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MICROLEAKAGE AND FACTURE RESISTANCE OF ENDODONTICALLY TREATED TEETH RESTORED WITH BULK-FILL RESTORATIVE MATERIALS

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ABSTRACT

Objective: To evaluate the effect of bulk-fill restorative techniques on microleakage and fracture resistance of endodontically treated teeth.

Material and Methods: Eighty maxillary second premolars were selected and randomly divided into four groups (n=20). All teeth received class II cavity preparations followed by endodontic treatment. In Group I, 4mm of flowable bulk-fill material (Tetric EvoFlow Bulk Fill - TEFBF) were applied then overlaid with bulk-fill restorative resin (Tetric EvoCeram Bulk Fill - TECBF). In Group II, only Bulk Fill restorative resin (TECBF) was used to restore the entire preparation. In Group III: 1mm of conventional nanohybrid flowable composite (Tetric EvoFlow - TEF) was applied then overlaid with conventional nanohybrid composite (Tetric EvoCeram - TEC) using incremental layering technique. In Group IV, only conventional nanohybrid composite (TEV) with incremental layering was used. All specimens were then subjected to a thermocycling regimen. Microleakage was evaluated on half of the specimens by dye penetration at the tooth restoration interface. The remaining specimens were subjected to fracture resistance testing under occlusal load and the results analyzed using Kruskal-Wallis and Mann-Whitney U tests, with significance set at p=0.05.

Results: Specimens in Groups I and III showed dye penetration reaching the depth of the axial walls while none was observed in Groups II and IV. Groups I and II showed significantly higher fracture strength compared to groups III and IV.

Conclusion: ***1-*** The use of bulk-fill restorative technique improved the fracture strength of endodontically treated teeth. ***2-*** The use of bulk fill resin did not affect the cervical microleakage of restorations. ***3-*** Both bulk fill resin and conventional nanohybrid resin restorations have greater tendency for cervical microleakage when flowable resin is used underneath them.

KEY WORDS: Microleakage, fracture resistance, endodontically treated premolars, bulk-fill

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INTRODUCTION

Post endodontic treatment has always been a matter of concern for the long-term success of endodontically treated teeth (ETT). The restorative materials and techniques used, should among other requirements, provide adequate coronal seal as well as resistance to fracture in order to prevent failure of the restoration and possible loss of the tooth. In fact, several clinical data have demonstrated the association of the history of endodontic treatment to high prevalence of tooth fracture[1,2,3].

The importance of obtaining a coronal seal for ETT in order to maintain the apical periodontal health cannot be overemphasized[4, 5]. It has been demonstrated that when the coronal portion of the root canal is exposed to the oral environment, saliva can reach apical tissues in just 3 days[6], while the obturated canals could become a potential route for the microorganisms to gain access to periapical tissues[7] in as fast as 20 days[8].

Besides aiming to achieve a hermetic marginal seal, these materials should reinforce the remaining tooth structure - another major consideration for the long-term clinical success. It has been widely accepted that ETT are more prone to fracture than vital teeth[9]. In the earlier literature, it was often suggested that the biological changes occurring to the tooth structure after endodontic treatment were the ones mainly responsible for their increased susceptibility to fracture [10,11]. For that, ETT commonly received full coverage restorations, with or without post and core in an attempt to reinforce the tooth structure[12]. Unfortunately, this often resulted in additional loss of sound tooth structure and further weakening of the teeth[13,14]. More recently, a more conservative approach for the restoration of ETT is being advocated due to the development of more reliable bio-adhesive systems. It is being suggested that, with certain preparation parameters[15], the use of resin-based adhesive restorations for ETT could improve the tooth's fracture resistance and longevity [16] and result in less catastrophic fracture under occlusal load[17,18].

Nonetheless, restoring ETT with adhesive techniques becomes more challenging compared to vital teeth[19]. This is in part due to the greater volume of the restoration requiring more resin increments to fill the preparations. In addition, the loss of the pulp chamber support renders the cusps of ETT more prone to flexing which may further challenge the marginal quality of the bonded restoration[20, 21].

Until recently, incremental layering techniques for composite restorations have been universally recommended to prevent gap formation due to polymerization stress and to achieve adequate curing of composite resin[22]. However, such techniques pose some concerns to the clinician in terms of time consumption and risk of incorporating air bubbles or contaminants between the resin layers[23]. In an attempt to overcome some of the technical difficulties associated with the incremental layering of resin composite restorations, a new class of esthetic filling material has been recently introduced to the market, the "bulk fill composites". According to the manufacturers, these materials can be light-cured in bulks of 4 or even 5mm, owing to several modifications introduced, such as the use of more potent initiator systems[24], lower filler content, larger filler particles[25] or higher translucency[26,27].

