©Operative Dentistry, 2016, **41-5,** E131-E140

Fracture Resistance of Endodontically Treated Teeth Restored With Bulk Fill, Bulk Fill Flowable, Fiber-reinforced, and Conventional Resin Composite

C Atalay • AR Yazici • A Horuztepe • E Nagas • A Ertan • G Ozgunaltay

Clinical Relevance

The restoration of endodontically treated teeth with either bulk fill/flowable bulk fill or fiber-reinforced resin restorative did not change the fracture resistance of teeth compared with that of a conventional nanohybrid resin composite.

SUMMARY

The aim of this *in vitro* study was to evaluate the fracture resistance of endodontically treated teeth restored with different types of restorative resins.

Methods and Materials: Seventy-two sound maxillary premolar teeth were randomly divided into six groups (n=12). The teeth in the first group were left intact and tested as unprepared negative control (group I) specimens. The teeth in the remaining five groups were prepared with MOD cavities and endodontically treated. The teeth in one of the five groups (positive control group II) were unrestored. The rest of the prepared cavities were restored as follows: group III: bulk fill resin composite/Filtek Bulk Fill (3M ESPE); group IV: bulk fill flowable resin composite + nanohybrid/SureFil SDR Flow + Ceram.X Mono (Dentsply); group V: fiber-reinforced composite + posterior resin composite/GC everX posterior + G-aenial posterior (GC Corp.); and group VI: nanohybrid resin composite/Tetric N-Ceram (Ivoclar/Vivadent). Each restorative material was used with its respective adhesive system. The restored teeth were stored in distilled water for 24 hours at 37°C and were then thermocycled (5-

Cansu Atalay, DDS, Department of Restorative Dentistry, School of Dentistry, Hacettepe University, Ankara, Turkey

*A Rüya Yazici, DDS, PhD, Department of Restorative Dentistry, School of Dentistry, Hacettepe University, School of Dentistry, Ankara, Turkey

Aynur Horuztepe, DDS, PhD, private practice, Ankara, Turkey

Emre Nagas, DDS, PhD, Department of Endodontics, School of Dentistry, Hacettepe University, Ankara, Turkey

Atilla Ertan, DDS, PhD, Department of Prosthodontics, School of Dentistry, Hacettepe University, Ankara, Turkey

Gul Ozgunaltay, DDS, PhD, Department of Restorative Dentistry, School of Dentistry, Hacettepe University, Ankara, Turkey

*Corresponding author: Sihhiye, Ankara, 06100, Turkey; e-mail: ruyay@hacettepe.edu.tr

DOI: 10.2341/15-320-L

55°C, 1000×). Specimens were subjected to a compressive load until fracture at a crosshead speed of 0.5 mm/min. The data were analyzed using one-way analysis of variance followed by the post hoc Tukey honestly significantly different test ($p<0.05$).

Results: Sound premolar teeth (group I negative control) showed significantly higher fracture resistance than did the other tested groups ($p<0.05$). No statistically significant differences were found in the fracture resistance values of the restored groups (groups III, IV, V, and VI) ($p>0.05$). The lowest values were obtained in the positive control group (group II); these values were significantly lower than those of the other groups ($p<0.05$).

Conclusion: The fracture resistance values of endodontically treated teeth restored with either bulk fill/bulk fill flowable or fiber-reinforced composite were not different from those restored with conventional nanohybrid resin composite.

INTRODUCTION

Trauma, caries, extensive cavity preparation, and endodontic treatments are the most common reasons for tooth fragility.[1] As a result of the loss of water content and anatomic structures, such as the pulp chamber roof, endodontically treated teeth are more susceptible to fracture than are vital teeth.[2] The amount of residual coronal dentin is considered of primary importance in the prognosis of endodontically treated teeth. Supporting the remaining dental structures is crucial for the long-term success of treatment.[3] Deciding how to implement a restorative protocol for endodontically treated teeth with variable remaining tooth structure is challenging for operators when excessive structure has been lost. There are many different direct and indirect treatment options for these kinds of teeth, such as crowns (with or without post placement), onlays/inlays, and direct resin-based restorative materials.[4]

Restoration of a tooth with adhesive procedures and direct resin composites eliminates excessive loss of sound tooth structure and overpreparation. Direct resin-based composite restorations are applied in one treatment session at relatively low cost. As there are many different types of tooth-colored direct restorative materials available in the dental market, it is important to determine which materials are successful to ensuring a long-lasting restoration in endodontically treated teeth.

Although conventional resin composites are used for restoration of endodontically treated teeth, their major shortcoming, polymerization shrinkage, is still present.[5] In larger cavities, the polymerization shrinkage that leads to higher stress accumulation on the tooth than on the restoration is considered responsible for a series of clinical complications, including higher risk of tooth fracture.[6] In order to reduce polymerization shrinkage stress and to maintain adequate depth of cure, incremental placement of resin composites has been routinely used in daily practice. However, the use of 2-mm-thick resin composite materials incrementally for direct restorations is time consuming, increases the risk of contamination between layers, and may include voids in the restoration.[7,8]

Bulk fill resin composites are an innovative class of dental resin composite materials, developed to simplify the placement of direct composite restorations.[9] They include low-viscosity, flowable, and high-viscosity material types. According to the manufacturers, they can be efficiently light-cured at depths up to 4-5 mm and cause low polymerization shrinkage stress at the same time. However, as their surface hardness and modulus of elasticity are low, there is a requirement to place a final capping layer (made of a conventional composite material) on top of these restorative materials. In contrast, high-viscosity bulk fill resin composites are indicated for use without veneering and can thus be applied as single-step bulk fill materials.[10,11] In a recent study,[12] it was found that the tested bulk fill resin composites can be cured effectively at a depth of at least 4 mm.

