Fracture Resistance of Tunnel-Restored Teeth at Different Marginal Ridge Heights

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Abstract

This study aimed to investigate fracture strength of restored tunnel-prepared teeth with different marginal ridge heights, using various adhesive systems and restorative materials. 130 intact premolars were randomly allocated into 13 groups based on 3 remaining marginal ridge heights (1.0 mm, 2.0 mm and 3.0 mm). 3 restorative systems (Optibond™ FL, selective enamel etching mode Single Bond Universal, Equia Forte Fil), positive control or tunnel prepared tooth without restoration, and intact unprepared teeth served as negative control. Tunnel preparation and restoration were performed. After 10,000 cycles of thermocycling, each specimen underwent fracture strength test and evaluated for mode of failure. The data were analyzed using two-way ANOVA, one-way ANOVA followed by a post hoc test. The results of the experiment showed that fracture strength values of tunnel restoration were significantly affected by remaining marginal ridge heights, but did not significantly affect by restorative systems. All restorative systems were unable to support tunnel preparation at remaining marginal ridge heights of 1.0 mm. At remaining marginal ridge heights of 3.0 mm, strength of tunnel preparation was equivalent to intact teeth or negative control. At remaining marginal ridge heights either of 2.0 mm or 3.0 mm, strength of tunnel restoration with Optibond™ FL, selective enamel etching mode Single Bond Universal, and Equia Forte Fil were as strong as intact teeth. It can be concluded that, tunnel restoration at remaining marginal ridge height of at least 2.0 mm with Optibond™ FL and paste-like bulk fill resin composite, selective enamel etching mode Single Bond Universal and paste-like bulk fill resin composite, or Equia Forte Fil was comparable to intact teeth.

Keywords: *Dental adhesive systems / Fracture strength test / Marginal ridge strength / Tunnel restoration.*

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Introduction

The principle of diagnosis and cavity design for dental decay 'extension for prevention concept' by G.V. Black was established in the late 1800s, and the epoch direct dental restorations required significant tooth structure regardless of caries invasion. Over time, understanding of dental caries process and continuing development of restorative materials have led to a 'minimal intervention' concept, which tries to minimally sacrifice sound tooth structure and focuses on merely removal of infected dentin.

The 'tunnel restoration concept' was proposed to be an alternative and conservative treatment of interproximal dental caries[1,2] or Black's class II cavity, in which access to the lesion must surgically approach through marginal ridge, hence, proximal contour and contact area may not be properly regained leading to food impaction and decreased mastication efficiency. This technique accesses proximal caries via occlusal surface leaving unaffected marginal ridge uncut, therefore preserving marginal ridge integrity resulting in minimal loss of intact dental tissue. Initially, this concept was suggested to be operated in conjunction with glass ionomer cement restorative material (GIC), which bond to enamel and dentin and leach fluoride.[1,2] However, studies showed that predominant problem of tunnel restoration using glass-ionomer restorative materials included fracture of marginal ridge,[3–5] indicating that after tunnel preparation retained amount of marginal ridge and subsequent supportive restoration played a major role in its success. A previous study suggested that occlusogingival thickness of marginal ridge of tunnel restoration should be remained by at least 2.5 mm.[6]

Resin composite, used with bonding agent, is ideally accommodating minimally invasive treatment concept.[7] It has been developed and introduced in many subtypes, including 'bulk-fill' resin composite, which may help to reduce technique sensitivity and became more user-friendly.[8] The use of resin composite has been shown to reinforce dental structures, and restored the strength of

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marginal ridge of tunnel-prepared teeth back to the level of intact teeth in some laboratory investigations.[6,9] There were some clinical studies using resin composite in tunnel restoration.[10,11] Most resin composites used to replace dental hard tissue effectively bound to tooth structure by means of 'dental adhesive systems'. There are three classified bonding approaches according to adhesion strategy and number of application steps: 'etch and rinse', 'self-etch', and 'glass-ionomer' strategies.[12] The multi-mode or 'universal adhesive' system has been recently introduced and shares the nature of single step self-etch system.[13]

The improvement of tooth-colored adhesive restorative materials also included high-viscosity glass ionomer cement (HV-GIC), which was a modification of conventional GIC that enhanced mechanical properties,[14] but chemical polymerization reaction allowed bulk-filling technique and still exhibited the same mechanism of fluoride release and recharge. Thus HV-GIC may be indicated for certain definitive restoration in permanent posterior dentition.[15] Therefore, the current advancement of dental adhesive systems and restorative materials arises question that whether or not we could improve marginal ridge strength in relation to occlusogingival distance using various contemporary adhesive systems and restorative materials in tunnel preparation tooth.

The aim of the present study was to investigate fracture strength of the marginal ridge of restored tunnel preparation with different remaining marginal ridge heights, using various dental adhesive systems and restorative materials. The null hypotheses were 1) there was no significant difference in fracture strength of restored tunnel preparation on different marginal ridge heights, and 2) there was no significant difference in fracture strength of restored tunnel-preparation using different adhesive restorative materials.