Bulk-fill materials were first introduced as flowable or low viscosity composites[28,29], and required, due to their lower mechanical properties, the coverage by a conventional or high viscosity composite[30]. Later on, high viscosity bulk fill materials were introduced with higher filler loading and improved mechanical properties, that can be placed without any capping material[28].

Ever since their introduction, bulk-fill restorative materials have been intensively investigated, however, there is scarcity of published data regarding their use for restoration of ETT.

The aim of the present study was to evaluate the gingival seal and fracture strength of endodontically treated premolars restored with bulk fill and conventional nanohybrid composite materials. The null hypothesis tested was two-folds, that the use of bulk fill restorative material with or without a flowable liner (1) would have no influence on the gingival seal of the restoration and (2) would not influence the fracture resistance of the restored teeth, in comparison to conventional nanohybrid composite resin.

MATERIALS AND METHODS

Specimen Preparation

Eighty non-carious and intact human maxillary second premolars, with straight canals and fully developed apices, extracted for orthodontic reasons were selected for this study. The teeth were obtained from pooled and unidentified extracted teeth collected for research purposes from the Oral Surgery department at Faculty of Oral and Dental Medicine, Cairo University. The teeth were first inspected by light microscope at 10x magnification to ensure no enamel cracks or fractures were visible. Those having similar buccolingual and mesiodistal diameters as measured by a digital caliper were selected and thoroughly cleaned with ultrasonic scaler then sterilized by immersion in 0.5% chloramine T solution for one week before storage in normal saline at room temperature. The selected teeth were used within 3 months of extraction.

All teeth received class II (mesio-occlusal) cavity preparations with bucco-lingual width of 3 ± 0.1 mm on the occlusal and gingival surfaces. Preparations were done using no.245 tungsten carbide burs in a high-speed handpiece under copious air-water spray and dimensions were verified using a periodontal probe. The gingival margin on the mesial surface was placed 1mm below the cemento-enamel junction. All internal angles of the cavity preparations were rounded and no bevels were added to any margin of the preparation. The burs were replaced every 4 preparations to ensure cutting efficiency. The roofs of the pulp chambers were then removed to gain access to the root canals, after which the pulp tissue was removed using a barbed broach no. 25 (Dentsply-Maiffefer, Ballaigues, Switzerland). The root canals were negotiated and the working length was established 1.00 mm short of the apical foramen by inserting a K-Flexofile size 010 into the root canal until it could be visualized at the apical foramen then subtracting 1mm from this length to determine the working length.

Canals were first enlarged to K-Flexofile size 015 before being prepared with Protaper nickel-titanium rotary system (Dentsply Malleiffer) at a rotational speed of 250 rpm. File sequence consisted of Shaping files 1 and 2 (S1 and S2) followed by the Finishing files 1 through 3 (F1- F3). Canals were copiously irrigated with 5.25% sodium hypochlorite solution between each file. On completion of the root canals preparation, canals were obturated with gutta-percha points using lateral condensation technique in conjunction with a resin-based sealer (AH Plus, Dentsply De Trey, Konstanz, Germany).

Tooth Restoration

Prior to receiving the adhesive restorations, the teeth were surrounded by metal matrix bands. Clearfil SE Bond (Kuraray, Osaka, Japan) self-etch adhesive was used according to manufacturer's recommendation. The primer was applied on canal orifices and all cavity walls, left for 20 seconds then lightly air dried. The bond was then applied and distributed with light air flow then light cured for 10 seconds. Teeth were randomly divided into four groups (n=20) according to the restorative material and technique being tested. In Group I, the preparations were restored with 4mm of flowable bulk fill material (Tetric EvoFlow Bulk Fill), light-cured, then overlaid with bulk fill restorative resin (Tetric Evo Ceram Bulk Fill). In Group II, only bulk fill restorative (Tetric EvoCeram Bulk Fill) was used to restore the entire preparation. In Group III: 1mm of conventional nanohybrid flowable composite (Tetric EvoFlow) was first applied and light-cured at the depth of the cavity then the rest of the cavity restored with conventional nanohybrid composite (Tetric EvoCeram) using incremental layering technique. In Group IV, only conventional nanohybrid composite (Tetric EvoCeram) was used with incremental layering technique. The materials' composition and manufacturers are shown in Table 1.

