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Original Article

An *in vitro* comparison of the fracture resistance of standard and modified mesio-occluso-distal cavity designs restored with resin composite restoration

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ABSTRACT

Objectives: The main goal of this study was to evaluate the fracture resistance of maxillary second premolar teeth with standard and conservative mesio-occluso-distal (MOD) cavity designs.

Methods: Sixty maxillary second premolars were randomly divided into 6 Groups of 10 teeth. G1 consisted of intact teeth. G2 was prepared with separated proximal boxes that were designed to be 1 mm approximately above the cement-enamel junction for the cervical margins. The occlusal outline of the proximal was performed as approximately half of the intercuspal distance buccolingually and one-third of the mesiodistal dimension. The proximal preparation was standardized in all tested groups. G3 was prepared with an occlusal extension that extended approximately one-third of buccolingual width and 2 mm in depth. G4 was prepared with the occlusal extension of 1mm in depth and width. G5: The occlusal extension was 1mm in depth and 2 mm in width. G6: The occlusal extension was 2 mm in depth and 1 mm in width. Samples were restored with composite resin and subjected to load to failure test to evaluate the fracture resistance.

Results: G1 showed the highest fracture resistance value (1737.1 N) while G3 had the lowest mean value (522.9 N). Furthermore, the fracture resistance of G4 and G5 was significantly higher than G3 and G6 ($P < 0.05$), where in both groups, the preparation of the occlusal extension mostly remained in the enamel layer.

Conclusion: Modified MOD cavity designs with 1 mm depth in the enamel layer have significantly higher fracture resistance than the standard MOD cavity.

Keywords: Composite restoration, fracture resistance, Mesio-Occluso-Distal cavity

Introduction

Cavity geometry of the tooth preparation for direct and indirect restorations has been reported as a major factor in determining the ability of the tooth resistance to fracture.[1-4] Teeth with large cavity preparations have exhibited greater cuspal deflection than others with small cavity preparations.[3] Greater cuspal deflections potentially enhance dental deformations, and then, restoration failure or cuspal fracture may occur.[5-7]

Polymerization shrinkage of composite restorations subjects cusps of teeth with large cavities to high stresses which may generate dental deformation under repeated occlusal load and consequently increase the cuspal deflection.[8,9] This deflection ranged between 6 and 47 µm based on the cavity size, the tooth stiffness, the restoration size, the composite restoration flow, the bonding system, the placement of restoration, and the curing mode and intensity.[8-12]

The destructive nature of the tooth preparation has been encountered as the main reason of reduction in the tooth strength. Furthermore, endodontic procedure, occlusal tooth preparation, and mesio-occluso-distal (MOD) cavities are the principal procedures in the tooth weakening and consequently increase the susceptibility of the tooth to fracture.[2,4,13] Reeh *et al*.[4] reported that 63% reduction of cuspal stiffness happens with MOD cavity preparation. They proposed that this high reduction of tooth stiffness was due to loss of marginal ridge integrity.

The fracture resistance of standard MOD cavity has been investigated in the literature. Recently, Firouzmandi *et al*.[14] evaluated the fracture resistance of standard MOD cavities restored with amalgam restorations, composite restorations, and combination of both restorations. They found that the fracture resistance ranged between 874 N for amalgam restorations and 1287 N for amalgam/composite combination.

It has been proposed that the adhesive nature of composite restoration reinforced the remaining tooth structure by stress distribution along the bonding junction that consequently increases the fracture resistance.[14,15]

However, composite resin restoration has been indicated for minimal MOD cavity preparations that maintain the remaining tooth structure and then increase the fracture resistance of teeth.[16] The fracture resistance of teeth with standard MOD cavities has been investigated in the literature. However, conservative MOD cavities where the occlusal extension remains in the enamel layer have not been investigated for the cuspal fracture resistance. This study was designed to evaluate the fracture resistance of maxillary second premolar teeth with standard and modified conservative MOD cavity designs where caries lesion does not extend beyond the dentinoenamel junction (DEJ) to mimic the clinical situations.

