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FRACTURE RESISTANCE OF MOD CAVITIES IN MAXILLARY PREMOLAR TEETH RESTORED WITH DIFFERENT RESTORATIVE PROTOCOLS: AN IN-VITRO STUDY

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ABSTRACT

Aim: this study was to determine influence of different restorative protocols on fracture resistance of maxillary premolars with MOD cavities.

Materials & Methods: three direct resin-based composites were used in this study; sonically activated bulk-fill resin composite (Sonic-fill ™ Kerr, USA), short fiber-reinforced composite, everX-Posterior (G.C., Tokyo, Japan), and nanoceramic resin-based composite, Ceram.X® one (DENTSPLY, Germany). An indirect CAD/CAM composite block Grandio Blocs (VOCO GmbH, Germany) was also used. Sixty extracted maxillary premolars were collected. According to restorative protocol tested, premolars were randomly divided into six groups (ten each) and stored at room temperature in distilled water containing 0.2% sodium azide for three months.

Results: One-Way ANOVA followed by Tukey's post-hoc test showed a statistically significant difference between study groups ($P < 0.001$). The positive control, Grandio blocs (IGG), and Ever-X- posterior (BEG) groups yielded the significantly highest mean values for maximum load. The mean value of the Sonic-fill (BSG) group did not differ from those of the IGG and BEG groups. Ceram-X-one (NCG) group had a substantially lower mean value than the positive control, IGG, BEG, and BSG groups, but a greater mean value compared to the negative control group. The negative control produced the lowest mean value among all study groups.

Conclusion: The current results illustrated that the fracture resistance of maxillary premolars with MOD cavities is highly dependent on the restorative material used. Accordingly, by selecting the suitable restorative material, the restored tooth can be reinforced to a level comparable to that of a sound tooth.

Clinical significance: Establishing a standard restorative protocol and evaluating the efficacy of restorative materials used to repair deficient with variable remaining tooth structure to improve their fracture resistance under occlusal load.

KEYWORDS: fracture resistance, bulk fill resin composite, fiber reinforced composite, nano-ceramic resin composite

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INTRODUCTION

Restoration of mesio-occluso-distal (MOD) cavities in premolar teeth is always considered a challengeable procedure because the loss of marginal ridges in premolar teeth weakened the remaining tooth structure and drastically diminished its fracture resistance to occlusal stresses. [1,2] The adhesive techniques are widely used to reinforce the weakened teeth, thereby increasing the stiffness of the restored tooth unit and protecting the restored tooth against fracture in clinical service.

It is well documented that the most clinically relevant problem of direct resin-based composite material is the polymerization shrinkage with its associated stresses. Multiple attempts have been made to overcome this most important critical problem.[3] Most of these attempts have been directed at reducing the released shrinkage stresses through using the incremental layering technique and, more recently, toward developing novel classes of bulk-fill resin-based composites materials. Manufacturers have launched bulk-fill composites that can be placed in a single 4-mm increment with improved physical and mechanical properties to endure the higher masticatory stresses. [4,5,6]

Manufacturers have made several attempts to improve the bulk-fill category, such as modifying the monomers, using special restoration application instruments, or reinforcing the composition with fibers. From this bulk-fill category, a product named Sonic-Fill™ was introduced to the market. It is a sonically-activated high viscosity bulk-fill resin composite that becomes low viscous using sonic vibration, providing dentists with the benefits of high strength for extensive large cavity buildup, good adaptation, and deeper depth of cure. [7,8]

The short fiber-reinforced composite resin is another bulk-fill category containing randomly oriented short glass fiber fillers, which reinforce in multiple directions. Thus, it is recommended for use in high-stress areas. [9]

Major advancements in resin-based composites have been expanded to CAD\CAM systems, leading to a significant increase in using CAD\CAM and indirect CAD\CAM composite blocks for restoring the weakened teeth. Compared to ceramic, the CAD/CAM composite has advantages, such as having less hardness that results in less wear on opposing enamel. Further, it is more convenient to fabricate and repair and has a higher marginal quality. However, only a few studies have been conducted on CAD/CAM composite blocks to evaluate their mechanical properties and clinical performance. [10,11]

Unfortunately, there is a controversy concerning definitive restorative protocols and the performance of restorative materials for treating weakened maxillary premolars with variable remaining tooth structures to improve their fracture resistance under occlusal load. Therefore, it is critical to evaluate the influence of various restorative protocols on the fracture resistance of maxillary premolar teeth with MOD cavities following thermo-cycling. Hence, the current study hypothesizes that the various restorative protocols would not affect the fracture resistance of maxillary premolar teeth with MOD cavities.

MATERIALS AND METHODS

All the used Materials name, description, composition and manufacturers are shown in table 1.

Sample size calculation

Sample size calculation was conducted using G*Power 3.1.9.4 Software based on data obtained from previous studies (Fahad and Majeed, 2014). The power of the t-test was set at 95% using a two-tailed significance level of 5%. An effect size of 2.07 was determined using a sample size of eight premolars per group. The sample size was increased by 30% to ten premolars per group, for a total of sixty premolars per six groups, to compensate for pre-test failures.

