Original Article

pISSN, eISSN 0125-5614
M Dent J 2022; 42 (Suppl) : S15-S24

Fracture resistance of endodontically treated teeth restored with bulk-fill materials at different depths in root canals

Panuwat Seekongpan[1,2], Chayada Teanchai[3], Pong Pongprueksa[4], Pisol Senawongse[4]

[1] *Graduate student in the Master of Science Program in Operative Dentistry, Faculty of Dentistry, Mahidol University, Bangkok, Thailand*
[2] *Khon kaen hospital, Khon kaen, Thailand*
[3] *Ultrastructural Service Center, Research office, Faculty of Dentistry, Mahidol University, Bangkok, Thailand*
[4] *Department of Operative Dentistry and Endodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand*

Objective: This study aimed to compare fracture resistance of endodontically treated teeth restored with different bulk-fill materials as core materials and with different depths into the root canals.

Materials and Methods: Endodontically treated teeth with mesio-occluso-distal (MOD) cavities were prepared from extracted premolar teeth and divided into 3 experimental groups and 1 positive control group without any restorations. The teeth in experimental groups were divided into 2 subgroups according to the depth of gutta percha removal (*1:* the level of cemento-enamel junction (CEJ), and *2:* the level of 3 mm-below CEJ). The teeth were then restored with an Clearfil™ SE bond in combination with one of the following materials; light-curing bulk-fill materials: Ever-X posterior or SDR flow, or a self-curing core material: Multicore flow, and finally restored the top layer by Filtek Z350XT. The intact teeth were used as a negative control. All specimens were subjected to fracture resistance testing.

Results: The highest fracture resistance was observed in the negative control group (1438.83 ± 224.11N). No statistically significant differences were found between the group restored with bulk-fill materials (p>0.05) except between the group restored with the Multicore flow at CEJ and the group restored with Multicore flow below the level of 3 mm-below CEJ (p=0.028). The lowest fracture resistance value was found in the positive control group (298.16 ± 62.67N).

Conclusion: The restorations of endodontically treated teeth with light-curing bulk-fill materials could improve fracture resistance which was less than the fracture resistance of intact teeth.

Keywords: bulk-fil materials, depth, endodontically treated teeth, fracture resistance, root canal

How to cite: Seekongpan P, Teanchai C, Pongprueksa P, Senawongse P. Fracture resistance of endodontically treated teeth restored with bulk-fill materials at different depths in root canals. M Dent J 2022; 42(Suppl): S15-S24.

Introduction

Endodontically treated teeth become more prone to fracture than sound teeth as a result of loss of tooth structure from dental caries, dental fractures before endodontic treatment [1], endodontic procedures, and restorative procedures [2]. Consequently, an appropriate restorative technique is required to increase the survival rate for endodontically treated teeth [3]. Restoring endodontically treated teeth should preserve the tooth structure, exhibit good retention, and protect the remaining tooth structure. Good restoration may decrease the incidence of tooth fracture and the overloading occlusal forces [4]. Moreover, the restorations following the root canal treatment should improve the patient's aesthetics, gain the masticatory function, and prevent the reinfection of oral bacteria [5].

Correspondence author: Pisol Senawongse
Department of Operative Dentistry and Endodontics, Faculty of Dentistry, Mahidol University
6 Yothi Road, Ratchathewi, Bangkok 10400, Thailand
Tel. +66 2200 7997
Email: pisol.sen@mahidol.ac.th
Received: 12 May 2022 Revised: 27 June 2022 Accepted: 28 June 2022

The conventional restoration concept of endodontically treated teeth consists of a core building up and full-coverage restoration. In case of a tooth with one or no wall remaining, post-placement with core building up and full coverage restoration is necessary and recommended [6]. From a previous study, root canal-treated teeth with and without post-placement showed no significant difference in fracture resistance value. Therefore, this study demonstrated a negative result for the limitation of post-placement for strengthening the tooth [7]. Furthermore, the posts fixed in the root canals could dislodge [8], and more than 83% of endodontically treated teeth restored with either cast metallic posts or cores were fractured, extending over the middle of the root [9].

Currently, a new concept of restoration mimicking the natural teeth is named biomimetic restoration, which uses dental materials and technologies to mimic both tooth structures and functions. These current materials may provide stress absorption and distribution similar to the natural tooth and produce mechanical properties like human enamel and dentin [10,11]. Thus, biomimetic restoration for endodontically treated teeth is recommended to avoid post-placement and full crown preparation. Using the appropriate dental adhesives and reinforced fiber materials to distribute occlusal loads is preferable for this concept [12].