Fiber-reinforced composites have been suggested[13] to reduce polymerization shrinkage and to increase toughness and impact strength, thereby enhancing the fracture resistance of restored teeth. These composites have been improved as a base filling material in high–stress-bearing areas, especially in large cavities. They contain E-glass fiber made of aluminoborosilicate glass with less than 1 wt% alkali oxides. Nayar and others[14] have reported that E-glass fibers are able to maintain strength properties over a wide range of conditions and are relatively insensitive to moisture and are chemical-resistant. Garoushi and others[15] compared the physical properties and curing depth of a new short fiber–reinforced composite with that of conventional and bulk fill resin composites. They found that the fiber-reinforced composite exhibited higher fracture toughness and flexural strength and a lower percentage of shrinkage strain than did all other tested materials.

There are limited data about the fracture resistance of endodontically treated teeth restored with fiber-reinforced and bulk fill resin composites.[16,17] In order to learn more in this respect, the current study was conducted to investigate the fracture resistance of endodontically treated teeth restored with bulk fill, bulk fill flowable, fiber-reinforced, and nanohybrid composites. The null hypothesis was that there would be no statistically significant difference in the fracture resistance of endodontically treated teeth restored with different types of tooth-colored restorative resins.

METHODS AND MATERIALS

Seventy-two sound human maxillary premolars extracted for orthodontic purposes were used for the study. Any calculus and soft tissue deposits were removed from the teeth using a hand scaler. Each tooth was carefully examined under a light microscope at 20× magnification for any existing enamel cracks or fractures. Teeth of similar buccolingual and mesiodistal width in millimeters (buccolingual width: 8.47-10.59 mm; mesiodistal width: 6.38-8.19 mm) were selected by measuring with a digital micrometer (Series 480–505, resolution 1 μm, SHAN; Precision Measuring Instruments, Guilin, China) and allowing for a maximum deviation of 10% from the determined mean. The roots of the teeth were also similar in size and shape. The samples were stored in distilled water at 37°C for up to one month before use.

Standardized Class II MOD cavities were prepared with diamond burs (Diatech, Heerbrugg, Germany) that were replaced after every fourth cavity preparation. The gingival floor was 1.0 mm above the cemento-enamel junction (CEJ). The width of the cavities in the isthmus was one-third of the intercuspal distance, and the approximal box was two-thirds of the buccal palatal width. The cavosurface margins were prepared at 90°, and all internal line angles were rounded. The dimensions of the preparations were verified with a periodontal probe.

Standard endodontic access cavities were prepared using a high-speed handpiece. The pulp chamber roof was penetrated with a #2 diamond round bur (Dentsply, Tulsa Dental Specialties; Tulsa, OK, USA), then extended with a tapering cylinder bur; wall overhangs were removed with the same round bur. Thereafter, size 10 K files (Mani Inc, Tochigi, Japan) were inserted into the root canals until their tips could be seen at the apical foramen. The working length was determined by subtracting 0.5 mm from this length. The root canals were prepared using ProTaper rotary instruments (Dentsply-Maillefer, Ballaigues, Switzerland) up to master apical rotary size F3 (#30), in conjunction with 2 mL of 5.25% sodium hypochlorite irrigation between each file. Prepared root canals were rinsed with 5 mL of 17% ethylenediamine tetraacetic acid (Pulpdent Corporation, Watertown, MA, USA), followed by a final rinse with 5 mL of distilled water, and were then dried using paper points. Thereafter, the roots were filled with ProTaper F3 gutta-percha and AH Plus (Dentsply DeTrey, Konstanz, Germany) epoxy resin-based root canal sealer by single-cone technique. Excessive coronal gutta-percha was removed, and samples were stored in 100% humidity for seven days to allow the sealer to set. The endodontic access cavities were sealed with a thin layer of resin-modified glass ionomer cement (Novaseal, President Dental, Munich, Germany). A specialist in endodontics performed the endodontic treatments.

A universal metal matrix band/retainer (Tofflemire) was placed around each prepared tooth and supported externally by low-fusing compound to maintain adaptation of the band to the cavity margins.

The teeth were randomly divided into six groups of 12 teeth, as follows.

Group I

Group I comprised intact teeth without any cavity preparation; these teeth were used as negative controls.

Group II

Group II comprised MOD-prepared teeth only; these teeth were not restored and were used as positive controls.

Group III

For group III teeth, the cavities were etched for 30 seconds on enamel and for 15 seconds on dentin with 35% phosphoric acid (Scotchbond Universal Etchant, 3M ESPE, St Paul, MN, USA), rinsed for 15 seconds, and gently air-dried, leaving the tooth moist. The adhesive Single Bond Universal (3M ESPE), used in etch-and-rinse mode, was applied for 20 seconds; the solvent was air-dried for five seconds and then light-cured for 10 seconds by LED (Cromalux 1200, Mega-Physik, Rastatt, Germany; 1400 mW/cm^2). The cavities were restored with a bulk fill resin composite, Filtek Bulk Fill Posterior Restorative (3M ESPE). Each layer was approximately 5 mm thick

and was cured for 40 seconds with the same light-curing unit.

