way analysis of variance (ANOVA) was performed to detect any intergroup differences. The Newman-Keuls test was used for post hoc pairwise multiple comparisons. The level of significance was set at $p>0.05$. All statistical calculations were done using computer programs Microsoft Excel 2007 (Microsoft Corporation, New York, NY, USA) and SPSS (Statistical Package for the Social Science; SPSS Inc, Chicago, IL, USA) version 15 for Microsoft Windows.

RESULTS

The results of the mean failure values (N) and standard deviation (SD) for all tested groups are shown in Table 2. The results of the one-way ANOVA test indicated a significant difference among tested groups ($p<0.001$). Group 1VF and group 2TS/MF were not statistically different from group 5FW (the nonflared group), while they were statistically significantly higher than group 3ED/PF and group 4UF (Newman-Keuls test, $p<0.01$). Modes of failure

Table 3: *Modes of Failure Among the Tested Groups*

	Fracture Plane Location			Fracture Plane Direction		
	C	M	A	Oblique	Horizontal	Cracked Vertically
Group 1VF	8	—	2	10	—	—
Group 2TS/MF	10	—	—	10	—	—
Group 3ED/PF	10	—	—	10	—	1
Group 4UF	10	—	—	10	—	—
Group 5NW	9	—	1	9	1	2

Abbreviations: ED/PF, ED primer II/Panavia F2.0; NW, unweakened roots; TS/MF, Clearfil Tri-S Bond/Clearfil Majesty Flow; UF, unfilled flared canals; VF, Vertise Flow.

of each group are presented in Table 3. The predominant mode of failure was cervical.

The descriptive data and test of significance of microhardness results are shown in Table 4. The one-way ANOVA test revealed no significant difference among the cervical, middle, and apical microhardness values of each tested group.

DISCUSSION

Endodontic treatment of fractured immature anterior teeth with thin dentinal walls is one of the worst-case scenarios that can face practitioners. The quantity of residual coronal structure and the residual root dentin thickness is a crucial factor that designates the type of definitive restoration.[32] When coronal damage is minimal, additional retention effect gained from post placement is not that critical. However, it is widely agreed that in a severely damaged coronal structure, placement of a post provides sufficient retention to the core.[32,33] Tooth reinforcement was also suggested to decrease the incidence of root fracture with thin dentinal walls.[1,6,8]

Maxillary human anterior teeth were used for this study as they are more susceptible to traumatic injuries. In the present study, extreme care was taken in the selection of the tooth dimensions, their distribution within the experimental groups, and their standardized preparation, thus minimizing the effect of human tooth variation, as was recently discussed by Tanalp and others.[34] Artificial crowns could alter the distribution and transmission of stresses into a post-root complex,[35] masking the reinforcing effect of tested approaches. Therefore, in this study as well as in other studies,[25,29] no crown restorations were made for teeth to allow evaluation of these approaches. Although the test standards and conditions are not identical to the clinical situation, they allow the comparison of different materials within given standards, as explained by Kivanc and others.[25] Further laboratory studies should consider the impact of completed crowns.

The results of the present study revealed that there was a significant increase in fracture load when reinforcing materials and the new fiber post were used compared with unfilled flared canals. Three-dimensional finite element analysis simulations have pointed out the relevance of using restorative materials with elastic properties similar to dentin, such as resin composite, for more favorable performance of the restored teeth under stress.[9] Previous studies on fracture resistance, although different in methodology, confirmed the reinforcing effect of resin composite materials used with the fiber post.[7,8] In these studies, either weakened or immature roots were simulated. Yet, in the current study, immature weakened roots (thin-walled tapered canals with immature apices) were simulated. To simulate immature tooth preparation, tubular canals were prepared apically. In addition, coronally, teeth were decoronated and further flared out, simulating thin-walled canals. Nevertheless, these previous studies[7,8] and ours were common in that the root canals were enlarged more than 1.5 mm in diameter and fracture load was tested using static loading. Although dynamic loading would have replicated the clinical situation, static loading was used to minimize the experimental variables.[7]