Nowadays, a new fiber-reinforced resin composite, EverX posterior, has been introduced as a material for dentin replacement. Its modulus of elasticity is comparable to dentin [13] which can increase fracture resistance for endodontically treated teeth [14,15]. This material consists of short fibers which distribute stress from the polymer matrix to fibers [15]. Numerous studies demonstrated either comparable or superior mechanical properties of this material, including compressive strength, flexural strength, and fracture toughness, compared to other bulk-fill composite resins. In addition, this material has been suggested to be used for restoration in a high stress-bearing area [13,16].

This study aimed to compare fracture resistance of endodontically treated upper premolar teeth restored with different core materials and depths of core materials into the root canals. Besides, fracture patterns were observed.

The null hypothesis of this study was that the teeth restored with different bulk-fill materials used as core materials and different depths into the root canal provided no statistically significant difference in fracture resistance.

Materials and Methods

The study protocol was approved by the Faculty of Dentistry/Faculty of Pharmacy, Mahidol University Institutional Review Board. Ninety-six extracted upper premolars stored in 0.1% Thymol solution (M Dent, Bangkok, Thailand, at 4 °C for up to six months after extraction were used in this study. The conditions of selected teeth were no carious lesion, no crack line, no craze line, no cervical lesion, and no restorative material. All teeth were alike on root and crown dimensions determined by a digital caliper that was not different over 10%.

The extracted upper premolar teeth were randomly divided into 8 groups of twelve teeth. The first twelve intact teeth were used as a negative control group. The remaining 84 teeth were subjected to endodontic treatment with rotary instruments. Endodontic access cavities were prepared using round diamond burs (016, Intensiv SA, Grancia, Switzerland). The cavity size was determined by 2/3 of the bucco-lingual intercuspal distance and 1/3 of the mesial to distal marginal ridge distance. The bur was changed after 10 teeth preparation. For root canals preparation, the root canals were negotiated by a size 10 K file (Dentsply Maillefer, Ballaigues, Switzerland) until the apical foramen. The working length was determined by subtracting 1 mm from the apical foramen. The root canals were prepared by the rotary files, Protaper NEXT (Dentsply Maillefer, Ballaigues, Switzerland), following the company instructions for both the rotary file size and the rotary motor. The rotary motor (VDW Silver Reciroc®, VDW GmbH, Munich, Germany) was set for torque 3 N/cm^2 and speed of 250 rpm. The root canal preparation method was the crown down technique until the final rotary file no. X3 (master apical file) was used. The root canal irrigation was performed with 2.5% Sodium hypochlorite (M Dent, Bangkok, Thailand) 2 ml between each file usage. Before the root canal obturation, the root canals were flushed with 17% EDTA (M Dent, Bangkok, Thailand) 2 ml for 1 minute and then 2.5% sodium hypochlorite 10 ml for 1 minute. Each root canal was dried using paper points. The root canals were obturated by Protaper X3 gutta percha (Dentsply Maillefer, Ballaigues, Switzerland) and sealed with an epoxy resin root canal sealer (AH Plus root canal sealer, Dentsply DeTrey, Konstanz, Germany). The lateral condensation technique was used for this gutta percha obturation at the level of CEJ. Then, the pulp chamber was cleaned with 70% alcohol (GPO Alcohol, the Government Pharmaceutical Organization, Bangkok, Thailand). Access cavities were filled with temporary filling material (Cavit™, 3M ESPE, St. Pual, MN, USA) and kept in 100% relative humidity for 24 hours at 37 °C.

MOD cavities were prepared on treated teeth by using a diamond taper bur (012, Intensiv SA, Grancia, Switzerland) with the dimension of 2/3 of the bucco-lingual intercuspal width and the proximal gingival floor located at the CEJ level. The new bur was changed every 10 teeth. Twelve prepared teeth without restoration were used for a positive control group.