Materials and Methods

Specimen preparation

Ethical approval was certified by the Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University (HREC-DCU-2021-081). Initially, the population of specimens has been calculated using data from previous study[16] with G*Power version 3.1.9.4 software, by selecting F tests family for one-way ANOVA with α=5%, Power (1-β)=80%, and then calculated effect size f=0.4266234. The total sample size has been found to be at least 117, with 10% compensation for error, and the sample size should be 10 per group (13 groups), therefore, the total sample size of this study was 130. 130 sound human maxillary premolars extracted for orthodontic reasons, collected with informed consent, were used in the study. All teeth were cleaned, debrided, and stored in a 0.5% Chloramine-T trihydrate solution for no longer than 90 days after extraction. Crown dimensions of entire premolars in mesiodistal, buccolingual, and occlusogingival width were within a maximum deviation of 10% from their mean.

Long axes of premolar crowns were adjusted to be perpendicular to horizontal plane while their roots were mounted in dental stone type 4 (Antimicrobial dental stone type 4, Mdent, Thailand) up to the level of 2.0 mm below cementoenamel junction (CEJ) to simulate the crestal bone level,[17] which were intended to be a criterion level for fracture or failure mode identification after marginal ridge strength test, using a 2.0 cm in diameter, 3.3 cm in height, polyvinyl chloride tube mold (Zeberg, Thailand). After stone was set, adjustments of marginal ridge were done by a fine grit round diamond bur #022 (FG 4400S, Intensiv, Switzerland) with a high-speed handpiece, to provide an approximately 1.5 mm X 1.5 mm contact area for the loading rod of the fracture strength test machine.[18] All specimens were examined under a 10x magnification stereomicroscope (SZ 61, Olympus, Japan) to ensure that they were free of any defects. Teeth were kept moist at 37°C throughout the study in an incubator (Contherm 160M; Contherm Scientific Ltd., Lower hut, New Zealand), except during specimen preparation and testing.

All 130 teeth were randomly divided, according to remaining marginal ridge heights and adhesive systems and restorative approaches, into 13 groups of 10 specimens each, consisted of 9 test groups and 4 control groups. Detail of the experimental groups is shown in Table 1.

Table 1 Experimental groups classification

Tooth	Preparation	Adhesive and restorative systems	Group code
130 extracted maxillary premolars	Intact tooth, no preparation Negative control (n=10)	-	NC
	Tunnel preparation with remaining marginal ridge heights of 1.0 mm (M1) (n=40)	3-step etch and rinse adhesive and paste-like bulk fill resin composite	M1ER
		Selective enamel etching, universal adhesive and paste-like bulk fill resin composite	M1UA
		Dentin conditioner and high-viscosity glass ionomer cement	M1HGI
		No restoration (Positive control)	M1PC
	Tunnel preparation with remaining marginal ridge heights of 2.0 mm (M2) (n=40)	3-step etch and rinse adhesive and paste-like bulk fill resin composite	M2ER
		Selective enamel etching, universal adhesive and paste-like bulk fill resin composite	M2UA
		Dentin conditioner and high-viscosity glass ionomer cement	M2HGI
		No restoration (Positive control)	M2PC
	Tunnel preparation with remaining marginal ridge heights of 3.0 mm (M3) (n=40)	3-step etch and rinse adhesive and paste-like bulk fill resin composite	M3ER
		Selective enamel etching, universal adhesive and paste-like bulk fill resin composite	M3UA
		Dentin conditioner and high-viscosity glass ionomer cement	M3HGI
		No restoration (Positive control)	M3PC

Tunnel preparation

Tunnel preparation was adapted from a study by Covey et al,[9] using a high-speed handpiece under constant water spray with a standard grit, long neck, round diamond bur #012 (FG 200L, Intensiv, Switzerland). The initial occlusal approach was located at approximately 2.0 mm from the marginal ridge in a slightly oblique direction, then gradually curved towards the proximal surface of the tooth, extending to the distances of 1.0 mm, 2.0 mm, and 3.0 mm gingivally below the marginal ridge, according to the test groups. (Figure 1 and Figure 2) All cavity preparations were performed by one operator using loupes with a magnification of 2.7x. (PeriOptix® loupes, DenMat, USA)

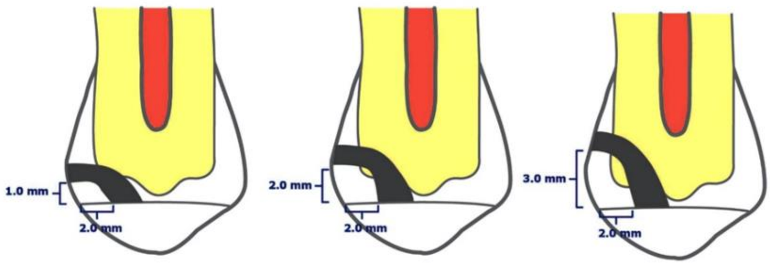

Figure 1 Illustration of tunnel preparation at different marginal ridge heights.

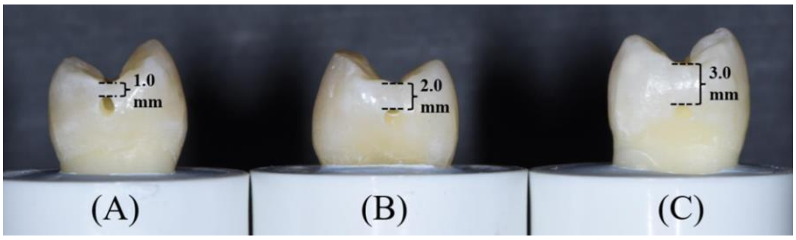

Figure 2 Preparation opening on proximal surface at various remaining marginal ridge heights: (A) 1.0 mm (B) 2.0 mm (C) 3.0 mm.