Table 4: *Vickers Microhardness Results*

Material	Coronal	Middle	Apical	*p* Value
Vertise Flow (Group 1VF)	39.81 (2.9)	38.94 (5.5)	38.43 (3.9)	0.77
ClearFil Majesty Flow (Group 2TS/MF)	42.86 (5.9)	39.50 (4.4)	41.20 (5.9)	0.45
Panavia F2.0 (Group 3ED/PF)	37.83 (5.0)	37.31 (6.1)	36.19 (2.7)	0.76

The achieved reinforcement in the current study may be due to characteristics of the materials used. For Majesty Flow, the high filler content up to 62% by volume and polymerization shrinkage of 1.88%, as reported,[36] might render it to be comparable to the conventional micro-hybrid resin composite while maintaining the recommended flow behavior. For the VF, it belongs to the new category of restorative materials defined as "self-adhering resin composite." These materials are claimed to eliminate the need for a separate bonding application step, thus simplifying the restorative procedure. For this reason, VF may be considered to start the eighth generation of dental adhesive systems or to represent a cross-link between all-in-one adhesive systems and flowable resin composite. VF was suggested to bond to tooth structure in two ways: primarily through the chemical bond between the phosphate functional groups of a glycerol phosphate dimethacrylate monomer and calcium ions of the tooth and, secondarily, through a micro-mechanical bond as a result of an interpenetrating network formed between the polymerized monomers of VF and collagen fibers of dentin.[10] Recent studies have raised a concern about the high water sorption properties of the VF that might affect its mechanical properties and sealing ability.[10,37] However, VF in this study was enclosed in the root canal by MTA apically and core material coronally, which might have had a positive effect on isolating this material from the direct deteriorating hydrolytic effect of surrounding fluids. Although the self-adhering material represents an attractive approach to clinicians, long-term success is not yet validated, as these materials have only been recently introduced into the market.

Contraction stresses are affected by volume and flow of the used resin as well as the cavity configuration (C-factor). Within a root canal, the C-factor might exceed 200.[32] In the present study, minimizing the bonded to the unbounded ratio was done through the modified layering technique, in which the volume of each resin layer was decreased; thus, the total shrinkage stress is expected to decrease accordingly.[32] The bonding to root dentin results obtained in previous research,[17] when the modified layering technique was used, may support this suggestion. Also, through the use of the light-transmitting posts, the layers toward the post were considered to be unbonded. The easy removal of the light-transmitting post, Luminex, in the pilot study after curing confirmed the lack of bonding between the post and the resin composite.

The predominant mode of failure in the present study was the cervical obliquely directed mode. Most of the obliquely oriented fracture lines extended from the palatal to the buccal side. This oblique orientation was explained by Fukui and others[29] to be due to specimens being loaded at 45° to their long axis. The reported mode of failure corroborates other studies explaining the distribution of stresses along the fiber post due to its modulus of elasticity being similar to dentin.[25,29,30,35]

Microhardness results revealed no significant difference between the different root levels (cervical, middle, and apical) in each tested group. The light-transmitting post, Luminex, was used with the aim of allowing a better polymerization in the deepest canal regions.[38] For such purpose, the Elipar S10 curing unit was also used. This unit has been reported to have the capacity to maintain, according to the manufacturer, an intensity $\geq$800 mW/cm^2 at a depth of 7 mm. Having layers of resin composite of less than 2-mm thickness,[36] with the aid of different sizes of light-transmitting posts, might have also helped the light-transmitting post to activate the thin resin layer surrounding the post surface, enabling the resin to cure promptly along the post.

Based on this study, reinforcement was achieved with the light-cured materials that were applied and cured using the modified layering approach presented in the current study. Nevertheless, further long term in vitro and in vivo studies are still required. Also, the impact of fatigue loading and thermal cycling on fracture should be considered.

CONCLUSION

It may be possible to reinforce teeth with coronal fractures and immature weakened roots to be comparable with unweakened teeth when composite is applied and cured by the modified layering technique.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 24 May 2013)

REFERENCES

1. Katebzadeh N, Dalton BC, & Trope M (1998) Strengthening immature teeth during and after apexification *Journal of Endodontics* **24(4)** 256-259.
2. Cvek M (1992) Prognosis of luxated non-vital maxillary incisors treated with calcium hydroxide and filled with

gutta-percha: a retrospective clinical study *Endodontics Dental Traumatology Journal* **8(2)** 45-55.