Group IV

For the teeth in group IV, after etching, as was done for the teeth in group III, a two-step etch-and-rinse adhesive, Prime&Bond NT (Dentsply/De Trey), was applied and remained fully wet for 20 seconds; teeth were then gently air-dried for five seconds and light-cured for 10 seconds. The cavities were filled with bulk fill flowable composite (SureFil SDR Flow, Dentsply) at up to 4 mm in thickness and were then cured for 40 seconds. The remaining parts of the cavities were restored with increments at a maximum of 2 mm in thickness using nanoceramic resin composite (Ceram.X Mono, Dentsply) and were light-cured for 40 seconds.

Group V

For the teeth in group V, a one-step self-etch adhesive, G-aenial Bond (GC Corp, Tokyo, Japan), was applied, remaining undisturbed for 10 seconds, and teeth were then dried for five seconds under maximum air pressure and light-cured for 10 seconds by LED. Fiber-reinforced composite (GC everX posterior, GC Corp) measuring approximately 4 mm in thickness was placed, and enough space was left for the overlaying composite on all surfaces of the restoration. The resin composite was cured for 40 seconds. The remaining parts of the cavities were restored with increments at a maximum of 2 mm in thickness using a posterior resin composite, G-aenial Posterior (GC Corp), and light-cured for 40 seconds.

Group VI

For the teeth in group VI, after etching, as in group III, a two-step etch-and-rinse adhesive, Excite F (Ivoclar/Vivadent, Schaan, Liechtenstein), was applied, agitated for 10 seconds, gently air-dried, and light-cured for 10 seconds. The cavities were restored with a conventional nanohybrid resin composite, Tetric N-Ceram, (Ivoclar/Vivadent), incrementally. Each layer was 2 mm thick and was light-cured for 40 seconds.

All restorative materials were used with their respective adhesive system. The materials for the restorative procedures are listed in Table 1. The restorations were finished with a high-speed handpiece under an air/water spray using diamond finishing burs (Diatech Dental AC). Subsequently, polishing was completed with polishing discs (Soflex, 3M ESPE) and rubber points. All preparations and restorations were performed by the same operator except in the case of the endodontic treatments. The specimens were stored in distilled water at 37°C for 24 hours. They were then subjected to thermocycling at between 5°C and 55°C (dwell time 30 seconds) for 1000 cycles (MTE 101 Thermocycling Machine, Esetron, Ankara, Turkey).

A coat of wax (0.2-0.3 mm) was applied to the external root surface of each tooth. All teeth were embedded in a block of self-curing acrylic resin up to 1 mm apical to the CEJ, with the long axis of the tooth perpendicular to the base of the block. Then the wax on the root surfaces was melted with boiling water, and this space was filled with polyvinyl siloxane impression material (Vinylight, BMS Dental, Pisa, Italy) to simulate periodontal ligament.

The specimens were submitted to compression in a universal testing machine (Instron, Lloyd, UK). A steel sphere 8 mm in diameter in contact with the occlusal slopes of buccal and palatal cusps was used to apply an occlusal load perpendicular to the long axis of the tooth at a crosshead speed of 1 mm/min. The load was applied until fracture occurred and was recorded in newtons (N).

Means and standard deviations were determined for each group, and data were statistically analyzed with one-way analysis of variance followed by the post hoc Tukey honestly significantly different test. Analyses were carried at the 5% significance level using SPSS 11.5 for Windows (SPSS Inc, Chicago, IL, USA).

The fractured specimens were examined under a stereomicroscope (40×) to evaluate the fracture patterns, which were classified as follows: mode I, minimal destruction of teeth; mode II, fracture of one cusp, intact restoration; mode III, fracture of at least one cusp, involving up to one-half of restoration; mode IV, fracture of at least one cusp, involving more than one-half of restoration; and mode V, severe fracture, involving tooth structure completely and/or longitudinal fracture.[18]

RESULTS

The mean fracture resistance values (N) and the standard deviations for each group are presented in Table 2. Sound premolar teeth (group I—negative control, 924.1 N) showed significantly higher fracture resistance than did the other tested groups ($p<0.05$). The lowest values were obtained in the positive control group (group II, 497.8 N), which were significantly lower than those of the other groups ($p<0.05$). No statistically significant differ-