The occlusal opening cavity was oval, 2.3 mm mesiodistally x 1.5 mm buccopalatally in dimension, and the round proximal exit was 1.5 mm in diameter (Figure 3). Cavity size and remaining marginal ridge height were confirmed with a digital vernier caliper (Digital micrometer, Mitutoyo, Japan), then all specimens were inspected under a 10x magnification stereomicroscope (SZ 61, Olympus, Japan) to ensure absence of any defects from the preparation process. The diamond bur was replaced after every 5 preparations.

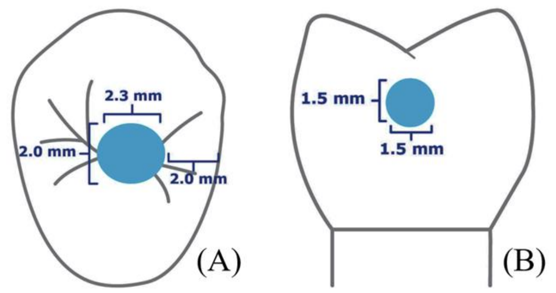

Figure 3 Illustration of tunnel preparation at occlusal opening (A) proximal exit (B).

Tunnel restoration

All the test subgroups were restored with different adhesives and restorative materials using Ivory matrix retainer and Ivory metal band no.13 (Hahnenkratt, Germany). Table 2 showed chemical compositions, manufacturers, and batch number of materials used in this study. Restoration techniques used in this experiment were presented in Table 3 and Figure 4. The amount of primer and adhesive solutions were measured by micropipette (Rainin™ Pipet-Lite SL-10XLS, Mettler-Toledo, USA). Light curing was made using a LED machine (Elipar Deep Cure-L, 3M ESPE, USA), and the irradiance at tip was constantly checked to be 1,100–1,300 mW/cm^2 by a radiometer (L.E.D. radiometer by Demetron, Kerr, USA). Excess restorative materials were removed using a no.12 blade (Havels, USA), and resin-based restorations were polished with a series of abrasive discs (Sof-Lex®, 3M ESPE, USA). All restorative procedures were performed by one operator.

Table 2 Chemical compositions, manufacturers, batch number, and type of materials used.

Materials, Manufacturers, Batch number	Type	Compositions
Gel Etchant (Kerr, USA) Lot. 8237355	37.5% phosphoric acid	37.5% ortho-phosphoric acid, silica, thickener
OptiBond™ FL (Kerr, USA) Group name: ER Lot. 8308264	3-step etch and rinse adhesive	(Etchant: 37.5% phosphoric acid, silica thickener) Primer: HEMA, GPDM, MMEP, ethanol, water, photo-initiator Bond liquid: TEGDMA, UDMA, GPDM, HEMA, Bis-GMA, ytterbium trifluoride, fillers, photo-initiators, stabilizers.
Single Bond Universal Adhesive (3M ESPE, USA) Group name: UA Lot. 10608A	Universal adhesive	10-MDP, dimethacrylate resins, HEMA, methacrylate-modified polyalkenoic acid copolymer, nanofiller, ethanol, water, initiators, silane.
Filtek™ Bulk Fill Posterior Restorative, Compule, A2 shade (3M ESPE, USA) Lot. NE86675	Paste-like bulk fill resin composite	Bis-GMA, BisEMA, UDMA, Procrylate monomers with zirconia/silica filler, ytterbium trifluoride filler (58.4% Volume).
GC Dentin conditioner (GC, Japan) Lot. 2104161	Dentin conditioner	10% polyacrylic acid
Equia Forte Fil (GC, Japan), Capsule, A2 shade Group name: HGI Lot. 2107061	High-viscosity glass ionomer cement (HV-GIC)	Powder: fluoroaluminosilicate glass, polyacrylic acid, iron oxide Liquid: polybasic carboxylic acid, water
Equia Forte Coat (GC, Japan) Lot. 1904081	Coating material	Methylmethacrylate, multifunctional methacrylate, camphorquinone

Abbreviations; HEMA: hydroxyethyl methacrylate; GPDM: glycerol phosphate dimethacrylate; MMEP: mono-2-methacryloyloxyethyl phthalate; TEGDMA: triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate; Bis-GMA: bisphenol-A diglycidyl ether dimethacrylate; 10-MDP: 10-Methacryloyloxydecyl dihydrogen phosphate; Bis-EMA: bisphenol A diglycidyl methacrylate ethoxylated.

Table 3 Adhesive systems and restorative approaches and their application.

