Cuspal Deflection and Fracture Resistance of Maxillary Premolars with Complex Class II and Restored with Contemporary Bulk-Fill Resin Composite

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Abstract:

Objective: This study aimed to evaluate cuspal deflection (CD) and fracture resistance (FR) of maxillary premolars with Mesio-occluso-distal (MOD) cavities and restored with conventional and bulk-fill resin composites. **Materials and Methods:** One conventional (Filtek Z350XT) and two recent bulk-fill (Aura, and Reveal HD) resin composites were used. A total number of 120 maxillary premolars were used in this study. For CD test, 45 maxillary premolars prepared with standardized MOD cavity preparations and were divided into three groups (n=15). The different three resin composites (RCs) were used to restore the three groups. The CD values were measured using a digital micrometer five minutes after restoration completion. For FR test, 75 maxillary premolars were divided into five groups (n=15), positive control group (intact unprepared), and four groups received MOD cavities, negative control (prepared unrestored), and three groups restored as in CD test. A universal testing machine (Instron) was used to measure FR in Newton (N), and mode of failure was assessed. **Results:** The mean CD was significantly different in the three groups ($p \leq 0.001$). The highest deflection was noted in Filtek Z350XT (12.73±2.52 µm), the lowest was noted in Aura BF (5.60±0.74 µm). Highest FR was noted in the positive control group (1502±183.85 N) with significant difference with other groups ($p \leq 0.001$), followed by Aura BF (964.3±183.8 N) and Filtek Z350 XT (927.62±177.1 N) with no significant difference (p=0.501). The lowest FR value within the restored groups was noted in Reveal HD BF (787.9±98.2 N), and the negative control group revealed the lowest FR value in all tested groups (353.9±40.51 N). There was no significant difference between the materials regarding the failure mode. **Conclusion:** Bulk-Fill resin composites had less significant CD. However, fracture resistance values were material dependent.

Introduction:

Resin composite (RC) is the most extensively utilized direct restorative material in dentistry treatment, especially in stress-bearing posterior teeth, due to rising patient expectations for cosmetic restorations and a desire for a more conservative approach.[1] The resin matrix changes from a paste or pre-gel condition to a solid state when the polymer is created, and the gel point reflects the transition from a viscous paste to an elastic solid.[2] When RC is in pre-gel state, no shrinkage stress is conducted to surrounding tooth structure, and is able to flow from unbound surfaces to relieve the stresses.[3] As the RC becomes more rigid and the elastic modulus increases, flow ends and the ability to correct for shrinkage is lost. As a result, higher stresses in the RC- glue and the surrounding tooth structure accompanied post-gel polymerization.[4] Bonding failure will occur if the polymerization shrinkage stresses at the restoration/tooth contact exceed the bonding capacity, resulting in post-operative sensitivity, marginal discoloration, marginal leakage, and secondary caries.[5] If the adhesive bond strength exceeds the polymerization shrinkage stress, however, the restoration maintains internal strain, resulting in tooth deformation such as cuspal deflection (CD), enamel crack, or even tooth fracture.[6] Cuspal deflection changes the occlusal contact of the teeth, and causes enamel cracks with postoperative sensitivity.[7] The amount of CD is affected by C- factor, thickness of cavity walls after preparation, mechanical properties, and placement technique.[8]

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Bulk-fill resin composites were introduced to the market, and claimed to be used in increments of up to 4-5 mm in thickness without negative effects on the degree of conversion or the mechanical properties at this depth.[9] This allows faster and easier restorative process, especially in the extensive cavities in depth or width.[10] Also, they were designed to lower volumetric shrinkage, and polymerization stress.[11] Bulk-fill composites have been popular among clinicians due to its benefits over traditional composites, such as reduced chair time, control of polymerization shrinkage stress, and reduced CD.[12]

Fracture resistance (FR) is considered as one of the most important characteristics of dental materials, as it depends on the material resistance to cracks propagation from its internal defects.[13] Fracture resistance depends on cavity design, magnitude of stress, RC composition, and the restoration technique.[14] The fragility of cusps increases when a considerable portion of tooth structure is lost especially the marginal ridges.[15] Cusps may be forced apart by occlusal forces in teeth with broad Class II cavities under repetitive load.[16] Thus, this study was designed to evaluate the cuspal deflection and fracture resistance of premolars restored with different resin composites.

Null hypotheses

This study was conducted to test the null hypothesis that different bulk-fill resin composites neither affect cuspal deflection nor fracture resistance of maxillary premolars with complex Class II cavities.