Table 1: *Materials Used in the Study*

Product Name	Type	Manufacturer/Batch No.	Composition
Filtek Bulk Fill	Bulk fill posterior restorative	3M ESPE, St Paul, MN, USA/ N604746	Inorganic fillers, Bis-GMA, UDMA, Bis-EMA, procrylat resins, ytterbium trifluoride, zirconia/silica
Single Bond Universal	Universal adhesive (etch-and-rinse mode)	3M ESPE, St Paul, MN, USA/ 527687	MDP phosphate monomers, dimethacrylate resins, HEMA, methacrylate-modified polyalkenoic acid copolymer, fillers, ethanol, water, initiators, silane
SureFil SDR Flow	Bulk fill flowable resin composite	Dentsply DeTrey, Konstanz, Germany/1207205	Barium and strontium alumino-fluoro-silicate glass, TEGDMA, modified UDMA, dimethacrylate, Bis-EMA, pigment, photoinitiator
Ceram.X Mono	Nanoceramic resin composite	Dentsply DeTrey, Konstanz, Germany/1203000406	Methacrylate modified polysiloxane, dimethacrylate resin, barium-aluminum-borosilicate glass, methacrylate functionalized silicon dioxide nanofillers
Prime&Bond NT	Nano-technology dental adhesive (two-step etch-and-rinse)	Dentsply DeTrey, Konstanz, Germany/1306000189	Di- and trimethacrylate resins, functionalized amorphous silica, PENTA, stabilizers, cetylamine hydrofluoride, acetone
everX Posterior	Fiber-reinforced resin composite	GC Co, Tokyo, Japan/1309121	Bis-GMA, TEGDMA, PMMA, triethylene glycol dimethacrylate, glass fillers and inorganic granular fillers
G-aenial Posterior	Posterior resin composite	GC Co, Tokyo, Japan/1211192	Methacrylate monomers, UDMA, dimethacrylate co-monomers, prepolymerized fillers, camphorquinone and amine, fluoroaluminosilicate, fumed silica
G-aenial Bond	One-component self-etch adhesive	GC Co, Tokyo, Japan/1401271	Phosphoric ester monomers, 4-MET, a hydrophilic methacrylate monomer, water, acetone, photoinitiator, nano-silica
Tetric N-Ceram	Nanohybrid resin composite	Ivoclar Vivadent, Schaan, Liechtenstein/S37370	Bis-GMA, urethane dimethacrylate, TEGDMA, barium glass, ytterbium trifluoride, silicon dioxide, mixed oxide, initiators, stabilizers, pigments
Excite F	Dental adhesive (two-step etch-and-rinse)	Ivoclar Vivadent, Schaan, Liechtenstein/P56445	Phosphonic acid acrylate, HEMA, dimethacrylate, highly dispersed silicone dioxide, initiators, stabilizers and potassium fluoride in an alcohol solution
Scotchbond Universal Etchant	Etching gel	3M ESPE, St Paul, MN, USA/ 524441	30%-40% Phosphoric acid, synthetic amorphous silica (fumed), polyethylene glycol, aluminum oxide, water

Abbreviations: Al, aluminum; Ba, barium; Bis-EMA, ethoxylated bisphenol A dimethacryrlate; Bis-GMA, bisphenol A glycidyl methacrylate;, DMA, dimethacrylate; HEMA, hydroxyethyl methacrylate; MDP, methacryloyloxy-decyl-dihydrogen-phosphate; PENTA, phosphonated penta-acrylate ester; TEGDMA, triethylene glycol dimethacrylate; UDMA; urethane dimethacrylate; PMMA, polymethyl methacrylate; 4-MET, methyl-N-ethyltryptamine

Table 2: *Means and Standard Deviations (SDs) of Fracture Resistance of Groups (n=12)*

Groups	Mean ± SD. N[a]
Group I (intact teeth) negative control	924.1 ± 87.8 A
Group II (MOD prepared teeth) positive control	497.8 ± 80.8 B
Group III (Bulk Fill Posterior Composite) Filtek Bulk Fill	702.4 ± 129.3 C
Group IV (Bulk Fill Flowable + Nanoceramic Resin Composite) SureFil SDR Flow + Ceram.X Mono	733.1 ± 143.7 C
Group V (Fiber Reinforced + Posterior Resin Composite) everX Posterior–G-eanial Posterior	685.7 ± 107.9 C
Group VI (Nanohybrid Resin Composite) Tetric N-Ceram	768.8 ± 91.5 C

[a] *Different letters indicate significant differences at level of significance $p<0.05$.*

Table 3: *The Frequency (%) of Failure Modes Among the Experimental Groups (n=12)*

Restored Groups	Mode I, n (%)	Mode II, n (%)	Mode III, n (%)	Mode IV, n (%)	Mode V, n (%)
Group III	—	8 (66.6)	1 (8.3)	—	3 (25)
Group IV	5 (41.6)	2 (16.6)	2 (16.6)	3 (25)	—
Group V	—	4 (33.3)	3 (25)	2 (16.6)	3 (25)
Group VI	2 (16.6)	1 (8.3)	4 (33.3)	1 (8.3)	4 (33.3)
Total	7 (14.5)	15 (31.25)	10 (20.8)	6 (12.5)	10 (20.8)

ences were found in the fracture resistance values of the restored groups (groups III, IV, V, and VI) ($p>0.05$). All groups showed lower values than the negative control group.

Table 3 illustrates the fracture pattern of the restored groups. None of the samples in group IV (bulk fill flowable + nanoceramic resin composite/ SureFil SDR Flow + Ceram.X Mono) showed severe fractures involving the tooth structure completely and/or longitudinal fracture (mode V). In most cases, mode II (fracture of one cusp, intact restoration) was observed. Representative images of different fracture modes are shown in Figure 1a-e.