Restorative system group	Restorative steps
ER [OptiBond™ FL, Kerr, USA]	Etch: Apply etchant (entire cavity) 15 s, rinse with water 15 s, gently airdry 3 s Prime: Apply primer 5 microliters (µl) with light agitation 15 s, gently air dry 5 s Bond: Apply a thin uniform layer of 5 µl bond liquid and light cure 40 s Restoration: Apply Filtek™ Bulk Fill Posterior Restorative in one increment (Figure 4A) and light cure 40 s on occlusal surface, another 40 s light cured on buccal and palatal surface after band removal
UA [Single Bond Universal Adhesive, 3M ESPE, USA]	Etch: Apply etchant (occlusal enamel) 15 s, rinse with water 15 s, gently air dry 3 s Bond: Apply adhesive 5 µl with light agitation 20 s, gently air dry 10 s and light cure 40 s Restoration: Apply Filtek™ Bulk Fill Posterior Restorative in one increment and light cure 40 s on occlusal surface, another 40 s light cured on buccal and palatal surface after band removal
HGI [Equia Forte Fil, GC, Japan]	Surface pretreatment: Apply GC Dentin conditioner (entire cavity) 20 s, rinse with water 10 s, gently airdry 3 s Restoration: Mixing Equia Forte Fil using amalgamator (ProMix 402E, Dentsply, USA) 10 s, apply in one increment (Figure 4B), initial setting 2 mins 30 s Coat: After band removal, apply Equia Forte Coat on occlusal and proximal surface, light cured 20 s for each surface

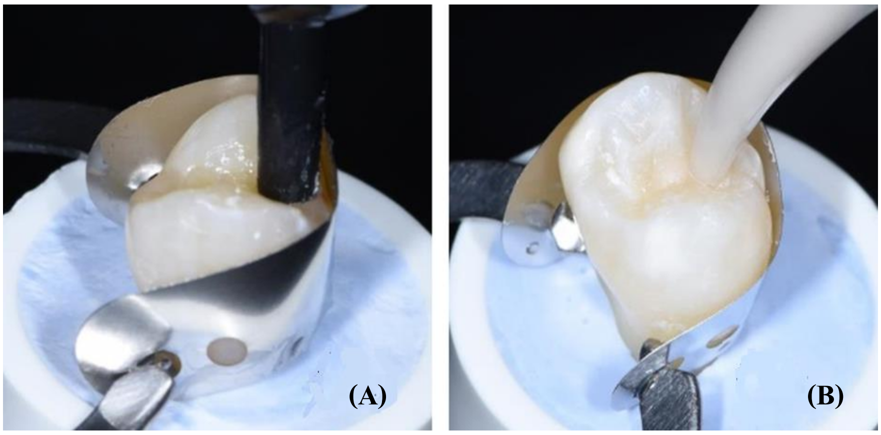

Figure 4 Restoration of tunnel preparation: (A) with bulk-fill resin composite (B) with high-viscosity glass ionomer cement.

Artificial aging process

After restorative procedures, all premolars were kept in distilled water at 37°C for 24 hours, and were subsequently artificially aged by 10,000 cycles of thermocycling (Thermocycler THE-1100/THE-1200, SD mechatronic, Germany) between 5°C and 55°C with a dwell time of 30 seconds in each bath and a transfer time of 5 seconds.

Marginal ridge strength test

The fracture strength tests were achieved by axial compression[9,18,19] using a universal testing machine (Instron 8872, UK). The specimens in the molds were installed in the test plateau of the lower member of the machine, and the load was transferred to the marginal ridge by a steel rod on the upper member of the Instron. The sphere tip of the rod is 2.0 mm in diameter and the contact point is approximately 1.0 mm away from the marginal ridge. The end tip of the loading rod was carefully established to be contacted with the tooth structure, not the restorative material (Figure 5). The crosshead speed was 0.5 mm/minute until fracture occurred. Maximum fracture strength values in Newton (N) were recorded when the specimens were fractured.

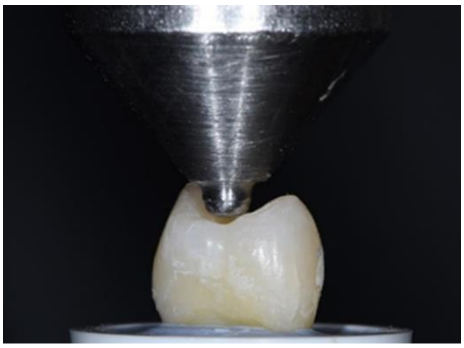

Figure 5 Marginal ridge fracture strength test of tunnel restoration.

Failure mode analysis

The specimens were examined under a stereomicroscope at a 10x magnification (SZ 61, Olympus, Japan) to evaluate fracture patterns, which were defined as followed:[17] favorable fractures, identified as restorable failures, above the level of bone simulation, and unfavorable fractures, identified as unrestorable failures, below the level of bone simulation.

Data analysis

Descriptive statistics were presented in the mean of fracture strength values and standard deviations. Remaining marginal ridge heights and adhesive systems and restorative approaches were independent variables, whereas the mean fracture strength values were dependent variables. Statistical analyses were performed using SPSS 28.0.0.0 for Windows (Chicago, USA). The normality of data distribution was determined by a Shapiro–Wilk test. Data were subsequently statistically analyzed using two-way analysis of variance (ANOVA), one-way analysis of variance (ANOVA), and Fisher's Least Significant Difference (LSD) post-hoc multiple comparisons. Levels of significant difference were determined at $p<0.05$.

Results

Fracture strength test

The mean fracture strength values for all experimental groups in this study were normally distributed ($p>0.05$). Two-way ANOVA revealed that fracture strength values were significantly affected by marginal ridge heights ($p<0.001$), but did not significantly affect by restorative systems ($p=0.974$) The mean fracture strength values and standard deviations were presented in Table 4 and Figure 6.

Table 4 Mean fracture strength values and standard deviations of the remaining marginal ridge heights and restorative systems.