Materials and Methods:

Three restorative systems were employed in this study; one conventional RC (Filtek Z350XT, 3M ESPE), and two bulk-fil RCs (Reveal HD, Bisco) and (Aura BF, SDI).

Each restorative system consists of an acid etchant, universal adhesive, and RC as presented in Table 1.

1. Teeth selection

A total number of 120 freshly extracted maxillary premolars for orthodontic purpose were collected from the clinic of Oral and Maxillofacial Surgery Department, Faculty of Dentistry, Mansoura University. Teeth were collected from healthy patients with age ranged from 20-25 years after patients and family approval, and Ethical Approval for scientific Research was granted (A 11 14 04 20). All the selected teeth were free from any decay or visible cracks, and disinfected in 0.5% chloramine-T solution.[17]

2. Cuspal Deflection Test

2.1. Specimen preparation and grouping:

Forty five maxillary premolars were selected with maximum bucco-palatal width (BPW) of each tooth was measured using a digital micrometer gauge (Mitutoyo, Kawasaki, Japan; resolution 0.001mm). The teeth were selected such that the mean standard deviation of BPW between teeth was less than 5%.[18] The premolars were embedded in a plastic mold of 2 cm diameter filled with chemical-cured acrylic resin (Acrostone, Egypt) extended to within 2 mm of the cement-enamel junction (CEJ).[19] The specimens were divided into three groups (n=15), based on the restorative system was used: Group1; Filtek Z350XT, Group 2; Reveal HD, Group 3; Aura BF.

Table 1: Materials used in the study.

Restorative system	Components	Composition	Patch no	Manufacturer
Aura Bulk-Fill	**Etch:** Super Etch	37% by weight phosphoric acid etching gel	190981	SDI, Melbourne, Australia
	Bonding agent: Zipbond universal adhesive	MDP, Ethanol, Acrylic monomers	201352	
	RC	**Matrix** UDMA(3-20%), Bis-GMA, Bis-EMA(15-18%), TEGDMA(0.01-7%) **Filler** 81% by weight Amorphous sio2, Barium aluminosilicate glass, Prepolymerized fillers	200126	
Reveal HD Bulk-fill	**Etch:** SELECT HV®* ETCH	35% semi-gel phosphoric acid etchant with BAC (Benzalkonium chloride)	2100001026	Bisco, Schaumburg, IL, USA
	Bonding agent: All bond universal	10-MDP, Dimethacrylate resins, HEMA, Ethanol, Water, Initiators	2000006421	
	RC	**Matrix** UDMA(10-30%), Bis-GMA (10-30%), Trimethoxysilylpropyl metchacrylate (1-3%) Tert-butyl Perbenzoat (<1%) **Filler** Ytterbium Fluoride Filler loading: Unreported	2000005228	
Filtek Z350 XT	**Etch:** Scotchbond™ Universal Etchant	32% by weight phosphoric acid etching gel	6771584	3M ESPE, St Paul, MN,USA
	Bonding agent: Single universal bond	MDP phosphate monomer, Dimethacrylate Resin, HEMA, filler, Ethanol, water, initiators, Silane, Vitrebond(methacrylate modified polyalkenoic acid)copolymer	01111A	
	RC	**Matrix** Bis-GMA(1-10%), Bis-EMA(1-10%), UDMA(1-10%), TEGDMA(<1%), PEGDMA(<5%) **Filler** 78.5% by weight Zirconia/Silica cluster and silica nanoparticles	NC00148	

2.2. Cavity preparation:

Standardized MOD cavity preparations were prepared using a rotary abrasive (6836 KR 314 018; Komet, Brasseler, Lemgo, Germany) under copious air-water cooling. The hand-piece was fixed in a surveyor for standardization of the cavity throughout the preparation procedure, and cutting abrasive was replaced after five preparations.[20] The cavity dimensions were as follow: the BPW was one third of the inter-cuspl distance, and the depth was 4 mm gauged from the palatal cusp tip to the pulpal floor. The proximal boxes had no steps in order to minimize the variations in the preparations; gingival walls were located above the CEJ, and butt joint cavo-surface margins.

2.3. Pre-restoration cuspal measurement:

The buccal and palatal cusp inclines of each premolar were carefully etched with 37% phosphoric acid, rinsed, dried, bonded using adhesive, and Filtek Z350XT RC to build two cylindrical reference points for CD measurements.19 Both the micrometer and the specimen were secured in a specially designed device to keep them both fixed in their position and to avoid any movement during the measuring and the restorative procedure. The distance between the two reference points was measured using a digital micrometer and was registered as the initial reading.