DISCUSSION

In the present study, no difference was found in fracture resistance among different direct restorative materials. Therefore, the null hypothesis should be accepted. Endodontic treatment is considered to weaken teeth, resulting in their increased

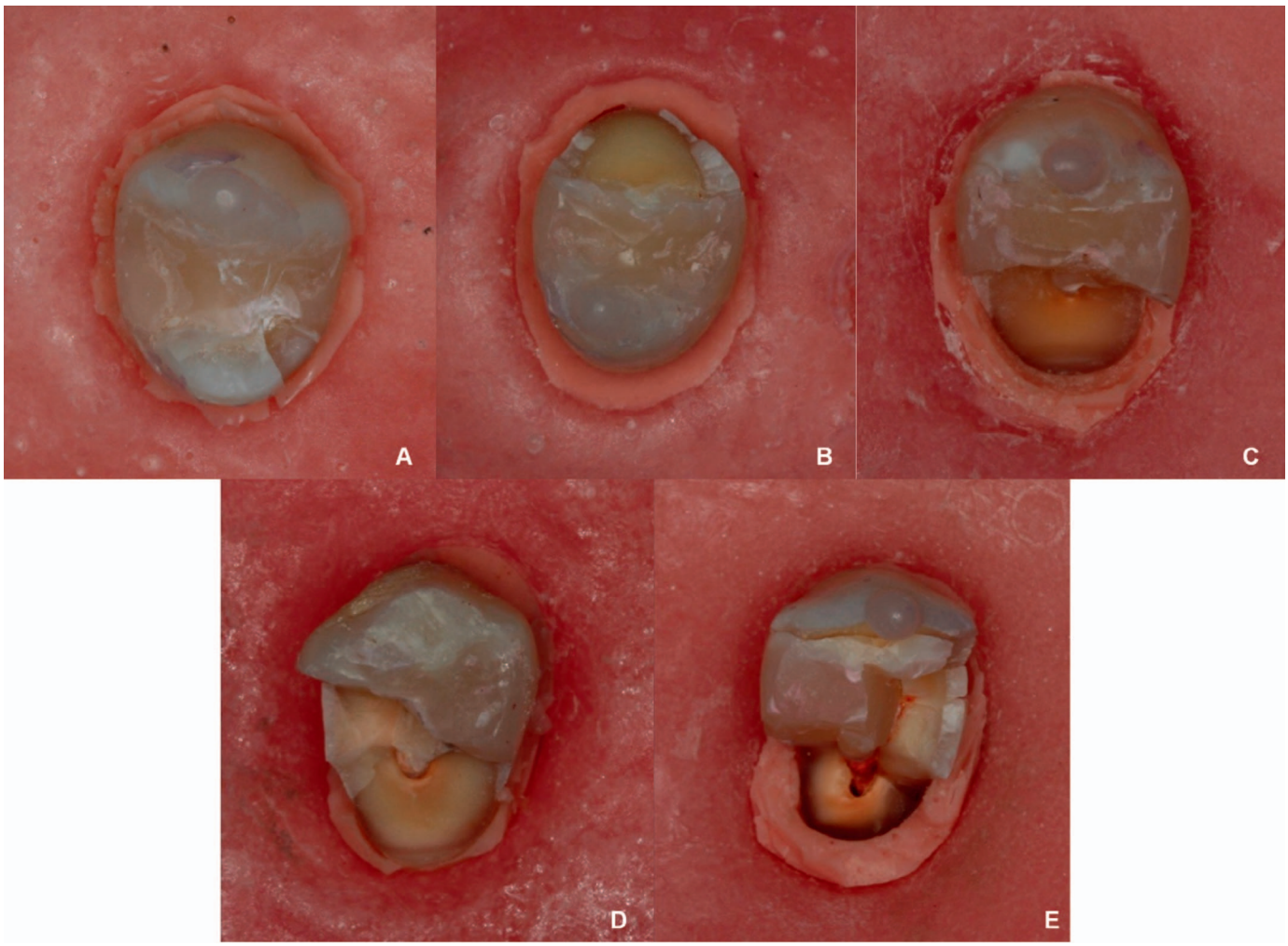

Figure 1. *Representative images of different fracture modes. (A) mode I; (B) mode II; (C) mode III; (D) mode IV; and (E) mode V.*

susceptibility to fracture. The selection of an appropriate restorative resin is primordial to yielding adequate resin/dentin bond strength and long-lasting restorations in endodontically treated teeth. As direct restorations are able to reinforce the weakened tooth structure,[19,20] the mechanical and physical properties of direct restorative materials, such as fracture toughness, modulus of elasticity, creep, hardness, and polymerization shrinkage, should be taken into consideration before restoration occurs.

Polymerization shrinkage stress, which may result in clinical problems such as fractures, is affected by the composition and filler content of resin composites and their elastic modulus.[21] An increase in the filler content would reduce polymerization shrinkage.[22] The manufacturers claim that bulk fill materials have lower volumetric polymerization shrinkage stress. In the present study, the polymerization shrinkage of the bulk fill resin composite Filtek Bulk Fill was 1.39%, which is slightly lower than that of the conventional resin composite Tetric N-Ceram, with its polymerization shrinkage of 2%. However, the filler content of the two products was similar (Filtek Bulk Fill, 64.5%; Tetric N-Ceram, 63.5% by weight).

Flowable resin composites act as an intermediate layer and stress-breaker. SureFil SDR Flow incorporates a polymerization modulator that offsets the inherent stress buildup that occurs during light polymerization.[23] In many studies,[24-27] the polymerization stress and cuspal flexure of SDR were found to be lower than those of other conventional flowable composites and comparable with those of low-shrinkage resin composites. Although the polymerization shrinkage of SDR (3.5%) was higher than that of the other tested restorative resins, their fracture resistance was similar. The materials' polymerization shrinkage is not the only factor involved in the development of contraction stress.[28,29] The positive results obtained might be related to the properties of lower flexural modulus and slower contraction rate.[24,30] On the other hand, it is known that bulk fill flowables require a 2-mm increment of a conventional resin composite because of their lower physical and wear properties. In the present study, Ceram.X Mono, with a polymerization shrinkage rate of 2.3, was used to cap flowable bulk fill composite. Its polymerization shrinkage value was quite similar to that of the other tested restorative resins. This might be a second reason for the similarity in fracture resistance values.