Restorative systems (Dental adhesives and restorative materials)	Remaining marginal ridge heights		
	1.0 mm Mean (SD)	2.0 mm Mean (SD)	3.0 mm Mean (SD)
Positive control (Tunnel preparation, no restoration)	245.12 (134.83) ^{a,A}	305.70 (154.55) ^{a,A,B}	372.85 (120.30) ^{a,B}
Optibond™ FL + Filtek™ Bulk Fil Posterior Restorative	336.02 (134.76) ^{a,A}	490.36 (200.91) ^{b,A,B}	511.43 (168.46) ^{a,B}
Single Bond Universal + Filtek™ Bulk Fil Posterior Restorative	334.89 (127.93) ^{a,A}	493.78 (227.89) ^{b,A,B}	511.37 (204.24) ^{a,B}
Dentin conditioner + Equia Forte Fil	326.12 (149.58) ^{a,A}	474.55 (140.93) ^{b,A,B}	511.17 (192.10) ^{a,B}
Negative control (Intact tooth)	519.16 (156.17) ^{b,A}	519.16 (156.17) ^{b,A}	519.16 (156.17) ^{a,A}

Mean fracture strength values (n=10) with standard deviations (SD) are listed in Newton (N). Values with different superscript capital letters indicate significant differences within the same row for each restorative system. Different superscript small letters indicate significant differences within the same column for each remaining marginal ridge height. Significantly difference was at $p<0.05$ level (one-way ANOVA, Fisher's Least Significant Difference (LSD) post-hoc test)

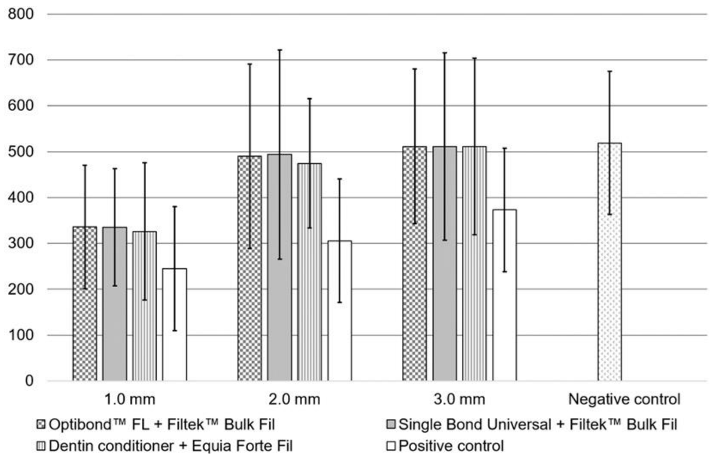

Figure 6 Mean fracture strength values and standard deviations of tunnel restoration on maxillary premolar by different remaining marginal ridge heights and restorative systems.

Statistical analysis with one-way ANOVA followed by LSD post-hoc multiple comparisons revealed that at the remaining marginal ridge height of 1.0 mm there was no statistical difference between M1PC group and all other restorative groups (M1ER, M1UA, and M1HGI). At the remaining marginal ridge height of 2.0 mm, there was a significant statistical difference between the M2PC group versus M2ER group (p=0.031), M2UA group (p=0.029) and also M2HGI group (p=0.048). At the remaining marginal ridge height of 3.0 mm, the fracture strength values exhibited no significant difference between all experimental groups (M3ER, M3UA, M3HGI, M3PC and NC). The NC group showed a significant statistical difference between M1PC group (p=0.000) and M2PC group (p=0.005). Statistical differences of the NC group were also demonstrated with M1ER group (p=0.015), M1UA group (p=0.014), and M1HGI group (p=0.010).

In terms of the adhesive systems and restorative materials, there were statistically significant differences between the remaining marginal ridge height of 1.0 mm (M1) versus the remaining marginal ridge height of 3.0 mm (M3) in all four restorative subgroups, as identified in ER group (p=0.029), UA group (p=0.049), HGI group (p=0.017) and PC group (p=0.047).

Failure mode analysis

The data showed that all 130 maxillary premolar specimens represented favorable fractures or restorable failures, which occurred above the level of bone simulation, as presented. (Figure 7)