The other 6 groups were used as experimental groups. Gutta percha was removed to the level of CEJ (CEJ groups) for 3 groups with an endodontic heat source (System B, Sybron Dental Specialties, WA, USA). For the remaining 3 groups, gutta percha was removed to 3 mm below CEJ (3 mm CEJ groups). The tofflemire matrix system (Hu-friedy, Chicago, IL, USA) was used to restore the prepared teeth in experimental groups. The cavity was then treated with a 2 step self-etching, light-cured adhesive system (Clearfil™ SE bond, Kuraray Medical Inc., Kyoto, Japan) following the manufacturer's instructions. The adhesive was cured with visible blue light for 10 seconds with a light intensity of 1,100 mW/mm^2 (Bluephase®, Ivoclar Vivadent, Schaan, Leichtenstein) as measured by a curing radiometer (Bluephase meter, Ivoclar Vivadent, Schaan, Leichtenstein). Twelve teeth in the CEJ group and twelve teeth in the 3 mm CEJ group were restored with Ever-X posterior (GC EUROPE N.V., Leuven, Belgium), SDR flow (Caulk Dentsply, York, PA, USA), or Multicore Flow (Ivoclar Vivadent, Schaan, Leichtenstein). The compositions used materials are demonstrated in Table 1. The teeth were restored using an incremental technique, 4 mm thickness, with 20 seconds of light-curing for bulk-fill materials, and then restoring the top layer 2 mm thickness by Filtek Z350XT shade A2 (3M ESPE, St. Paul, USA) with 20 second light curing. For Multicore flow, a bulk technique with 20 seconds of light-curing was used, then restoring the top layer 2 mm thickness by Filtek Z350XT shade A2. The restored specimens were then polished with a polishing system (Enhance, Dentsply, Milford, DE, USA). All specimens were stored in a 100% humidity container for 24 hours at 37 °C before fracture resistance testing.

Table 1 Composition of materials

Materials	Type	Compositions
MultiCore Flow (Ivoclar Vivadent, Schaan, Liechtenstein)	Self-curing core build-up composite with light-curing option	- Bis-GMA, urethane dimetha-crylate, Triethyleneglycoldimethacrylate - Barium glass fillers, Ba-Al-fluorosilicate glass, highly dispersed silicon dioxide (Base: 54.9 wt% Catalyst: 54.4 wt%) - Ytterbium trifluoride (Base: 16.4 wt% Catalyst: 16.2 wt%) - Catalysts, stabilizers, pigments
Ever-X Posterior (GC EUROPE N.V., Leuven, Belgium)	Light-curing bulk-fill fibre reinforced composite resin	- Bis-GMA, TEGDMA, PMMA (Semi-Interpenetrating Polymer Network Matrix) - Short E-Glass Fibre Fillers, Barium Glass, Inorganic Particulate Fillers (74.2 wt%)
Surefil SDR flow (Caulk Dentsply, York, PA, USA)	Light-curing bulk-fill composite resin	- Modified UDMA, EBPADMA, TEGDMA - Barium-aluminofluoroborosilicate glass, strontium-aluminofluoroborosilicateglass (68 wt%)

Before the fracture resistance testing, the root surfaces were marked 2 mm below the CEJ and covered by the 0.3 mm thick modeling wax (Covex Set Up Regular Modelling Wax, Covex Holland BV, Haarlem, Netherlands). Then, the tooth was embedded in a polyvinyl chloride (PVC) plastic cylindrical mold 25 mm in width and 22 mm in height by the self-cured acrylic resin (Ortho-Jet^{TM}, Lang Dental Manufacturing Co. Inc., IL, USA). Then, the modelling wax was removed from the root surfaces. The polyether impression materials (Impregum^{TM} Soft, 3M ESPE, St Paul, USA) was injected into the acrylic resin blocks in the site that was previously occupied by the tooth root and wax, then the tooth was reinserted into the resin blocks. For this attempt, the periodontal ligament was simulated (Figure 1).

All embedded specimens were subjected to fracture resistance testing by the universal testing machine (Instron 5566, London, England). The 6 mm stainless steel sphere was set to contact at the inclined plane of the buccal cusp and lingual cusp (Figure 2). The compressive force was applied onto the tooth that was parallel to the long axis of the tooth and subjected to 1 mm/min crosshead speed until the fracture occurred. Fracture resistance values were recorded in newton (N).