Light curing was conducted using LED light cure unit (SmartLite, Dentsply, USA). The intensity of the light cure was checked periodically with a radiometer to ensure that the 1000 mW/cm^2 was delivered at all times. For the bulk fill materials (whether flowable or high viscosity), each 4mm increment was light cured twice for 20 seconds, while for the conventional composite, each 1.5mm increment was light cured twice for 20 seconds.

Upon removal of the matrix band, the restorations were further light cured from both buccal and lingual surfaces for an additional 20 seconds on each side. Any visible overhangs were removed using a posterior scaler followed by final polishing of the restorations using fine and extra-fine Sof-Lex discs (3M ESPE, St. Paul, MN, USA). After 24 hours of storage in deionized water at 37°C, all teeth were subjected to a thermocycling regimen of 1000 cycles between 5 and 55°C for 60 s each with a dwell time of 30 seconds.

Microleakage Testing

Half of the specimens in each group were used for microleakage testing (n-=10). Root apices were sealed with sticky wax to prevent dye penetration, then the specimens were coated with two layers of nail varnish 1mm from the restoration margins. The specimens were then immersed in a 0.5% aqueous solution of methylene blue at room temperature for 24 hours. The specimens were then thoroughly rinsed under tap water, air-dried and embedded in

TABLE (1) Restorative Materials Used in this Study (composition as obtained from the manufacturer)

Material (abbreviation)		**Composition**	**Manufacturer**
Resin Composite	Tetric EvoFlow Bulk Fill (TEFBF)	**Matrix type:** dimethacrylates **Fillers:** barium glass, ytterbium trifluoride and copolymers **Filler Content:** 68.2 wt%, 46.4 vol%	Ivoclar Vivadent, Mississauga, ON, Canada
	Tetric EvoCeram Bulk Fill (TECBF)	**Matrix type:** dimethacrylates **Fillers:** barium glass, ytterbium trifluoride, mix-oxide, PPF **Filler Content:** 80 wt%, 60 vol%	Ivoclar Vivadent, Mississauga, ON, Canada
	Tetric EvoFlow (TEF)	**Matrix type:** dimethacrylates **Fillers:** barium glass, ytterbium trifluoride, highly dispersed silicon dioxide, mixed oxide and copolymer **Filler Content:** 57.5 wt%, 30.7 vol%	Ivoclar Vivadent, Mississauga, ON, Canada
	Tetric EvoCeram (TEC)	**Matrix type:** dimethacrylates **Fillers:** barium glass, ytterbium trifluoride, mixed oxide and opolymers **Filler Content:** 57.5 wt%, 30.7 vol%	Ivoclar Vivadent, Mississauga, ON, Canada
Adhesive System	Clearfil SE Bond	**Self-Etch Primer:** MDP, HEMA, hydrophilic aliphatic dimethacrylate, dl-CQ, N,N-Diethanol-p-toluidine, water **Bond:** MDP, Bis-GMA, HEMA, hydrophobic aliphatic dimethacrylate, dl-CQ, N,N-Diethanol-p-toluidine, silanated colloidal silica	Kuraray Co., Ltd, Osaka, Japan

MDP: 10-methacryloyloxydecyl dihydrogen phosphate; HEMA: 2-hydroxyethyl methacrylate; CQ: camphorquinone; BisGMA: bisphenol-A-diglycidyl methacrylate

phenolic rings with epoxy resin. Two parallel mesio-distal cuts were prepared longitudinally through the restored specimens using a low-speed water—cooled diamond saw mounted on a cutting machine (Isomet, Buehler Ltd, Lake Bluff, IL, USA).

For microleakage evaluation, dye penetration at the tooth restoration interface at the gingival wall was observed on all sections under stereomicroscope (Olympus, Tokyo, Japan) and assessed using digital photographs at 20x (resolution of 1,280 x1,024). Degree of dye penetration was recorded according to the following parameters: score; 0 = no evidence of dye penetration; score 1 = partial dye penetration along the gingival margin (beyond the amelodentinal junction); score 2 = dye penetration to the canal orifice; score 3 = dye penetration into the canal space or along the axial wall opposite the unprepared proximal tooth surface[31].