Materials and Methods

Study design and sample collection

Sixty maxillary second premolar teeth were collected after tooth extraction for orthodontic treatment reason and stored in 5% formalin. These teeth were sound and free of cracks, caries lesions, dental restorations, and dental anomalies. The selected teeth were imbedded in auto-polymerized acrylic resin (Trayplast, Vertix Dental, Netherlands) according to the following steps. A measurement of 2 mm below the cement-enamel junction (CEJ) was identified by a periodontal probe UNC-15 (UNC-15, Paterson Dental) for each tooth and marked with a permanent marker to simulate the biologic width of the natural teeth.[9] After that, Wax up line (Modeling wax, BEGO) of 2 mm height was performed on this marker, and it was used as a reference mark during embedment of the teeth in the acrylic resin. A silicon mold was fabricated to mount teeth perpendicular in the resin block with dimensions of 3 mm of resin around the tooth structure, 5 mm below the tooth apex, and 2 mm below the CEJ. All laboratory procedures were performed by the same operator.

Study groups and sample preparation

Samples were randomly divided into six experimental groups (n = 10) [Figure 1] where Group #1 (G1) consisted of 10 intact premolar teeth (control group). Group #2 (G2) included 10 samples that were prepared with separated proximal (mesial and distal) boxes that were designed to be 1 mm approximately above the CEJ for the cervical margins. In addition, the occlusal outline of the proximal boxes was performed as approximately half of the intercuspal distance buccolingually and one-third of the mesiodistal dimension for each tooth.[9] Group #3 (G3) consisted of 10 samples where standard MOD cavity design was prepared as proximal boxes as G2 with an occlusal extension that extended approximately one-third of buccolingual width and 2 mm in depth. Group #4 (G4) consisted of 10 samples that were designed for modified MOD cavity (MOD1) as in G3 except for that occlusal extension that was prepared as 1mm in depth and width, and the proximal boxes were kept as G2. Group #5 (G5): 10 samples were prepared for another modified MOD cavity (MOD2) design where the occlusal extension was 1mm in depth and 2 mm in width, and the proximal boxes were kept as G2. Group #6 where 10 samples had the occlusal extension was 2 mm in depth and 1 mm in width, with proximal boxes were kept as G2 (MOD3).

Cavity preparation and adhesive procedures

Graphite pencil was used to draw the outline of the cavity before preparation. Enamel access preparation was performed with a 330-carbide bur (Brasseler USA Dental, GA, USA) [Figure 2a]. After that, a medium coarse-tapered cylindrical diamond stone with a round end (Brasseler USA Dental, GA, USA) was used to complete the rest of the cavity preparation where a high-speed handpiece was operated with water coolant. These two burs were only used to standardize the cavity preparation for all samples. In addition, the periodontal probe UNC-15 was used to control all measurements. Any used bur was replaced with new one every five tooth preparations.[2]

After complete cavities' preparation for all the group samples, etching (total etch, Ivoclar Vivadent, Liechtenstein) was applied for each cavity for 15 seconds. After that, the cavity was rinsed thoroughly using water, followed by gently air-drying. Single bond adhesive (Stae, SDI dental limited) was applied to the cavities, then air was blown gently for 2 s with keeping the cavity surface glossy, and then, the light cure was applied for 10 seconds with standard LED lamp with an 8mm