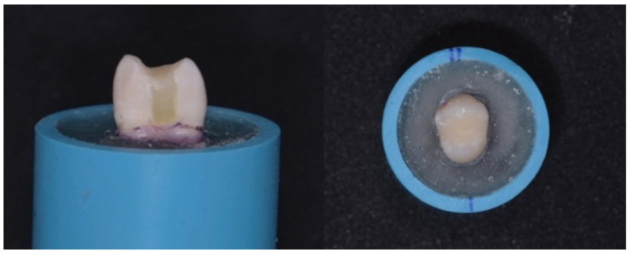

Figure 1 The embedded specimens

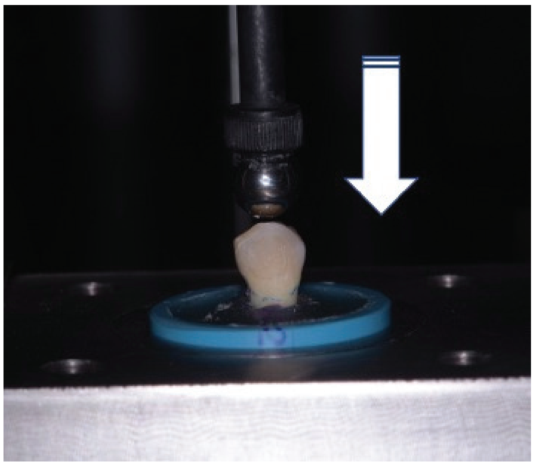

Figure 2 Fracture resistance testing (the arrow demonstrates the direction of loading)

Thereafter, fracture patterns were further observed under a stereomicroscope (Nikon SMZ1000, Nikon; Kanagawa, Japan) at 20x magnification. The types of fracture patterns were divided into 2 groups as following; restorable fracture (R): fracture occurring near gingival margin and below CEJ less than 1 mm and non-restorable fracture (NR): fracture occurring near gingival margin and below CEJ more than 1 mm.

Result

The mean fracture resistance and standard deviation for each group were demonstrated in Table 2. The highest fracture resistance value occurred in a negative control group (1438.83 ± 224.11 N). The mean fracture resistance in Multicore flow CEJ group was 560.74 ± 162.81 N. SDR CEJ group was 495.90 ± 109.61 N. SDR 3mm CEJ group was 475.46 ± 88.48 N. Ever-X 3mm CEJ group was 455.13 ± 128.72 N. Ever-X CEJ group was 427.02 ± 58.22 N and Multicore flow 3mm CEJ group was 356.37 ± 69.48 N subsequently. The lowest fracture resistance value occurred in a positive control group (298.16 ± 62.67N).

Data was tested for normality by using Kolmogorov-Smirnov test at $\alpha = 0.05$. All groups showed normal data distribution ($p>0.05$) except the group that restored with SDR flow below the level of CEJ 3 mm. and the group that restored with the Multicore flow at the level of CEJ. The Levene's test was used to test the homogeneity of variance. The data revealed no statistically significant difference. The fracture resistance was accepted by parametric statistics. The one-way ANOVA and Dunnett T3 multiple comparisons were used for analysis. The means fracture resistance value and the standard deviations for each group are reported in Table 1. The negative control group (intact premolar tooth) showed the highest statistically significant fracture resistance among other groups ($p<0.05$). No statistically significant difference was found in each group that was restored with bulk-fill resin composite ($p>0.05$) except between the group restored with the Multicore flow at CEJ and the group restored with the Multicore flow at below the level of 3 mm CEJ ($p=0.028$). The positive control group showed the lowest statistically significant fracture resistance among other groups ($p<0.05$) except for the group that restored with the multicore flow below the level of 3 mm CEJ ($p=0.602$). The fracture resistance of the group restoring with the Multicore flow at the level of CEJ (560.74 ± 162.81 N) was significantly higher than the group restoring with the Multicore flow at the level of 3 mm CEJ (356.37 ± 69.48 N).

Table 2 Means ± standard deviations of fracture resistance recorded in newton (N)

Group description	CEJ	3 mm CEJ
Ever-X posterior	*427.02 ± 58.22^{B,C}*	455.13 ± 128.72^{B,C}
SDR® flow	*495.90 ± 109.61^{B,C}*	475.46 ± 88.48^{B,C}
Multicore flow	*560.74 ± 162.81^{B}*	356.37 ± 69.48^{C,D}
Negative control	*1438.83 ± 224.11^{A}*	
Positive control	*298.16 ± 62.67^{D}*	

The data with the same superscripts demonstrate no statistically significant differences. (CEJ: cemento-enamel junction, 3 mm CEJ: 3 mm below the CEJ)

The representative specimens of restorable fracture mode and non-restorable fracture mode are demonstrated in Figures 4 and 5. The restorable fracture specimen showed the fracture occurring near the gingival margin above CEJ, whereas the non-restorable fracture specimen showed the fracture occurring below CEJ more than 1 mm. The percentages of fracture modes for each group are shown in Figure 6. All teeth in a negative control group and Ever-X 3 mm CEJ group demonstrated a restorable pattern. Restorable fracture mode was found in 40% of the SDR CEJ group, 41.66% in the SDR 3 mm CEJ group, 25% in the Multicore flow CEJ group, and 41.66% in the Multicore flow 3 mm CEJ group, respectively. All the teeth in a positive control group showed a non-restorable pattern. The fracture modes were statistically analyzed using the Wilcoxon and Mann-Whitney U tests. The significant values between groups are demonstrated in Table 3.