Fracture Strength Testing

The other half of the specimens in each group (n=10) were assigned to fracture resistance testing. Each specimen was mounted on a universal testing machine (Llyod instruments LR 5K, England). A steel sphere ball 4 mm in diameter was mounted in the moving arm and was placed in contact with both buccal and lingual cusps of the restored teeth during the fracture test. The teeth were loaded under continuous compressive force at a cross head speed of 0.5mm/min, parallel to their long axis until fracture. The ultimate fracture load was recorded in newton (N) and the mode of fracture was determined according to the following criteria: Mode I - simple fracture: cracks or small fractured pieces of dental structure or the restoration; Mode II - moderate fracture: complete fracture of one cusp; Mode III - catastrophic fracture: longitudinal fracture, running towards the dental root[32]. Statistical analysis was performed using SPSS Version 23.0 (IBM SPSS for Mac OS, IBM corp, Chicago, IL). Fracture strength data were analyzed using Kruskal-Wallis and Mann-Whitney U tests, with significance set at p=0.05.

RESULTS

The results of the microleakage test (shown in table 2 and Figure 1) revealed that specimens in Group I restored with bulk fill flowable overlaid by bulk fill restorative resin and those in Group III where the specimens were restored with 1mm of conventional nanohybrid flowable composite overlaid by conventional nanohybrid composite using incremental layering technique showed the greatest dye penetration (scores 2 and 3) as shown in figure 1. No dye penetration (score 0) was observed in specimens of Groups II and Group IV where the specimens were restored only with either bulk-fill restorative or conventional resin composite respectively.

TABLE (2) Microleakage Scores among the Tested Groups

	Microleakage Scores			
	Score 0	Score 1	Score 2	Score 3
Group I (TEFBF/TECBF)	0	0	4	6
Group II (TECBF)	10	0	0	0
Group III (TEF/TEC)	0	0	7	3
Group IV (TEC)	10	0	0	0

The mean and standard deviation of the fracture resistance test are shown in table 3. The results revealed that the specimens in Group I and Group II showed the highest mean values of fracture resistance as they recorded 1010.00 (±109.72) and 1025.55 (±93.14) respectively with no significant difference between them. However, they both showed statistically significant higher values compared to the specimens in Groups III and IV with mean scores of 855.99 (±59.32) and 459.52 (±90.66) respectively. There was also a statistically significant difference between the results obtained with Groups III and IV at $p \leq 0.001$.

Regarding the fracture pattern modes (shown in table 4), it was observed that none of the specimens tested in any of the 4 groups showed simple fractures.

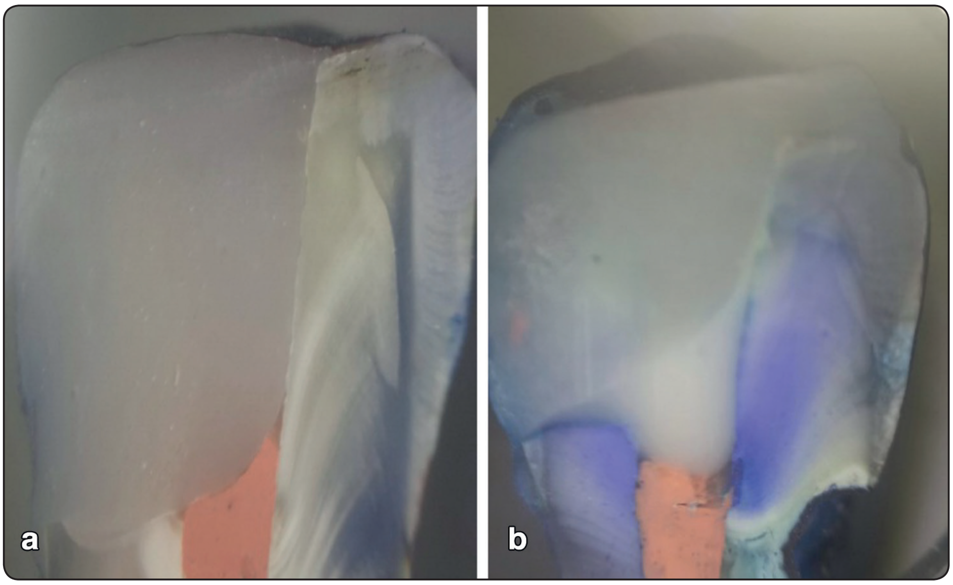

Fig. (1) Sample Specimen showing different dye penetration scores. a: sample specimen of Group III showing no dye penetration (score 0). b: sample specimen of Group II showing dye penetration extending to the full length of the gingival margin and up to axial wall opposite the unprepared proximal tooth surface.