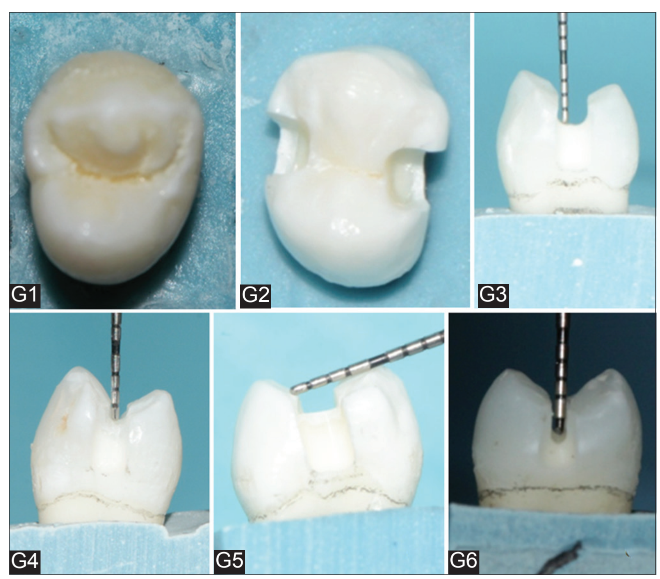

Figure 1: Images representing study groups; G1: Control group. G2: M and D cavities. G3: Standard MOD cavities. G4: MOD1 cavities. G5: MOD2 cavities. G6: MOD3 cavities

diameter light tip, 1200 mW/cm²actual irradiation output, and 440–490 nm [Figure 2b] (Litex 695C Dentamerica, Taiwan) according to the manufacturer instructions.

All cavities were restored with A2 radiopaque light curing nanohybrid composite resins using layering technique (Tetric N-Ceram, Ivoclar Vivadent, Liechtenstein) [Figure 2c].

Thermal cycling, cyclic loading, and load to fracture test

All samples were subjected to artificial aging where thermal cycling and dynamic occlusal loading have been performed. Samples were placed into the thermal cycling machine (Proto-Tech, El Segundo, CA, USA) using mesh bags and subjected to 2000 thermal cycles. Furthermore, the bath temperature ranged between 5°C and 55°C with a dwell time of 30 s for each bath and transfer time of 10 s between different baths [Figure 3a].

After that, samples were attached to a custom holder and then undergone to dynamic cyclic loading of 50 N for 10,000 cycles using chewing simulator (CS-4, SD Mechatronic GmbH, Germany) where the environment was wet. The crosshead diameter of the piston, which was contacting the internal inclines of buccal and lingual cusps, was 5 mm with rounded shape [Figure 3b].

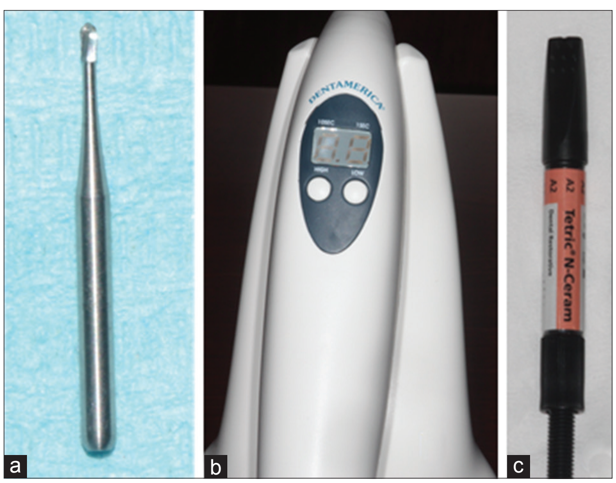

Figure 2: Cavity preparations and restoration materials; a: 330 bur. b: Light curing unit. c: Composite restoration

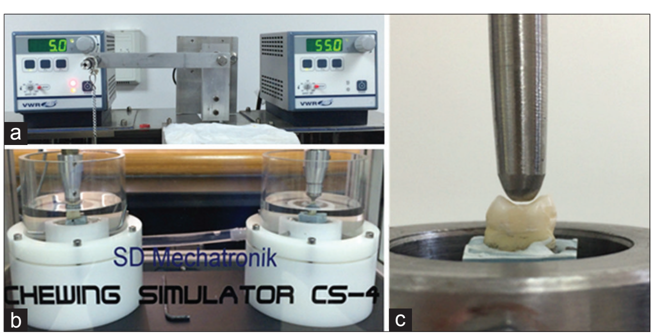

Figure 3: Samples subjected to artificial aging and fracture resistance test. a: Thermal cycling. b: Chewing simulator. c: Instron machine

To evaluate the fracture resistance of all groups, samples were subjected to load to fracture test under the Universal Testing Machine (Instron 8871 Universal Testing Machine, Instron, Shakopee, MN, USA) [Figure 3c]. A modified steel indenter with a diameter of 3 mm was customized to apply the compression load with a crosshead speed of 0.5 mm/min. The load was being applied vertically until the sample fracture occurred. The load at the sample fracture was recorded and analyzed.