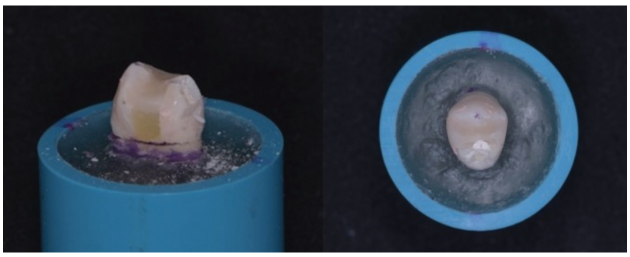

Figure 4 Restorable fracture mode

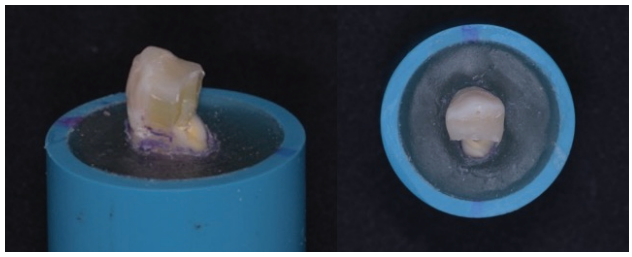

Figure 5 Non-restorable fracture mode

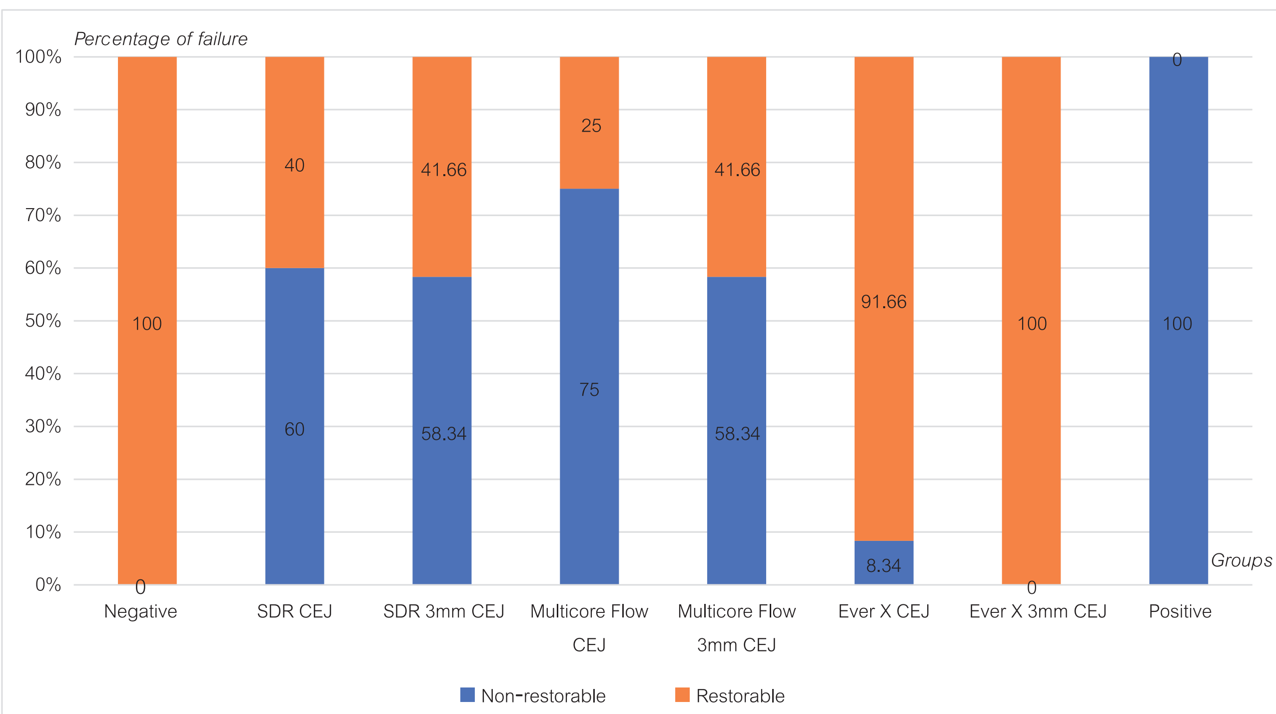

Figure 6 Percentages of failure modes distribution

Table 3 The *p*-values of statistical analysis of failure modes between two groups.