All the specimens in Group I showed moderate fractures, while all of those in Groups III, IV and most of Group II showed catastrophic fractures.

TABLE (3) Mean and Standard Deviation (N) of Fracture Resistance of the Different Tested Groups.

Groups	Mean values (±SD)	P value
Group I (TEFBF/TECBF)	1010.00 (±109.72)[a]	≤0.001*
Group II (TECBF)	1025.55 (±93.14)[a]	
Group III (TEF/TEC)	855.99 (±59.32)[b]	
Group IV (TEC)	459.52 (±90.66)[c]	

Different superscript letters denote statistically significant differences (p=0.05)

TABLE (4) Fracture Pattern Modes under Occlusal Load among the Different Tested Groups

	Fracture Pattern Modes		
	Mode I	Mode II	Mode III
Group I (TEFBF/TECBF)	0	10	0
Group II (TECBF)	0	3	7
Group III (TEF/TEC)	0	0	10
Group IV (TEC)	0	0	10

DISCUSSION

More conservative approaches are recently being considered for the restoration of ETT having moderate remaining tooth structure, with special attention given to the possible use of bulk-fill restorative materials[33]. Nevertheless, the quality of the coronal seal as well as the fracture resistance of the final tooth restoration play an influential role in the long term clinical success of the treatment and thus require thorough investigation.

Polymerization shrinkage is an inherent property of composite resin and if not properly controlled may result in gap formation at the tooth-restoration interface and subsequent microleakage. Different approaches have been proposed in an attempt to overcome this problem, of which the placement of a stress absorbing liner such as flowable composite resin[34] underneath the high viscosity composite. Flowable composite resin have a lower modulus of elasticity and thus are claimed to possibly absorb the polymerization shrinkage stress which could ultimately result in reduced gap formation at the interface[35]. Another approach for minimizing polymerization shrinkage stress is by the use of the incremental placement technique[36] which reduces the configuration factor (C-factor) during the restorative procedure. A lower C-factor ratio indicates less bonded to unbonded surfaces during composite resin placement and ultimately less shrinkage stresses at the interface. However, such technique is often more technique sensitive and time consuming especially with larger size restorations[37].

As their name implies, bulk-fill resin materials are made to cure in bulk which could be of interest while restoring ETT requiring larger restoration volume. Bulk curing is achieved through various modifications to the material such as the incorporation of new filler technology, increased material translucency and the use of a new initiator systems. The bulk fill materials used in this study were Tetric EvoCeram bulk fill and Tetric EvoFlow bulk fill nanohybrid composite resins. These materials incorporate a filler technology consisting of several different types of fillers including barium aluminum silicate glass, an "Isofiller" (glass fillers and ytterbium fluoride embedded in prepolymerized organic matrix), ytterbium fluoride and spherical mixed oxide. The resulting refractive index of the filler system approximate that of the resin matrix and result in higher translucency of the material[28] despite its relatively high filler loading. The material also contains a novel initiator, Ixoderin, a dibenzoyl germanium derivative, that is claimed to have higher reactivity to light and thus allowing greater depth of cure of the bulk fill material[38].

In the current study, microleakage was tested after thermocycling of the specimens to induce artificial aging. A self-etch adhesive (Clearfil SE) was used with all restorations. This mild adhesive, containing the functional monomer 10-methacryloxyloxydecyl dihydrogen phosphate (10-MDP), was shown to achieve good marginal seal and prevent dye penetration especially at the cervical margins of ETT restorations[20]. This was partially in accordance with the results of the current study where no microleakage was observed with the use of either bulk fill or conventional nano-hybrid composite resin when used for the entire restoration of the MO cavities of ETT. Nevertheless, it was noted that the use of flowable composite (weather bulk fill or conventional nanohybrid) underneath high viscosity composite resulted in greater dye penetration (scores 2 and 3 in Groups I and III). In fact, it appears that microleakage was primarily affected by the use of the flowable liner rather than by whether the restorative resin is conventional or bulk fill in nature. This warrants the partial rejection of the first null hypothesis which speculated that the use of bulk fill restorative material with or without a flowable liner would have no influence on the gingival seal of the restoration. This finding is in contrast with the studies[34] that support the use of flowable resin as a stress breaker under composite resin to counteract polymerization shrinkage stress and ultimately decrease gap formation. It is also in contrast with the findings of Tuncer et al[39] who found that the use of bulk resin whether flowable or fiber reinforced high viscosity did not have a significant difference on the microleakage results of the restorations of ETT. This contrast may be due to the different layering techniques used during the restorations. Tuncer et al[40] restored the class II restorations of ETT by first applying conventional composite to the cervical floor of the proximal box extending occlusally and in contact with matrix band converting the Class II into a Class I cavity. The rest of the cavities were filled with either conventional, bulk fill or flowable bulk fill composite resins. As opposite, in the current study, horizontal layering of all restorative material tested was performed as it was considered easier and more routinely performed[40].