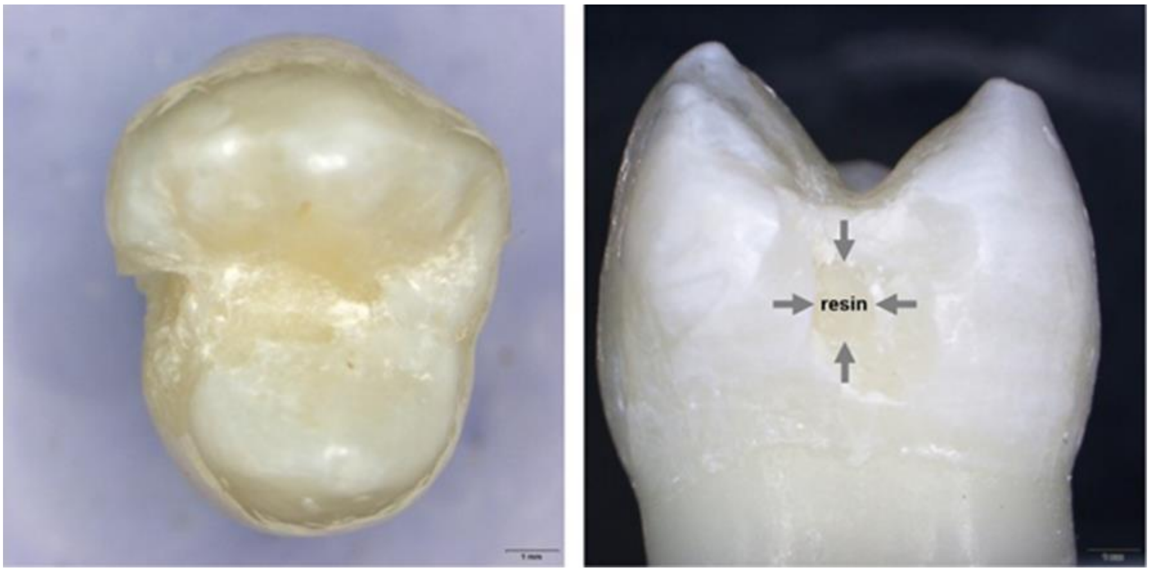

Figure 7 Favorable fracture of tunnel restoration. View from occlusal surface (left), view from proximal surface (right).

Discussion

This *in vitro* study evaluated the effect of various heights of remaining marginal ridge, at 1.0 mm, M1; 2.0 mm, M2; 3.0 mm, M3 restored using various restorative systems, which were 3 step etch and rinse adhesive with paste-like bulk fill resin composite or ER group; selective enamel etching mode universal adhesive with paste-like bulk fill resin composite or UA group; and high-viscosity glass ionomer cement or HGI group; tunnel prepared teeth without restoration as positive control (PC) group; and intact unprepared teeth negative control or NC group, on fracture strength values of maxillary premolar, after artificial aging by 10,000 thermocycled. The results of this experiment showed that fracture strength of each restored tunnel preparation revealed different values, influenced by different remaining marginal ridge heights, but did not influenced by different restorative systems. Therefore, the first null hypotheses were rejected, while fail to rejected the second null hypothesis.

The current investigation demonstrated that the mean fracture strength values at the M1 of all the ER, UA, HGI, and PC groups were found to be statistically significantly inferior to those of the M3 groups, these apparently indicated the effect of the remaining marginal ridge heights on the strength of tunnel preparation and restoration.

The tunnel preparation of M1PC and M2PC groups exhibited significantly lower fracture strength values when compared to the intact tooth or NC group, this finding is consistent with previous *in vitro* investigations.[9,18–21] However, the M3PC group was demonstrated to be as strong as unprepared tooth, which was in accordance with Fasbinder et al.[19] and Strand et al.[20] who had suggested that the strength of marginal ridge was not significantly subsided if the amount of tunnel preparation was conservative, compared to the size of marginal ridge. Consequently, all restorative systems in this study have not differed when restored the tunnel-prepared teeth at the remaining marginal ridge height of 3.0 mm.

The M1PC group was found to be drastically weakened compared to the NC group. All three restorative systems in this experiment, i.e., M1ER, M1UA, and M1HGI groups, failed to restore the 1.0 mm. thickness brittle undermined tooth structure back to the strength level of natural unprepared tooth, thus, tunnel-restored teeth at remaining marginal ridge height of 1.0 mm may not withstand occlusal loading. Therefore, our results suggested that the remaining strength of prepared tooth was a major contributor affecting the success of tunnel restoration, which was also in accordance with earlier studies.[6,22]

Some studies proposed that the mechanical properties of restorative materials were likely a main factor influencing strength of the approximal wall of the tunnel restoration.[6,22] GIC was not recommended to be used as definitive restoration in occlusal loading area due to inadequate mechanical strength.[14] Marginal ridge fractures in tunnel restoration of permanent teeth with GIC were evidenced in clinical studies.[4,5,23,24] Development of HV-GIC has been claimed to provide better mechanical properties, but consideration for their utilization should be achieved from clinical trials.[25] A two-year clinical study in 2020 suggested that the use of HV-GIC as permanent class II restoration was not clinically appropriate.[26] Nevertheless, a five-year randomized clinical trial in small class II restorations between Equia Forte (GC, Japan) and resin composite (Filtek Z250, 3M ESPE, USA) combined with a two-step etch and rinse adhesive (Adper Single Bond 2, 3M ESPE, USA) reported that retention and fracture of both materials were found to be no statistically significant over time.[27]

At the remaining marginal ridge height of 2.0 mm, both of the resin-based groups in this study or M2ER group and M2UA group were capable of reinforcing tunnel preparation to obtain the strength level of NC group, as well as Equia Forte Fil or M2HGI group. This outcome coincided with an *in vitro* study which revealed that conventional GIC re-established tunnel preparation to be as strong as sound tooth.[21] When dental restorations are subjected to forces, stresses occurs and therefore absorbed and transmitted. There were a number of factors affecting stress distribution of dental restorations, and the elastic modulus of restorative materials was one of the direct associated factors.[28] Some studies indicated that the higher elastic modulus materials supported higher loads and resisted the stresses, whereas the lower elastic modulus materials absorbed the forces then deformed and flexed, resulting in reduction of the stresses.[29] It was recognized that the elastic modulus of restorative materials close to that of dentin may reinforce and limit marginal ridge flexure and fracture.[18,19] Elastic modulus of dentin was 14-18.6 GPa.[30] The restorative materials used in this study, Filtek™ Bulk Fill Posterior Restorative had an elastic modulus at 17.2 GPa.[31] A study reported the elastic modulus of no-coat Equia Forte Fil at 20.75 GPa and the coated type was at 8.08 GPa.[32] Another study revealed the elastic modulus of no-coat Equia Forte Fil at 5.6 GPa.[33] Therefore the resultant effect of the elastic modulus of Equia Forte Fil (GC, Japan) in this study may not be justified.