3. Sarris S, Tahmassebi JF, Duggal MS, & Cross IA (2008) A clinical evaluation of mineral trioxide aggregate for root-end closure of non-vital immature permanent incisors in children: a pilot study *Dental Traumatology* **24(1)** 79-85.
4. Schwartz RS, Mauger M, Clement DJ, & Walker WA III (1999) Mineral trioxide aggregate: a new material for endodontics *Journal of the American Dental Association* **130(7)** 967-975.
5. Torabinejad M, & Chivian N (1999) Clinical applications of mineral trioxide aggregate *Journal of Endodontics* **25(3)** 197-205.
6. Wilkinson KL, Beeson TJ, & Kirkpatrick TC (2007) Fracture resistance of simulated immature teeth filled with resilon, gutta-percha, or composite *Journal of Endodontics* **33(4)** 480-483.
7. Ayad MF, Bahannan SA, & Rosenstiel SF (2011) Influence of irrigant, dowel type, and root-reinforcing material on fracture resistance of thin-walled endodontically treated teeth *Journal of Prosthodontics* **20(3)** 180-189.
8. Goldberg F, Kaplan A, Roitman M, Manfre S, & Picca M (2002) Reinforcing effect of a resin glass ionomer in the restoration of immature roots in vitro *Dental Traumatology* **18(2)** 70-72.
9. Goracci C, & Ferrari M (2011) Current perspectives on post systems: a literature review *Australian Dental Journal* **56(Supplement 1)** 77-83.
10. Wei YJ, Silikas N, Zhang ZT, & Watts DC (2011) Hygroscopic dimensional changes of self-adhering and new resin-matrix composites during water sorption/desorption cycles *Dental Materials* **27(3)** 259-266.
11. Jackson RD, & Morgan M (2000) The new posterior resins and a simplified placement technique *Journal of the American Dental Association* **131(3)** 375-383.
12. Yoshikawa T, Sano H, Burrow MF, Tagami J, & Pashley DH (1999) Effects of dentin depth and cavity configuration on bond strength *Journal of Dental Research* **78(4)** 898-905.
13. Nikolaenko SA, Lohbauer U, Roggendorf M, Petschelt A, Dasch W, & Frankenberger R (2004) Influence of c-factor and layering technique on microtensile bond strength to dentin *Dental Materials* **20(6)** 579-585.
14. Galhano GA, de Melo RM, Barbosa SH, Zamboni SC, Bottino MA, & Scotti R (2008) Evaluation of light transmission through translucent and opaque posts *Operative Dentistry* **33(3)** 321-324.
15. Goracci C, Corciolani G, Vichi A, & Ferrari M (2008) Light-transmitting ability of marketed fiber posts *Journal of Dental Research* **87(12)** 1122-1126.
16. Aksornmuang J, Nakajima M, Panyayong W, & Tagami J (2009) Effects of photocuring strategy on bonding of dual-cure one-step self-etch adhesive to root canal dentin *Dental Materials Journal* **28(2)** 133-141.
17. Mobarak E & Seyam R (2013) Interfacial nanoleakage and bonding of self adhesive systems cured with a modified-layering technique to dentin of weakened roots *Operative Dentistry*.**38(5)** e154-165.
18. Helvatjoglou-Antoniadi M, Papadogianis Y, Koliniotou-Kubia E, & Kubias S (1991) Surface hardness of light-cured and self-cured composite resins *Journal of Prosthetic Dentistry* **65(2)** 215-220.
19. Quance SC, Shortall AC, Harrington E, & Lumley PJ (2001) Effect of exposure intensity and post-cure temperature storage on hardness of contemporary photo-activated composites *Journal of Dentistry* **29(8)** 553-560.
20. Watts DC, Amer OM, & Combe EC (1987) Surface hardness development in light-cured composites *Dental Materials* **3(5)** 265-269.
21. Asmussen E (1982) Restorative resins: hardness and strength vs. quantity of remaining double bonds *Scandinavian Journal of Dental Research* **90(6)** 484-489.
22. Rode KM, Kawano Y, & Turbino ML (2007) Evaluation of curing light distance on resin composite microhardness and polymerization *Operative Dentistry* **32(6)** 571-578.
23. Tassery H, de Donato P, Barres O, & Dejou J (2001) In vitro assessment of polymerization procedures in Class II restorations: sealing, FTIR, and microhardness evaluations *Journal of Adhesive Dentistry* **3(3)** 247-255.
24. Erkut S, Gulsahi K, Caglar A, Imirzalioglu P, Karbhari VM, & Ozmen I (2008) Microleakage in overflared root canals restored with different fiber reinforced dowels *Operative Dentistry* **33(1)** 96-105.
25. Kivanc BH, Alacam T, Ulusoy OI, Genc O, & Gorgul G (2009) Fracture resistance of thin-walled roots restored with different post systems *International Endodontic Journal* **42(11)** 997-1003.
26. Bishop D, Griggs J, & He J (2008) Effect of dynamic loading on the integrity of the interface between root canal and obturation materials *Journal of Endodontics* **34(4)** 470-473.
27. Mobarak EH, El-Korashy DI, & Pashley DH (2010) Effect of chlorhexidine concentrations on micro-shear bond strength of self-etch adhesive to normal and caries-affected dentin *American Journal of Dentistry* **23(4)** 217-222.
28. Zorba YO, Erdemir A, Turkyilmaz A, & Eldeniz AU (2010) Effects of different curing units and luting agents on push-out bond strength of translucent posts *Journal of Endodontics* **36(9)** 1521-1525.
29. Fukui Y, Komada W, Yoshida K, Otake S, Okada D, & Miura H (2009) Effect of reinforcement with resin composite on fracture strength of structurally compromised roots *Dental Materials Journal* **28(5)** 602-609.
30. Chuang SF, Yaman P, Herrero A, Dennison JB, & Chang CH (2010) Influence of post material and length on endodontically treated incisors: an in vitro and finite element study *Journal of Prosthetic Dentistry* **104(6)** 379-388.
31. Mobarak EH, & El-Badrawy W (2012) Microshear bond strength of self etch adhesive systems to caries affected dentin differentiated using a dye *Journal of Adhesive Dentistry* **14(3)** 245-250.