The greater microleakage scores observed in this study with the flowable resin could arguably be explained due to the nature of the flowable resins. The lower filler content of the flowable composite resins in general makes them undergo greater polymerization shrinkage[41] which could result in debonding at the tooth-restoration interface. This finding has been supported by Ozel et al[42] and Sadeghi et al[43] who reported increased microleakage in Class II resin composite restorations when flowable linings were applied compared to those without a flowable lining.

The other parameter tested in this study was the fracture resistance of the ETT after restoration with either conventional or bulk fill resin and with or without a flowable liner. Since ETT were shown to be more susceptible to fracture, choosing the material and technique that could reinforce the remaining tooth structure, when cuspal coverage is not required, is of prime relevance. Maxillary premolars were selected as their anatomy and crown size make them more vulnerable to fracture[44]. The results of the current study indicated that bulk fill resin restorations whether with or without a flowable liner resulted in greater fracture resistance compared to conventional resin composite which necessitates the rejection of the second null hypothesis. This result could be attributed to the higher filler loading of the bulk fill material tested which would impart lower polymerization shrinkage stresses and ultimately higher fracture resistance of the restored teeth[45]. These findings are in agreement with those of Isufi et al[46] who reported higher mean fracture load of specimens restored with bulk fill flowable compared to those restored with traditional resin composites, however with no significant difference. Their study was conducted on maxillary and mandibular molars, rather than premolars as in this study, which may explain the difference in statistical significance. On the other hand, these results are in contrast with those of Atalay et al[47] and Toz et al[48] who found that the fracture resistance values of ETT restored with bulk fill/ bulk fill flowable were not different from those restored with conventional nanohybrid resin composite. However, in their protocols, the teeth had received MOD preparations rather than MO preparations as in the current study which would have a major impact on the overall fracture resistance of the teeth.

The current results also revealed that the use of a flowable liner under conventional nanohybrid composite resulted in significantly higher fracture resistance. These findings may be attributed to the elastic buffering effect imparted by the low viscosity flowable resin and which support the suggested, yet controversial, concept of the "elastic cavity wall". According to that concept, the shrinkage stresses generated by the higher modulus resin composite can be absorbed by an elastic intermediary layer, resulting in reduced stresses at the tooth-restoration interface, less cuspal deflection and ultimately increased fracture resistance[49].

The fracture pattern modes observed in the current study in Groups III and IV and most of Group II were of type 3, and described as catastrophic where the tooth would be non-restorable with longitudinal fracture running towards the roots of the teeth. This is in agreement with the findings of Toz et al[49] who compared the fracture pattern of endodontically treated premolars restored with different conventional and bulk fill materials. They observed that the majority of the fractures were non-restorable except with one bulk fill material. As in the current study, restorations with conventional composites yielded more severe fracture modes compared to those with bulk fill materials. In contrast, Atalay et al[48] reported that most fractures, regardless of the type of restoration, whether bulk-fill or conventional nanohybrid, included only one cusp with intact restorations and considered restorable. However, in their study MOD preparations were prepared on the maxillary premolars and different adhesive systems were used, which could influence the fracture pattern results.

Nevertheless, all restored teeth in the current study showed fracture resistance values (ranging from 459.52 N (±90.66) in Group IV to 1025.55N (±93.14) in group II) much higher than the reported clinical bite force on maxillary premolars ranging from 178 to 291N[50], which reassures that, in such respect, restoring ETT having moderate tooth structure loss, with adhesive resin restorations presents an adequate treatment option.

Within the limitations of the current study, it was concluded that restoration of endodontically treated premolars having one marginal ridge loss, with bulk fill restorative resin improved the fracture resistance of the teeth in comparison to restorations with conventional nanohybrid composite resin. The use of bulk fill resin did not affect the cervical microleakage; rather, microleakage was negatively affected by the use flowable resin liner, whether bulk fill or conventional nanohybrid. Further in vivo studies should be conducted to support these findings where the teeth are subjected to functional chewing movements and failure under fatigue.

Conflict of Interest

The authors have no conflict of interests to declare.

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