Statistical analysis

Data analysis was performed through SPSS 20.0 (IBM Product, Chicago, USA). The results were presented into arithmetic mean and standard deviation. Analysis of variance (ANOVA) was applied to compare the mean effect. *Post hoc* Tukey's test or Wilcoxon Signed rank test was applied to compare pair-wise differences between the means. $P \leq 0.05$ was considered statistically significant result.

Results

Fracture resistance values in Newton (N) with mean and SD of all groups were presented in Table 1. G1 showed the highest fracture resistance mean value (1737.1 N) while G3 (standard MODs) had the lowest mean value (522.9 N). Furthermore, the results of this study showed that the fracture resistance of G4 and G5 (MOD1 and MOD2) was significantly higher than G3 (standard MOD)($P < 0.05$), where in both groups, the preparation of the occlusal extension mostly remained in the enamel layer [Table 2]. In addition, the fracture resistance of G4 and G5 (MOD1, MOD2) was significantly higher G6 (MOD3) where the preparation of the occlusal extension was 2 mm in the depth and the width ($P < 0.05$) [Table 2].

However, there was no significant difference between G3 and G6 (MOD3) where both groups had the lowest fracture resistance means' values (522 N and 628 N), respectively, among all the groups ($P > 0.05$) [Table 2].

Discussion

This *in vitro* study was designed to evaluate and compare the fracture resistance of standard and modified conservative MOD cavity designs to mimic the clinical situations where the occlusal caries lesion does not extend beyond the DEJ. The result presented that as the progressive reduction of the tooth structure at the different groups increased as the fracture resistance decreased. Furthermore, the results showed that MOD cavities with occlusal extension in the enamel layer had significantly higher fracture resistance than MOD cavities that extended beyond DEJ.

Table 1: The fracture resistance values of all the groups

G #	G1: Sound Teeth (N)	G2: M and D boxes (N)	MOD cavity designs			
			G3: Standard MOD (N)	G4: MOD1 (N)	G5: MOD2 (N)	G6: MOD3 (N)
1	1849.78	1595.67	408.32	1152.45	1012.97	789.96
2	1479.81	1774.04	548.56	1123.86	941.85	700.96
3	1511.55	1245.96	484.09	1110.69	955.39	568.1
4	1935.5	1163.2	476.32	1399.07	847.49	499.65
5	1877.69	1144.97	496.84	1137.08	923.02	674.07
6	1819.84	1163.2	439.93	910.97	705.1	548.56
7	1859.35	1200.86	711.19	1197.69	805.19	531.14
8	1493.86	1366	450.47	896.55	974.89	807.93
9	1739.9	1536.74	455.43	1273.02	1084.36	604.19
10	1803.43	1366	758.79	1000.04	622.69	558.22
Mean±SD	1737.1±174.6	1355.7±216.1	522.9±118.3	1120.1±155.2	887.3±142.5	628.3±109.2

Table 2: The statistical analysis of the fracture resistance between the groups

Variables (groups)	Mean (N)±SD	vs./G3	vs./G2	vs./G1	vs./G4	vs./G5	vs./G6
G3	522.9±118.3	-	0.006*	0.001*	0.001*	0.001*	0.117
G2	1355.7±216.1	0.001*	-	0.006*	0.020*	0.001*	0.001*
G1	1737.1±174.6	0.001*	0.001*	-	0.001*	0.001*	0.001*
G4	1120.1±155.2	0.001*	0.020*	0.001*	-	0.002*	0.001*
G5	887.3±142.5	0.001*	0.001*	0.001*	0.002*	-	0.001*
G6	628.3±109.2	0.117	0.001*	0.001*	0.001*	0.001*	-