In a study conducted by Akbarian and others,[31] the fracture resistance of MOD cavity preparations restored with either low-shrinkage composite or with dimethacrylate-based composite in conjunction with or without cavity liners was compared. Although the silorane-based composite showed less volumetric shrinkage compared with dimethacrylate-based composites, the silorane composite showed resistance to fracture similar to that of the dimethacrylate-based composite. Kikuti and others[32] investigated the fracture resistance of teeth restored using methacrylate- and silorane-based composite restorations. The flexural strength and modulus of elasticity of both composites were also tested. The resistance to fracture of teeth to levels similar to that of the intact teeth group was found in the methacrylate-based resin group in which an etch-and-rinse system was used. On the other hand, in a recent study,[33] a significantly higher fracture resistance was recorded for teeth with MOD cavities restored with a low-shrinkage composite than for those restored with a conventional resin composite.

Use of a material with a low modulus of elasticity, especially in load-bearing areas, will result in a higher deformability under occlusal stresses.[10] In other words, the higher the filler content, the higher the modulus and the greater the resistance to deformation.[34] El-Damanhoury and Platt[30] found a significant correlation between stress and flexural modulus and between stress and filler loading by volume. In the present study, in spite of the tested restorative materials' different modulus of elasticity values (varying in the range of 85 to 124 GPa), their resistance to fracture was similar. Another study[32] found that fracture resistance was not related to elastic modulus. In that study resin composite with higher flexural strength and elastic modulus showed higher fracture resistance than did a composite with lower flexural strength and elastic modulus when used with an etch-and-rinse adhesive system. However, when used with a self-etch adhesive, no difference in fracture resistance was reported between the tested resin composites.

Our findings are in agreement with a study by Toz and others[17] that investigated the fracture resistance of endodontically treated teeth restored with bulk fill flowable and bulk fill resin composites. In their study no difference was found between groups restored with bulk fill flowable composite bases and conventional resin composite. Yasa and others[16] evaluated the fracture resistance of endodontically treated teeth restored with nanohybrid composite, bulk fill flowable composite, and short fiber–rein-

forced composite in the presence/absence of retention slots. Similar to our findings, no difference was observed between the restorative materials in the absence of retention slots.

everX fiber-reinforced resin is used in conjunction with a conventional resin composite. The manufacturers claim that this material prevents or arrests crack propagation. In a recent study[15] that examined the physical properties of a short fiber composite material in comparison to different bulk fill and conventional resin composites, fiber-reinforced resin showed higher fracture toughness and flexural strength than did all other materials tested. Moreover, shrinkage strain was found to be the lowest. They attributed these results to the plasticization of the polymer matrix by linear polymer chains of PMMA in the cross-linked matrix of bisphenol A diglycidyl ether dimethacryalate–triethylene glycol diemthacrylate, which increases the fracture toughness and stress transfer from polymer matrix to fibers, inducing a reinforcing effect of fibers. In another study[35] conducted by the same author, short fiber fillers' preventive effect on crack propagation and improvement of fracture resistance was reported. A recent study[36] compared nonreinforced resin composite with reinforced composites and it was found that fiber reinforcement improved the fracture resistance of composite resin. In a study[37] evaluating the efficiency of a short fiber–reinforced resin composite material compared to conventional composites when restoring Class II MOD cavities in molar teeth, the use of a short fiber–reinforced resin composite did not result in a statistically significant increase in fracture toughness; however, when using this material with an oblique layering technique, a clear tendency toward higher fracture resistance and restorable fractures was observed.

In the present study, the mean fracture resistance values of teeth restored with everX fiber-reinforced resin were not significantly different from those of teeth restored with other restorative materials. This contradictory finding might be attributed to the critical difference in sample preparation. In the studies mentioned above, restorative resins were placed in fabricated molds instead of in prepared teeth. A prepared tooth with a cavity has a certain degree of compliance. The different results might also be related to the adhesive system used. It is known that dentin adhesives play an important role in maintaining the bond between the cavity walls and restorative material. In the present study, all restorative materials were used with their respective adhesive system. All adhesive systems were etch-and-rinse, except for everX fiber-reinforced resin and G-aenial posterior's adhesive, which was a one-step self-etch, G-aenial Bond. Although the bond strength values of one-step self-etch adhesives are comparable with those of etch-and-rinse adhesives, they have inferior enamel bond strengths compared to etch-and-rinse systems.[38] Moreover, G-aenial Bond was the only adhesive system that was 2-hydroxyethyl methacrylate–free. The hydrophobic nature of the components and phase separation[39] might cause a decrease in bond strength and, thereby, in fracture resistance.

Intact teeth showed the highest fracture resistance, which is consistent with the findings of many studies[40-42] reporting that restored teeth had a significantly lower resistance to fracture.