2.4. Restorative procedure:

A pre-contoured Tofflemire matrix band was used to regain the proximal contour of the restoration. The metal band was adapted to the proximal side of the premolar using Ivory matrix no.1 with silicon pieces attached to its prongs and the matrix was carefully tightened to avoid any deformation of the band. For group 1, the samples were restored according to the manufacturer's instructions. The etching gel was selectively applied on the enamel for 30s, rinsed, and dried. Then, the adhesive was applied with microbrush to the entire cavity walls for 15s with slow agitation of the applicator, gently air pressure was applied for 5s, and light cured for 10s. The cavity was restored with a horizontal-incremental layering technique with 2 mm layer thick. The RC was placed and adapted using a clean non-stick titanium coated applicator (DuraFlex double paddle #38T, NourDent, USA). Each increment was light cured using a light emitting diode (LED) curing unit (BlueLEX; Monitex industrial CO, LTD) for 20s. After removal of the band and retainer, additional curing was applied from mesial and distal sides for 20s.

For group 2, selective etching for enamel was done as mentioned in Group 1. Two separate coats of the bonding agent were applied and agitated with a microbrush for 10s per coat. Gentle air pressure was applied for 10s, and light cured for 10s. The cavity was filled with one bulk increment and light cured for 20s. After band removal, additional light curing was done as previously mentioned. For group 3, selective etching was done as mentioned before and bonding agent was applied into the cavity surfaces by scrubbing for 10s with a microbrush. Then, adhesive was left on the cavity surfaces for 10s, the adhesive was blown with air until no movement of the adhesive was longer observed, and light cured for 10s. The RC was delivered into the cavity as one bulk increment and light cured for 20s and additional curing was done after band removal as mentioned before.

2.5. Cuspal deflection measurement:

The intercuspal distance between the reference points for each specimen of all groups was measured 5 min after completion of restoration and was registered as the final reading.[19] Cuspal deflection measurements were calculated in microns by subtracting the final readings from the initial ones.

3. Fracture Resistance Test

2.1. Specimens' preparation:

The roots of the remaining seventy five premolars were demarcated with red pencil 2 mm from the CEJ. To simulate the periodontal ligament space, the roots were dipped into melted wax to create a thin layer (0.2-0.3 mm) thickness approximately equal to the periodontal ligament space. The roots were vertically embedded in a cylindrical molds filled with cold cured acrylic resin up to 2 mm from the CEJ to simulate the alveolar bone, and left in place until the acrylic resin is completely polymerized. Each tooth was removed from the mold, the wax coating was removed from the root surface and the acrylic mold by dipping in boiling water. The wax spacer created then was substituted with polyether impression material (Impregum soft; 3M ESPE, St.Paul, MN, USA). The impression material was delivered into the artificial socket space, and each tooth was reinserted into the alveolus and left in place until the impression material set. The excess material was then removed using a scalpel blade.[20]

2.2. Specimens' Grouping, Cavity preparation and restorative procedure:

Seventy five premolars were divided into 5 groups (n=15): Group 1; as positive control (sound unprepared premolars), Group 2; as negative control (prepared and unrestored premolars), Group 3; Filtek Z350XT (3M ESPE),

Group 4; Reveal HD (Bisco), Group 5; Aura BF (SDI). Standardized MOD cavities were prepared in four groups as previously mentioned before. For groups 3, 4, 5, the samples were restored as mentioned before. The speciemens were finished using finishing carbides (Kerr Corp, USA) and the proximal surfaces were finished using Sof-lex discs (3M ESPE) in recommended order (coarse, medium, fine and superfine). Polishing was done using Astro-brushes (Ivoclar Vivadent). Then, the specimens were subjected to thermocycling aging in a thermal cycling machine (Robota, Egypt) for 2500 cycles between 5°C± 2ºC and 55°C ± 2º C, with a dwell time of 20 seconds and transfer time for 5 seconds.[21]

2.3. Fracture resistance measurements:

All the specimens were subjected to compressive axial loading with a crosshead speed of 0.5mm/min in universal testing machine (Instron 3345,Canton, MA, USA) using a metal sphere of 8 mm diameter which came in contact with the palatal slopes of the buccal cusp and buccal slopes of the palatal cusp. Load was applied with a crosshead speed of 0.5mm/min until the failure occurred, and the force at which the specimen fractured was recorded in Newton (N). Failure mode of each specimen was evaluated under magnification (40x) using a stereomicroscope (SZ TO, Olympus, Tokyo, Japan). The failure patterns were classified as follows: adhesive failure (AD) at the interface between the tooth structure and the restorative material, cohesive failure when the fracture occurred either in the restorative material itself (CM), or tooth structure (CT), and mixed failure (MI) when the fracture occurred in both the filling material and tooth structure.