	Negative	SDR CEJ	SDR 3mm CEJ	Multicore Flow CEJ	Multicore Flow 3mm CEJ	Ever-X CEJ	Ever-X 3mm CEJ	Positive
Negative	-	0.001*	0.002*	0.000*	0.002*	0.317	1.000	0.000*
SDR CEJ	0.001*	-	0.680	0.660	0.680	0.004*	0.001*	0.032*
SDR 3mm CEJ	0.002*	0.680	-	0.397	1.000	0.011*	0.002*	0.014*
Multicore Flow CEJ	0.000*	0.660	0.397	-	0.397	0.001*	0.000*	0.070
Multicore Flow 3mm CEJ	0.002*	0.680	1.000	0.397	-	0.011*	0.002*	0.014*
Ever-X CEJ	0.317	0.004*	0.011*	0.001*	0.011*	-	0.317	0.000*
Ever-X 3mm CEJ	1.000	0.001*	0.002*	0.000*	0.002*	0.317	-	0.000*
Positive	0.000*	0.032*	0.014*	0.070	0.014*	0.000*	0.000*	-

The data with * demonstrate a statistically significant difference. (CEJ: cemento-enamel junction, 3 mm CEJ: 3 mm below the CEJ)

Table 3 revealed that failure mode was not a statistically significant difference between the negative control group and Ever-X posterior group (p=0.317), which demonstrated a similar restorable pattern. No significant differences in failure patterns among groups were found when the teeth were restored with SDR and Multicore flow for both restoration at CEJ and 3 mm CEJ. A statistically significant difference in the failure mode pattern between the positive control group and other groups was found, which showed a non-restorable pattern.

Discussion

The results of the present study demonstrated significant differences between light cure bulk-fill materials and different depths in root canals; therefore, the null hypotheses should be rejected.

The worst-case scenario of endodontically treated teeth with MOD cavity preparation has been reported in clinical simulation. From previous studies, root canal treated teeth with extensive MOD preparation showed increased cuspal deflection and decreased tooth stiffness by 69% [2,17]. In addition, the MOD cavity with the dimension of half of the intercuspal distance could further reduce the strength of the remaining tooth structure [18]. According to the results of this study, the fracture resistance of intact teeth was 1438.83 ± 224.11 N and the fracture resistance of endodontically treated teeth with MOD preparation was 298.16 ± 62.67 N. From the calculation, the endodontic treatment and MOD preparation might cause reduction of fracture resistance 79.28%. This was supported by previous studies [17,18].

The resin composite core materials are often used for restoring endodontically treated teeth because these materials have a modulus of elasticity similar to dentin, resulting in decreased stress concentration within the root canal [19-21]. According to the biomimetic concept for restoration of endodontically treated teeth, avoiding post-placement and full crown preparation are recommended. Furthermore, using the appropriate dental adhesives and reinforced fiber materials to distribute occlusal loads is preferable for this concept [12].

Currently, bulk-fill resin composites are a new class of dental resin composite materials, which were introduced to ease the placement of direct composite restorations with a greater depth of cure. These composite materials are clinically recommended for a 4-mm bulk increment with appropriate polymerization [22]. In addition, these materials were designed to decrease the shrinkage stress and allow bulk placement of resin composite; this procedure is called the stress-decreasing technology [23,24].

From current results, the restoration of endodontically treated teeth with either core material (Multicore flow) or bulk-fill composite materials could improve the fracture resistance of endodontically treated teeth. Therefore, the restorations could not achieve fracture resistance of intact teeth.

Dual-curing composite resins are recommended for core build-ups. The benefit of dual-curing resin materials may be the ability to do the core build-up in a single-step technique without the need for layering while minimizing the risk of light attenuation that would disrupt the setting of the deepest portions of the resin material [25]. The fracture resistance of the teeth restored to the level of CEJ with the Multicore flow of this study was 560.74 ± 162.81 N which was higher than a previous study (277.95±13.76 N) [26]. Because of the use of lower premolar in the previous study, the differences in teeth and testing methods might affect the difference in results from this study.

Therefore, no significant differences in fracture resistance among groups restored with light-curing bulk-fill composites and dual-curing composite resin for different depths of restoration were found. The different compositions and curing protocols might not affect the fracture resistance at each depth of restoration in this study. The poor polymerization from the inability of the light from the light-curing unit to penetrate the deep part of light-curing materials [27] might not be observed because of the use of bulk-fill materials. In addition, this study revealed no statistically significant differences in fracture resistance among groups that were restored with bulk-fill resin composite for any depth of restoration. This result corresponds to a previous study [28].