32. Aksornmuang J, Nakajima M, Senawongse P, & Tagami J (2011) Effects of C-factor and resin volume on the bonding to root canal with and without fibre post insertion *Journal of Dentistry* **39(6)** 422-429.

33. Pontius O, & Hutter JW (2002) Survival rate and fracture strength of incisors restored with different post and core systems and endodontically treated incisors without coronoradicular reinforcement *Journal of Endodontics* **28(10)** 710-715.

34. Tanalp J, Dikbas I, Malkondu O, Ersev H, Gungor T, & Bayirli G (2012) Comparison of the fracture resistance of simulated immature permanent teeth using various canal filling materials and fiber posts *Dental Traumatology*. **28(6)** 457-464.

35. Al-Omiri MK, Mahmoud AA, Rayyan MR, & Abu-Hammad O (2010) Fracture resistance of teeth restored with post-retained restorations: an overview *Journal of Endodontics* **36(9)** 1439-1449.

36. Ikeda I, Otsuki M, Sadr A, Nomura T, Kishikawa R, & Tagami J (2009) Effect of filler content of flowable composites on resin-cavity interface *Dental Materials Journal* **28(6)** 679-685.

37. Wei YJ, Silikas N, Zhang ZT, & Watts DC (2011) Diffusion and concurrent solubility of self-adhering and new resin-matrix composites during water sorption/desorption cycles *Dental Materials* **27(2)** 197-205.

38. Manicardi CA, Versiani MA, Saquy PC, Pecora JD, & de Sousa-Neto MD (2011) Influence of filling materials on the bonding interface of thin-walled roots reinforced with resin and quartz fiber posts *Journal of Endodontics* **37(4)** 531-537.