Statistical analysis

All the collected data from each test were collected, tabulated, and subjected to statistical analysis using the IBM SPSS software package version 21. Data were analyzed using one-way analysis of variance (ANOVA) and Least Significant Different (LSD) post hoc test.

Results:

The means, standard deviations and paired t-test changes results of the normality of data was first tested with Shapiro test. For all statistical tests, the threshold of significance is fixed at 5% level. The results were considered significant when $p \leq 0.05$.

1. Cuspal deflection test:

As presented in Table 2, Aura BF showed the lowest mean CD value (5.60±0.74 µm) followed by Reveal HD BF (10.20±2.18 µm), while the conventional Filtek Z350 XT showed the highest mean value (12.73±2.52 µm). One-way ANOVA test showed a significant difference among the groups (p≤0.001). Post hoc least Significant Difference (LSD) test showed that Aura BF was significantly different from Reveal HD BF (p≤0.001), and from Filtek Z350 (p≤0.001). Also, Reveal HD BF was significantly different from Filtek Z350 XT (p=0.001).

2. Fracture resistance test:

As presented in Table 3, the intact (positive control) group showed the highest mean of FR (1502±183.85) to be followed by Aura BF (964.3±183.8), Filtek Z350 XT (927.62±177.1), and Reveal HD BF (787.9±98.2); respectively. Moreover, the prepared un-restored (negative control) group revealed the lowest mean of FR (353.9±40.51). One-way ANOVA showed a statistically significant difference among all groups (p≤0.001). Post hoc least significant differece (LSD) test showed that positive control had a significant increase in FR, compared with all the tested groups (p≤0.001). Also, the negative control group revealed a significant decrease in FR compared with all other groups (p≤0.001). There was no significant difference in the FR between Filtek Z350 XT and Aura BF (p=0.501). However, there was a significant difference between Reveal HD and Filtek Z350 XT (p=0.012). Regarding the two BF restored groups, Aura BF showed a significant increase in FR values when compared with Reveal HD (p=0.002).

3. Mode of failure:

The mode of failure for Aura BF and Reveal HD BF groups were predominantly adhesive failure (53.3%), followed by mixed failure (40%) and (33.3%) for Aura BF, and Reveal HD, respectively. The mode of failure of Filtek Z350 XT group was predominantly mixed (46.7%) followed by adhesive failure (40%). The cohesive failure within the tooth structure was (13.3%) for Reveal HD, and Filtek Z350 XT. (6.7%) for Aura BF. There was no significant difference among the three restored groups regarding the fracture patterns using chi-square and Monte carlo tests. (p=0.757), (p=0.701), (p=1.0) for mixed, adhesive, and cohesive fracture within tooth structure, respectively. However, there was no cohesive fracture within the restoration observed in any sample of all restored groups.

Table 1: The comparison of CD in µm for all restorative systems

Group	CD		F test	P
	Mean ± SD	Min-Max		
Aura BF	5.60±0.74	5.0-7.0	F=50.56	≤0.001*
Reveal BF	10.20±2.18	8.0-15.0		
Filtek Z350	12.73±2.52	10.0-18.0		
Post hoc LSD test	P1≤0.001*,	p2≤0.001*,	p3=0.001*	

significant p≤0.05
P1: Comparison between Aura BF and Reveal BF groups
P2: Comparison between Aura BF and Filtek Z350 groups
P3: Comparison between Reveal BF and Filtek Z350 groups

Table 2: Comparison of FR (N) for all the groups

Group	FR (N)	Post hoc LSD test			
	Mean ± SD	P1	P2	P3	P4
Aura BF	964.3±183.8	-	-	-	-
Reveal BF	787.9±98.2	0.002*	-	-	-
Filtek Z350	927.62±177.1	0.501	0.012*	-	-
Positive control	1502± 183.85	≤0.001*	≤0.001*	≤0.001*	-
Negative control	353.9±40.51	≤0.001*	≤0.001*	≤0.001*	≤0.001*
F test	115.3				
P	≤0.001*				

P1: Comparison between Aura BF and other groups
P2: Comparison between Reveal BF and other groups
P3: Comparison between Filtek Z350 other groups
P4: Comparison between Negative and positive controls

Discussion:

According to the results, the null hypothesis of this study was rejected, as the bulk-fill RCs resulted in less cuspal deflection values, however the fracture resistance value was a material dependent.