Other properties of the restorative materials are also factors affecting stress distribution of dental restorations. The polymerization shrinkage nature of resin-based dental restorative material was inevitable, generating stress within material itself and neighboring dental structures,[8] and effective dental adhesive assisted to relieve the shrinkage stress.[34] Strand et al.[22] suggested that bonding ability of restorative materials may also be highly affecting strength of the tunnel-restored tooth. Generally, GIC were reported to have low bond strength and cohesive failure that represented intrinsic brittle nature of the materials.[14] To the extent of the author's knowledge, there is no literature comparing bond strength of Equia Forte Fil versus neither Optibond™ FL nor Single Bond Universal Adhesive to date. However, a 3-year clinical study of class V restoration in sclerotic dentin reported that EQUIA Forte Fil and a conventional resin composite with OptiBond FL survival rate and retention loss were not statistically differed.[35] The setting of conventional GIC revealed low or non-shrinking nature,[8] and GIC has been believed to act as a stress breaker.[36] Studies showed that GIC could reduce effect of stress concentration when compared to resin composite.[37] Additionally, evidence showed that with availability of water during the maturation phase, mechanical properties of GIC gradually increased with time.[38] Furthermore, the boundary conditions or cavity geometry factors and residual dental structures also played crucial roles in stress distribution.[39] All of the possible compensation and complex contributing factors may explained the statistical equivalent fracture strength values of the resin-based groups and the HV-GIC group at the remaining marginal ridge height 2.0 mm in this experiment.

In our investigation, fracture strength of tunnel restoration at the remaining marginal ridge height of 2.0 mm with paste-like bulk fill resin composite in conjunction with either OptiBond™ FL group (M2ER) or selective enamel etching mode Single Bond Universal Adhesive group (M2UA) were significantly equivalent to unprepared teeth group (NC), as shown in the Table 4 and Figure 6. These results were consistent with earlier published experiments that restoration with bonded resin composite reinforced the tunnel preparation equally to the strength of intact tooth.[6,9] A recent systematic review and meta-analysis in 2020 recommended resin composite as the material of choice for permanent direct posterior restoration.[40]

The fracture strength values of OptiBond™ FL and selective enamel etching mode Single Bond Universal Adhesive in this study were not statistically different. Both groups used phosphoric acid as enamel etchant, whereon resin tags were formed and created micromechanical interlocking that proved to be effective and durable.[12,41] Regarding the challenging dentin bonding, Single Bond Universal Adhesive contained the most widely used acidic functional monomer, 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP), which provided *in vitro* stability[42] and showed excellent bond durability performance from 5-year clinical studies.[43,44] 10-MDP partially demineralized and infiltrated into dentin substrate, creating micromechanical interlocking forming hybrid layer, whilst simultaneously releasing calcium and chemically bonded to hydroxyapatite, forming insoluble nanolayering MDP-calcium salts.[41] OptiBond™ FL has been proven of outstanding bond durability in a 13-year clinical study.[45] It contained glycerol phosphate dimethacrylate

(GPDM) as functional monomer, however, the dentin bonding mechanism mainly came from hybridization of acid-conditioned hydroxyapatite-deprived collagen scaffold.[12,41]

There were literatures comparing Optibond™ FL and Single Bond Universal Adhesive in various settings, but based on available information, this study provided the first *in vitro* investigation of the effect of Optibond™ FL versus Single Bond Universal Adhesive on tunnel restoration. There were literatures reported that *in vitro* dentin bond strength studies of OptiBond™ FL and multiple modes of Scotchbond Universal Adhesive (Single Bond Universal Adhesive's name in some countries) in various conditions were not statistical difference.[46,47] Three year randomized clinical trial revealed that in class V resin composite restoration, cumulative failure rate in the OptiBond™ FL group was not statistically different when compared to the Scotchbond Universal Adhesive groups in self-etch, selective-enamel-etch, and etch-and-rinse modes.[48] Optibond™ FL, Single Bond Universal Adhesive, and Filtek™ Bulk Fill Posterior Restorative were clinically well-performed adhesive restoration.[26,49]

There were suggestions to restore tunnel preparation with resin composite in conjunction with adhesive systems.[50,51] A randomized control clinical trial by Kinomoto et al. found that the survival rate and marginal ridge fracture of conventional resin composite in class II versus tunnel restoration had no significant difference.[10] A recent 5-year clinical study in 2020 reported that, with bonded resin composite restoration, annual failure rates were comparable in class II (2.2%) versus tunnel restoration (1.8%).[11]

Fracture pattern of all specimens in this experiment was favorable or restorable, corresponding to previous laboratory investigations.[9,18,22] In clinical situations, marginal ridge fracture or failure that occurred in tunnel preparation/restoration were recommended to be repaired into conventional class II restoration.[22,50]

The wide standard deviation indicated a lot of variances involved. Tunnel preparation and restoration have been recognized for high technique sensitivity, limited accessibility and visibility, and demand for operator skill.[50,52,53] A study suggested that the effect of marginal ridge height on strength of tunnel restoration may be considered as a cavity geometry factor.[6] All of contributing factors may affect our results.