*$P<0.05$

According to Bozkurt *et al*.,[17] the occlusal enamel thickness of premolar teeth ranged from 1.8 to 1.2 mm even with abrasion patterns after ultrasonic and histologic evaluations. As our methodology was designed to evaluate the effect of violation of DEJ on the fracture resistance of MOD cavities, G4 and G5, where the occlusal cavity preparation did not extend beyond the DEJ (1 mm in depth), presented significantly higher fracture resistance as compared to G3 where the preparation violated the DEJ. In the meantime, G6, where the preparation depth was 2 mm and the width was 1 mm, it showed significantly lower fracture resistance as compared to G4 and G5. Furthermore, there was no significant difference between G6 and G3 (standard MOD) which might be due to the violation of DEJ.

In disagreement with this result, Sakaguchi *et al*.[18] reported in two-dimensional finite element study that the premolar teeth stiffness was not affected by the separation of the enamel layer between the two cusps at the central groove. They suggested that the tooth deformation could be enhanced by dentin elasticity and integrity. This difference could be explained by the different methodology and experimental tests that have been used.

In agreement with this study, different studies showed that the standard MOD cavity affected the structural integrity of the tooth and might be considered as a major cause of cupsal fracture. Lopez *et al*.[9] compared the cuspal flexure between MOD cavity and M and D boxes. They concluded that higher cuspal deflection presented with standard MOD cavities. Mondelli *et al*.[19] found that MOD cavity had the lowest fracture resistance value as compared to Classes I and II two surfaces, especially when the one-third of the interocclusal distance was prepared. They considered that the isthmus width was the impact factor that affected the fracture resistance of different groups.

Several studies have suggested that the composite restoration is the preferred restorative material to restore MOD cavities.[20-22] Liu *et al*.[20] reported that composite resin significantly provided a higher fracture resistance for MOD cavities with proximal boxes than using ceramic materials. The explanation of this result is that the lower modulus of elasticity of composite resin could cause lower stresses generated around the junction between the tooth structure and the restoration. In addition, the bonding between the surrounding tooth structure and composite resin is better than that with the ceramic materials.

In the present study, samples were subjected to 2000 cycles of thermal cycling ranged between 5°C and 55°C to mimic clinical situations where dental restorations affected by the change in the temperature of oral environment. The essential factor for sample aging is the creation of mechanical stresses into the restoration which could affect the fracture resistance of restorations and remaining tooth structure.[23] The selection of temperature range was based on the most tolerated temperature in the oral cavity. Crabtree and Atkinson[24] reported that the temperature of tooth surface during eating hot meal ranged between 43°C and 53°C. The duration of thermal cycling has been varied in the literature to simulate the clinical scenario. Gale and Darvell[25] claimed in their extensive review that 10,000 cycles of thermal cycling test in the laboratory representing a clinical relevant of 1 year in service of dental restorations. Therefore, the number of cycles (2,000 cycles) that was used in this study simulating almost 2-3 months of dental restorations in the oral environment.

Limitations of the present study included that although this *in vitro* investigation was attempted to mimic clinical situations, it was with the limited presentation of actual oral cavity environment where multiple factors may affect the end result such as pH, saliva, oral temperature, and occlusal loading. Moreover, the MOD cavities in the present study were designed with specific dimensions, which in the actual clinical scenario controlled by the extent of caries lesions.

Clinical implications could be attributed to MOD cavities with minimum occlusal preparations that may not require full crown coverage because it significantly performed better than standard MOD cavities.

Conclusions

According to our results, modified MOD cavity designs with 1mm depth in the enamel layer had significantly higher fracture resistance than the standard MOD cavity while MOD cavities with 2 mm depth presented no significant difference as compared to standard MOD cavities.

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