In an attempt to minimize the cavity preparation variations, this study was conducted on maxillary first premolars due to their relative symmetry and similar buccal and palatal cusp height.[22] To simulate aging, thermo-cycling was done before the FR test for 2500 cycles as was done in other study.[23] Regarding to the results of this study, the first hypothesis was not accepted and there was a significant difference among all the tested restorative systems. This result was in agreement with Elsharkasi et al, and Bouillaguet et al who concluded that the polymerization shrinkage stress development after polymerization process caused inward CD.[24, 25] The BFRC materials caused statistically significant less CD than the conventional one. This reduced polymerization shrinkage stress and subsequent CD may be due to optimized resin matrix, initiator chemistry, and filler technology.[26] These results comply the studies of Yarmohamadi et al, McHugh et al, and Politi,[18, 27, 28] who reported that the CD was significantly greater with incremental than with bulk cure RC. This may be attributed to the lower elastic modulus of barium alumino silicate glass, and prepolymerized fillers incorporated in filler system.[29]

The volumetric shrinkage of composite is not the only reason for the polymerization shrinkage stress. It is also affected by the material's visco-elastic behavior or elastic modulus (EM) and its flow capacity.[29] Calheiros et al, and Chen et al reported that shrinkage values, and visco-elastic behaviour are determinant factors in stress development.[30, 31] Hence, The lower EM of Aura BF might leads to lower polymerization shrinkage stress and subsequent lower CD values.[29] On other hand, the filler system of the conventional RC is mainly zirconia/silica filler particles with high modulus of elasticity.[32] This may explain its significantly higher mean of CD values. Reveal HD BF showed significantly higher mean value of CD compared to Aura BF group. This may be related to the different filler system which is ytterbium fluoride. The claimed depth of cure in Reveal BF is attributed to the high density fillers which refract light deeper in the mass of material, allowing for a higher degree of conversion that may enhance EM and affect CD in the same manner.[33]

On other hand, this study is in disagreement with Tsujimoto et al who stated that paste-like BFRCs showed CD similar to conventional RC. The discrepancy between the two studies might be due to the different methodology as well the different RC types used.[34] Another study conducted by Yarmohammadi et al who reported that BFRCs have no superiority over conventional RC in the reduction of CD values.[21] This might be attributed to the different RC materials that were used in both studies. Besides, the conventional RC that was used in this study was inserted in bulk.

The positive control group (intact teeth) had the greatest FR values, which might be explained by the presence of a continuous circle of dental structure made up of buccal and palatal cusps, as well as intact marginal ridges, supporting and sustaining the tooth's integrity.[15] The negative control (prepared unrestored teeth) group, on the other hand, had the lowest FR values, which might be related to the MOD cavity preparation's weakening impact as a result of the damage at the marginal ridge, which weakens the residual tooth structure.[35]

Amongst the restored groups, Aura BF group showed the highest FR values with no significant difference with the conventional Filtek Z350 XT restored group. This result might be attributed to the high filler loading (81% and 78.5%) respectively. Also, both materials have Zirconia and Silica particles in their filler content. Besides, Aura BF contains prepolymerized fillers to reduce EM.[36] This could neutralize the forces of contraction during the polymerization process as was reported by Rauber et al.[37] On another hand, Fahad and Majeed,[38] and by Toz et al,[39] reported that there is no difference between BFRCs and conventional nanohybrid RC in terms of load bearing capacity when used in MOD cavities. Moreover, Rauber et al,[37] found that bulk-fill RC showed a similar fatigue resistance to the conventional RC. Leprince et al who stated that the mechanical properties of BFRC mostly lower compared with conventional RC.[40]The results demonstrated that Reveal HD restored group had significantly lower FR values compared with the other restored groups. This might be attributed to the different filler composition which are ytterbium fluoride compared with silica and zirconia particles in both Aura BF and Filtek Z350 XT.

Limitations of study

As this study was performed in-vitro, the results could vary under natural oral environment conditions. Such as, for the CD test, the RC restoration in oral cavity absorb water, which causes hygroscopic expansion and this might neutralize the effect of polymerization shrinkage and relive the CD.[34] For FR test, the results could vary under natural oral environment conditions such as, thermochemical factors and the variations in the magnitude, speed and the direction of forces which are peculiar for each individual's oral environment and occlusion.

For future research, the CD values would be more useful to be tested along with marginal adaptation, and microleakage to get more comprehensive evaluation about the material performance.

Conclusion:

Bulk-fill RCs could control polymerization shrinkage stress than conventional RCs.

Fracture resistance of restored teeth is related to RC filler technology.

RCs could not enhance teeth fracture resistance as sound teeth.

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