In the present study, the majority of fractures, regardless of the type of restoration, were type II, in which the restoration was intact with a cuspal fracture. In other words, they were defined as restorable. This finding is in contrast to the studies by Yasa and others[16] and Toz and others,[17] who reported most fractures as nonrestorable in endodontically treated teeth. However, these differences might be related to the fracture mode classification system used. In the studies mentioned, fracture modes were classified as restorable when the fracture line was above the CEJ or 1 mm or less apical to the CEJ, or as nonrestorable (including vertical root fractures) when the fracture line was more than 1 mm apical to the CEJ.[43] In the present study, however, a more detailed fracture mode classification system was used. Therefore, it might not be possible to compare our obtained results with those of the studies mentioned.

CONCLUSIONS

Within the limitations of this study, the fracture resistance of teeth restored with a conventional nanohybrid resin composite was not significantly different from that of either bulk fill/flowable bulk fill or fiber-reinforced resin restoratives. Compared to intact teeth, restored teeth had lower fracture resistance. However, the results should be validated with additional clinical studies as physiological and parafunctional occlusal forces were not taken into account in these *in vitro* conditions.

Acknowledgements

The authors thank 3M, Ivoclar, Dentsply and GC for donation of the materials.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subject's oversight committee guidelines and policies of Hacettepe University. The approval code for this study is 15/616-10.

Conflict of Interest

The authors 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 2 February 2016)

REFERENCES

1. Eakle WS (1986) Fracture resistance of teeth restored with Class II bonded composite resin *Journal of Dental Research* **65(2)** 149-153.
2. Burke FJ (1992) Tooth fracture in vivo and in vitro *Journal of Dentistry* **20(3)** 131-139.
3. Sandikci T, & Kaptan RF (2014) Comparative evaluation of the fracture resistances of endodontically treated teeth filled using five different root canal filling systems *Nigerian Journal of Clinical Practice* **17(6)** 667-672.
4. Ploumaki A, Bilkhair A, Tuna T, Stampf S, & Strub JR (2013) Success rates of prosthetic restorations on endodontically treated teeth; A systematic review after 6 years *Journal of Oral Rehabilitation* **40(8)** 618-630.
5. Taha NA, Palamara JE, & Messer HH (2009) Cuspal deflection, strain and microleakage of endodontically treated premolar teeth restored with direct resin composites *Journal of Dentistry* **37(9)** 724-730.
6. Bicalho AA, Pereira RD, Zanatta RF, Franco SD, Tantbirojn D, Versluis A, & Soares CJ (2014) Incremental filling technique and composite material—Part I: Cuspal deformation, bond strength, and physical properties *Operative Dentistry* **39(2)** 71-82.
7. Do T, Church B, Veríssimo C, Hackmyer SP, Tantbirojn D, Simon JF, & Versluis A (2014) Cuspal flexure, depth-of-cure, and bond integrity of bulk-fill composites *Pediatric Dentistry* **36(7)** 468-473.
8. Flury S, Hayoz S, Peutzfeldt A, Husler J, & Lussi A (2012) Depth of cure of resin composites: Is the ISO 4049 method suitable for bulk fill materials? *Dental Materials* **28(5)** 521-528.
9. Tarle Z, Attin T, Marovic D, Andermatt L, Ristic M, & Tauböck TT (2015) Influence of irradiation time on subsurface degree of conversion and microhardness of high-viscosity bulk-fill resin composites *Clinical Oral Investigations* **19(4)** 831-840.
10. Ilie N, Bucuta S, & Draenert M (2013) Bulk-fill resin-based composites: An in vitro assessment of their mechanical performance *Operative Dentistry* **38(6)** 618-625.
11. Furness A, Tadros MY, Looney SW, & Rueggeberg FA (2014) Effect of bulk/incremental fill on internal gap formation of bulk-fill composites *Journal of Dentistry* **42** 439-449.
12. Li X, Pongprueksa P, Meerbeek BV, & Munck JD (2015) Curing profile of bulk-fill resin-based composites *Journal of Dentistry* **43(6)** 664-672.
13. Karbhari VM, & Wang Q (2007) Influence of triaxial braid denier on ribbon-based fiber reinforced dental composites *Dental Materials* **23(8)** 969-976.
14. Nayar S, Ganesh R, & Santhosh S (2015) Fiber reinforced composites in prosthodontics—A systematic review *Journal of Pharmacy & Bioallied Sciences* **7(1)** 220-222.
15. Garoushi S, Sailynoja E, Vallittu PK, & Lassila L (2013) Physical properties and depth of cure of a new short fiber reinforced composite *Dental Materials* **29(8)** 835-841.
16. Yasa B, Arslan H, Yasa E, Akcay M, & Hatirli H (2015) Effect of novel restorative materials and retention slots on fracture resistance of endodontically-treated teeth *Acta Odontologica Scandinavica* **18** 1-7.
17. Toz T, Tuncer S, Bozkurt FO, Tuncer AK, & Bag HG (2015) The effect of bulk-fill flowable composites on the fracture resistance and cuspal deflection of endodontically treated premolars *Journal of Adhesion Science and Technology* **29(15)** 1581-1592.
18. Burke FJ, Wilson NH, & Watts DC (1994) Fracture resistance of teeth restored with indirect composite resins: The effect of alternative luting procedures *Quintessence International* **25(4)** 269-275.
19. Magne P, & Belser UC (2003) Porcelain versus composite inlays/onlays: Effects of mechanical loads on stress distribution, adhesion, and crown flexure *International Journal of Periodontics & Restorative Dentistry* **23(6)** 543-555.
20. Ausiello P, De Gee AJ, Rengo S, & Davidson CL (1997) Fracture resistance of endodontically-treated premolars adhesively restored *American Journal of Dentistry* **10(5)** 237-241.
21. Yeolekar TS, Chowdhary NR, Mukunda KS, & Kiran NK (2015) Evaluation of microleakage and marginal ridge fracture resistance of primary molars restored with three restorative materials: A comparative in vitro study *International Journal of Clinical Pediatric Dentistry* **8(2)** 108-113.
22. Kleverlaan CJ, & Feilzer AJ (2005) Polymerization shrinkage and contraction stress of dental resin composites *Dental Materials* **21(12)** 1150-1157.
23. Burgess J, & Cakir D (2010) Comparative properties of low-shrinkage composite resins *Compendium of Continuing Education in Dentistry* **31(2)** 10-15.
24. Ilie N, & Hickel R (2011) Investigations on a methacrylate-based flowable composite based on the SDR technology *Dental Materials* **27(4)** 348-355.
25. Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, & Fleming GJ (2012) Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials *Journal of Dentistry* **40(6)** 500-505.
26. Rullmann I, Schattenberg A, Marx M, Willershausen B, & Ernst CP (2012) Photoelastic determination of polymerization shrinkage stress in low-shrinkage resin