In this study, the fracture resistance value of Ever-X posterior was 427.02 N and 455.13 N when restored at the level of CEJ and below the level of CEJ 3 mm respectively. Previous studies demonstrated that the fracture resistance value of Ever-X posterior restored in premolar teeth was 909.2 N [29] and restored in molar teeth was 1994.8 N [30]. The different adhesive systems and the different experimental designs might affect the difference in results. From our calculation, the teeth restored with Ever-X posterior gained fracture resistance values equal to 43.29% and 52.68% at the level of CEJ and below the level of CEJ 3 mm. subsequently when compared with the positive control group. It indicated that these groups could absorb loading force properly. However, the intact teeth still have higher fracture resistance than these groups.

Regarding the analysis of fracture patterns, the restorations with Ever-X posterior showed fracture patterns in restorable pattern prominently. Because of short E-glass fibers in the Ever-X posterior, these glass fibers might inhibit crack propagation and transfer stress from the polymer matrix to fibers [14] leading to the fracture of the teeth in a restorable pattern.

For the selection of the materials in this study, Clearfil SE bond, a self-etching, the light-curing adhesive system was used. Clearfil SE Bond showed higher shear bond strength than other universal adhesives in a previous review [31]. This adhesive system has more hydrophobic, that cause increasing in the degree of conversion of the adhesive layer [32] and reducing the water movement from beneath the dentin to the adhesive layer [33]. Because of the high efficiency for bonding, the Clearfil SE Bond was used for bonding all specimens in this study. In addition, EverX posterior and SDR flow (light-curing bulk-fill materials) were used for dentin replacement because these materials have mechanical properties similar to dentin including the elastic modulus [13]. In particular, short E-glass fiber in EverX posterior transfers stress from the polymer matrix to fibers, as previous results improve the fracture resistance of the tooth structure and provide a favorable fracture pattern [14,15]. These materials were used for core build-up in this study that was compared with Multicore Flow which is commonly used in the core build-up.

Conclusion

Under the conditions and limitations of this study, the differences of fracture resistances were not found when the endodontically treated teeth were restored with light-curing bulk-fill materials which were less than the fracture resistance of intact teeth. The use of fiber-reinforced light-curing bulk-fill material reduced the incidence of non-restorable failure.

References

1. Maxwell EH, Braly BV, Eakle WS. Incompletely fractured teeth--a survey of endodontists. *Oral Surg Oral Med Oral Pathol* 1986; 61: 113-7.
2. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. *J Endod* 1989; 15: 512-6.
3. Lazarski MP, Walker WA, 3rd, Flores CM, Schindler WG, Hargreaves KM. Epidemiological evaluation of the outcomes of nonsurgical root canal treatment in a large cohort of insured dental patients. *J Endod* 2001; 27: 791-6.
4. Harold HM, Charles JG. Preparation for restoration. In: Mahmoud T, Richard EW, Ashraf FF. Endodontics principles and practice. 5th ed. Missouri: Elsevier saunders; 2015. p.304.
5. Didier D, Serge B, Avishai S. Restoration of the endodontically treated tooth in Kenneth MH, Louis HB. Cohen's pathways of the pulp. 11st ed. Missouri: Elsevier saunders; 2016. p.854-84.
6. Peroz I, Blankenstein F, Lange KP, Naumann M. Restoring endodontically treated teeth with posts and cores--a review. *Quintessence Int* 2005; 36: 737-46.
7. Baratieri LN, De Andrada MA, Arcari GM, Ritter AV. Influence of post placement in the fracture resistance of endodontically treated incisors veneered with direct composite. *J Prosthet Dent* 2000; 84:180-4.
8. Ferrari M, Vichi A, Mannocci F, Mason PN. Retrospective study of the clinical performance of fiber posts. *Am J Dent* 2000;13(Spec No):9B-13B.
9. Hayashi M, Takahashi Y, Imazato S, Ebisu S. Fracture resistance of pulpless teeth restored with post-cores and crowns. *Dent Mater* 2006; 477-85 :22
10. Goswami S. Biomimetic dentistry. *J Oral Res Rev* 2018; 10: 28-32.
11. Malterud, M.I. Minimally invasive restorative dentistry: biomimetic approach: *Pract Proced Aesthet Dent.* 2006; 18:409-14.
12. Randall GC. Biomimetic perspective on the restoration of endodontically treated teeth: *Inside Dentistry* 2017;131)) (https://www.aegisdentalnetwork.com/id/2017/01/biomimeticperspective-on-the-restoration-of-endodontically-treated-teeth)
13. Leprince JG, Palin WM, Vanacker J, Sabbagh J, Devaux J, Leloup G. Physico-mechanical characteristics of commercially available bulk-fill composites. *J Dent* 2014; 42: 993-1000.
14. Eapen AM, Amirtharaj LV, Sanjeev K, Mahalaxmi S. Fracture resistance of endodontically treated teeth restored with 2 different fiber- reinforced composite and 2 conventional composite resin core buildup materials: an in vitro study. *J Endod* 2017; 43: 1499-1504.