In summary, tunnel restoration may be the contemporary treatment of choice for conservative restoration of proximal carious lesion. Proper case selection is particularly important, therefore, contributing factors for decision-making to operate tunnel restoration in approximal caries would be the balancing of dental substrate conservation, the risk of pulp exposure, and the extent of decay invasion,[54,55] as secondary caries was another major cause of tunnel restoration failure.[3,56] Since the development and improvement of contemporary adhesive systems and restorative materials is ongoing, further investigations including long-term clinical studies are therefore suggested to determine their effects on tunnel restoration.

Conclusion

Within the limitation of the present study, the remaining occlusogingival marginal ridge heights affected strength of tunnel restoration, but did not affect by the adhesive systems and restorative materials. At the remaining marginal ridge height of 1.0 mm, all restorative systems in this study were unable to support tunnel preparation, therefore unable to withstand occlusal force. At the remaining marginal ridge height of at least 2.0 mm, Optibond™ FL or selective enamel etching mode Single Bond Universal, combined with Filtek™ Bulk Fill Posterior Restorative, and Equia Forte Fil reinforced tunnel preparation to the level of intact teeth.

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ความต้านทานการแตกหักของการบูรณะฟันแบบทันเนิลที่สันริมฟันหลายระดับความสูง

พีรินาถ เอื้อปัญจะสินธุ์ ศิริวิมล ศรีสวัสดิ์***

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาค่าความต้านทานการแตกหักของการบูรณะฟันในโพรงฟันแบบทันเนิลที่มีความสูงของสันริมฟันหลายระยะ โดยใช้สารยึดติดและวัสดุบูรณะแบบต่างๆ การทดลองนี้ใช้ฟันกรามน้อย 130 ซี่ แบ่งเป็น 13 กลุ่มย่อย ตามความสูงของสันริมฟัน 3 กลุ่ม (1.0 มม. 2.0 มม. และ 3.0 มม.) และตามสารยึดติดและวัสดุบูรณะ 3 กลุ่ม (สารยึดติดออพติบอนด์เอฟแอล สารยึดติดซิงเกิลบอนด์ยูนิเวอร์แซล วิธีซีเลคทีฟเอชท์เคลือบฟัน วัสดุอิเควียร์ฟอร์เต้ฟิล) กลุ่มควบคุมแบบบวกหรือโพรงฟันแบบทันเนลที่ไม่ได้รับการบูรณะ และกลุ่มควบคุมแบบลบซึ่งเป็นฟันที่ไม่ผ่านการกรอ หลังจากเตรียมโพรงฟันแบบทันเนิล บูรณะฟัน และเทอร์โมไซคลิง 10,000 รอบ แล้วนำไปหาค่าความต้านทานการแตกหักและประเมินรูปแบบความล้มเหลว การวิเคราะห์ทางสถิติใช้ความแปรปรวนสองทาง ความแปรปรวนทางเดียว และการเปรียบเทียบเชิงซ้อน ผลการศึกษาพบว่าความสูงของสันริมฟันส่งผลกระทบอย่างมีนัยสำคัญทางสถิติต่อความต้านทานการแตกหักของการบูรณะโพรงฟันแบบทันเนิล แต่สารยึดติดและวัสดุบูรณะไม่ได้ส่งผลกระทบอย่างมีนัยสำคัญทางสถิติต่อความต้านทานการแตกหักของการบูรณะโพรงฟันแบบทันเนิล โดยที่ความสูงของสันริมฟัน 1.0 มม. การบูรณะทุกระบบไม่สามารถป้องกันการแตกหักให้เทียบเท่าฟันปกติ ที่ความสูงของสันริมฟัน 3.0 มม. พบว่าโพรงฟันแบบทันเนิลที่ยังไม่ได้บูรณะ แข็งแรงเทียบเท่ากับฟันปกติ พบว่าที่ความสูงของสันริมฟันทั้ง 2.0 มม. และ 3.0 มม. โพรงฟันแบบทันเนิลที่บูรณะด้วยสารยึดติดออพติบอนด์เอฟแอล สารยึดติดซิงเกิลบอนด์ยูนิเวอร์แซลวิธีซีเลคทีฟเอชท์เคลือบฟัน และวัสดุอิเควียร์ฟอร์เต้ฟิล แข็งแรงเทียบเท่าฟันธรรมชาติ สรุปผลศึกษานี้คือ การบูรณะโพรงฟันแบบทันเนิลที่ความสูงของสันริมฟันอย่างน้อย 2.0 มม. ด้วยสารยึดติดออพติบอนด์เอฟแอลร่วมกับวัสดุเรซินคอมโพสิตชนิดบัลค์ฟิลล์แบบเพสต์ไลค์ หรือสารยึดติดซิงเกิลบอนด์ยูนิเวอร์แซลวิธีซีเลคทีฟเอชท์เคลือบฟัน ร่วมกับวัสดุเรซินคอมโพสิตชนิดบัลค์ฟิลล์แบบเพสต์ไลค์ หรือวัสดุอิเควียร์ฟอร์เต้ฟิล พบว่ามีความแข็งแรงเทียบเท่าฟันปกติ

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