composites *Schweiz Monatsschr Zahnmed* **122(4)** 294-299.

27. Francis AV, Braxton AD, Ahmad W, Tantbirojn D, Simon JF, & Versluis A (2015) Cuspal flexure and extent of cure of a bulk-fill flowable base composite *Operative Dentistry* **40(5)** 515-523.
28. Boaro LC, Gonçalves F, Guimarães TC, Ferracane JL, Versluis A, & Braga RR (2010) Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites *Dental Materials* **26(12)** 1144-1150.
29. Tantbirojn D, Pfeifer CS, Braga RR, & Versluis A (2011) Do low-shrink composites reduce polymerization shrinkage effects? *Journal of Dental Research* **90(5)** 596-601.
30. El-Damanhoury HM, & Platt JA (2013) Polymerization shrinkage stress kinetics and related properties of bulk-fill resin composites *Operative Dentistry* **39(4)** 374-382.
31. Akbarian G, Ameri H, Chasteen JE, & Ghavamnasiri M (2014) Fracture resistance of premolar teeth restored with silorane-based or dimethacrylate-based composite resins *Journal of Esthetic and Restorative Dentistry* **26(3)** 200-207.
32. Kikuti WY, Chaves FO, Di Hipolito V, Rodrigues FP, & D'Alpino PHP (2012) Fracture resistance of teeth restored with different resin-based restorative systems *Brazilian Oral Research* **26(3)** 275-281.
33. Barreto Bde C, Van Meerbeek B, Van Ende A, Sousa SJ, Silva GR, Soares PV, & Soares CJ (2015) Biomechanical behavior of extensively restored premolars: Cusp deformation, marginal integrity, and fracture resistance *Journal of Adhesive Dentistry* **17(3)** 213-218.
34. Braem M, Finger W, Van Doren VE, Lambrechts P, & Vanherle G (1989) Mechanical properties and filler fraction of dental composites *Dental Materials* **5(5)** 346-348.
35. Garoushi S, Vallittu PK, & Lassila L (2007) Short glass fiber reinforced restorative composite resin with semi-interpenetrating polymer network matrix *Dental Materials* **23(11)** 1356-1362.
36. Ereifej NS, Oweis YG, & Altarawneh SK (2015) Fracture of fiber-reinforced composites analyzed via acoustic emission *Dental Materials* **34(4)** 417-424.
37. Fráter M, Forster A, Keresztúri M, Braunitzer G, & Nagy K (2014) In vitro fracture resistance of molar teeth restored with a short fibre-reinforced composite material *Journal of Dentistry* **42(9)** 1143-1150.
38. Souza-Junior EJ, Prieto LT, Araújo CT, & Paulillo LA (2012) Selective enamel etching: Effect on marginal adaptation of self-etch led-cured bond systems in aged Class I composite restorations *Operative Dentistry* **37(2)** 195-204.
39. Van Landuyt KL, De Munck J, Snauwaert J, Coutinho E, Poitevin A, Yoshida Y, Inoue S, Peumans M, Suzuki K, Lambrechts P, & Van Meerbeek B (2005) Monomer-solvent phase separation in one-step self-etch adhesives *Journal of Dental Research* **84(2)** 182-188.
40. St-Georges AJ, Sturdevant JR, Swift EJ Jr, & Thompson JY (2003) Fracture resistance of prepared teeth restored with bonded inlay restorations *Journal of Prosthetic Dentistry* **89(6)** 551-557.
41. Allara FW Jr, Diefenderfer KE, & Molinaro JD (2004) Effect of three direct restorative materials on molar cuspal fracture resistance *American Journal of Dentistry* **17(4)** 228-232.
42. Plotino G, Buono L, Grande NM, Lamorgese V, & Somma F (2008) Fracture resistance of endodontically treated molars restored with extensive composite resin restorations *Journal of Prosthetic Dentistry* **99(3)** 225-232.
43. Scotti N, Coero Borga FA, Alovisi M, Rota R, Pasqualini D, & Berutti E (2012) Is fracture resistance of endodontically treated mandibular molars restored with indirect onlay composite restorations influenced by fibre post insertion? *Journal of Dentistry* **40(10)** 814-820.