15. Garlapati, TG, Krithikadatta J, Natanasabapathy V. Fracture resistance of endodontically treated teeth restored with short fiber composite used as a core material-an in vitro study. *J Prosthodont Res* 2017; 61: 464-70.
16. Abouelleil H, Pradelle N, Villat C, Attik N, Colon P, Grosgogeat B. Comparison of mechanical properties of a new fiber reinforced composite and bulk filling composites. *Restor Dent Endod* 2015; 40: 262-70.
17. Larson TD, Douglas WH, Geistfeld RE. Effect of prepared cavities on the strength of teeth. *Oper Dent* 1981; 6:2–5.
18. Belli S, Eraslan O, Eskitascioglu G. Direct restoration of endodontically treated teeth: a brief summary of materials and techniques. *Curr Oral Health Rep* 2015; 2:182–9.
19. Akkayan B, Gülmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. *J Prosthet Dent* 2002; 87: 431-7.
20. Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. *J Prosthet Dent* 2003; 89: 360-7.
21. Okada D, Miura H, Suzuki C, Komada W, Shin C, Yamamoto M, *et al.* Stress distribution in roots restored with different types of post systems with composite resin. *Dent Mater J* 2008; 27: 605-11.
22. Burgess J, Cakir D. Comparative properties of low-shrinkage composite resins. *Compend Contin Educ Dent* 2010;31(Spec No 2):10-15.
23. Rosatto CM, Bicalho AA, Veríssimo C, Bragança GF, Rodrigues MP, Tantbirojn D, *et al*. Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. *J Dent* 2015; 43: 1519-28.
24. Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, Fleming GJ. Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials. *J Dent* 2012; 40: 500-5.
25. Vandewalker JP, Casey JA, Lincoln TA, Vandewalker KS. Properties of dual- cure, bulk-fill composite resin restorative materials. *Gen Dent* 2016; 64: 68-73.
26. Lawbundis K, Vongphan N, Muangmingsuk A, Senawongse P. Effect of fiber post lengths on fracture resistance of endodontically treated teeth. Mahidol Dent J 2015; 35: 91-100.
27. Giachetti L, Scaminaci Russo D, Bambi C, Grandini R. A review of polymerization shrinkage stress: current techniques for posterior direct resin restorations. *J Contemp Dent Pract* 2006; 7: 79-88.
28. Atalay C, Yazici AR, Horuztepe A, Nagas E, Ertan A, Ozgunaltay G. Fracture resistance of endodontically treated teeth restored with bulk fill, bulk fill flowable, fiber-reinforced, and conventional resin composite. *Oper Dent* 2016; 41: E131-E40.
29. Kaur B, Gupta S, Grover R, Sadana G, Gupta T, Mehra M. Comparative evaluation of fracture resistance of endodontically treated teeth restored with different core build-up materials: an in vitro study. *Inter J Clin Pediatr Dent* 2021; 14: 51-8.
30. Garlapati TG, Krithikadatta J, Natanasabapathy V. Fracture resistance of endodontically treated teeth restored with short fiber composite used as a core material-an in vitro study. *J Prosthodont Res* 2017; 61: 464-70.
31. Van Meerbeek B, Yoshihara K, Yoshida Y, Mine A, De Munck J, Van Landuyt KL. State of the art of self-etch adhesives. *Dent Mater* 2011; 27: 17-28.
32. Sadek FT, Calheiros FC, Cardoso PE, Kawano Y, Tay F, Ferrari M. Early and -24hour bond strength and degree of conversion of etch-and-rinse and self-etch adhesives. *Am J Dent* 2008; 21: 30-4.
33. Tay FR, Pashley DH, Yoshiyama M. Two modes of nanoleakage expression in single-step adhesives. *J Dent Res* 2002; 81: 472-6.