TABLE (1): Materials name, description, composition and manufacturers

Material	Description	Composition	Manufacturer
Sonic-fill ™	Nanohybrid bulkfill composite material	**Matrix**: Glass, oxide, chemicals (10–30%), 3-trimethoxysilyl-propyl methacrylate (10–30%), silicon dioxide (5–10%), ethoxylatedbisphenol A dimethacrylate (1–5%), bisphenol A bis (2-hydroxy-3- methacryloxypropyl) ether (1–5%), and TEGDMA (1–5%) **Filler:** 83.5 % by weight	Kerr Corp, Orange, CA, USA
EverX-Posterior	Short-fiber reinforced resin composite	**Resin matrix:** Semi-interpenetrating polymer network (semi-IPN): netpoly (methyl meth'acrylate)-inter-net-poly (bis-glycid-yl- A-dimethacrylate): Bis-GMA, TEGDMA, and PMMA **Fillers**: E-glass fiber, barium borosilicate	GC, Tokyo, Japan
Ceram x- SpherTEC	Nanohybrid composite material	Matrix: (methacrylate-, acid-modified methacrylate-, inorganic polycondensate- or epoxide based) modified version of the poly-siloxane. it is combined with a well-established *poly*-urethane-methacrylate as well as bis-EMA and TEGDMA. **Fillers:** 77-79 weight	DENTSPLY, De Trey, Konstanz, Germany
Grandio Bloc	Nano-ceramic hybrid CAD / CAM composite	86% Nanohybrid Filler 14% UDMA+ DMA	VOCO GmbH, Germany, Cuxhaven

Selection of samples

Sixty maxillary premolars were extracted for periodontal reasons. Teeth were scraped of any residual tissue, washed under running tap water, and then examined microscopically at a magnification of 10X. All teeth were free of any caries, visible cracks, or hypoplastic defects, and teeth with any defects were excluded. For standardization, selected teeth were measured using a digital caliper to determine their average mesio-distal width (7 ± 0.5 mm) and bucco-lingual width (8mm ± 0.5mm). Any premolars with dimensions other than those indicated previously were excluded. The selected teeth were then stored at room temperature in distilled water containing 0.2% sodium azide for less than three months with changing of water every three days. [12, 13]

Sample grouping

According to the restorative protocol tested, the collected premolars were randomly divided into six groups (10 each):

Group 1 (PG): sound premolars without cavity preparation as a positive control.

Group 2 (NG): premolars with MOD cavity preparation but without restoration as a negative control.

Group 3 (NCG): specimens were restored with nanoceramic resin composite.

Group 4 (BSG): specimens were restored with sonically activated bulk-fill composite.

Group 5 (BEG): specimens were restored with short fiber-reinforced composite.

Group 6 (IGG): specimens were restored with indirect CAD/CAM resin-based composite block.

Specimens preparation

For the periodontium simulation, the roots of teeth were embedded in melted wax (Cavex, Holland B.V) except for a 2 mm length of root away from the cemento-enamel junction to generate a uniform coat of about 0.5 mm around the root. The tooth was then placed in self-curing acrylic resin and encased in a specially built cylindrical Teflon mold with a 2 cm length and 2 cm diameter. The teeth were precisely centralized using a specially designed metal device to ensure that the long axis of each tooth was perpendicular to the cylinder base. After removing the teeth from the casted acrylic block, the wax spacer was removed and replaced with a light body polyvinyl siloxane material (Speedex, Coltene Whaldent AG, Attstatten, Switzerland), and the teeth were then re-inserted in the mold. [14]

Cavity preparations

Except for the positive control group (PG), all groups were prepared to receive standardized class II MOD cavities using high-speed round-end parallel diamond bur *(881.31.014 FG; Brasseler USA Dental)* under copious cooling with water and air. For the indirect group, the teeth were prepared using the #4261 inlay preparation kit (Komet Inlay preparation Kit, Brasseler, GmbH, Germany) in the following sequence: #845KR, #8845KR, and #845KREF.[15] Every three preparations, a new bur was used. A waterproof marker (Faber Castell, Germany) was used to delineate the MOD class II cavity on the tooth, and the dimensions were as follows: buccolingual width = 3 mm and occluso-cervical depth = 4 mm using the cusp tip as a reference point with no proximal steps. Parallel walls were created for the cavities of the direct restorations, and all internal line angles were rounded. In contrast, the cavity walls for the indirect restorations were prepared with around 6-10 degrees of occlusal divergence. All preparations were performed with the same operator and cavity dimensions were rechecked using a periodontal probe *(Hu-Friedy Co., Rockwell St. Chicago)* and the same digital caliper after preparation. [16,2]

Restorative procedures

All tested materials were placed according to the manufacturer's instructions, using its recommended adhesives. A matrix retainer system, a metal matrix combined with its holder (Tofflemire, Miltex Inc, York, PA, USA), was placed to simulate the clinical conditions. Selective-etching adhesive technique was used according to the manufacturer's instructions. The enamel margin of all specimens was selectively etched using 37% phosphoric acid for 30 seconds, then rinsed with both air and water for 60 seconds and air-dried.

After applying the adhesive to both enamel and dentin, it was polymerized using LED light-curing unit (Elipar S10, 3M ESPE, St Paul, MN, USA) in standard mode at a light intensity of 1200 mW/cm^2. [17]

In Group 3 (NCG) restored with Ceram.X® one, a conventional incremental technique was used after curing the adhesive (Prime and Bond Universal, DENTSPLYSirona, Konstanz, Germany). A 2 mm thickness increment was firstly applied obliquely and vertically and then cured for 20 seconds. Afterward, the second increment was placed and cured.

In Group 4 (BSG) restored with Sonic-fill™ Bulk-fill composite, sonically activated bulk-fill technique was used after curing the adhesive (OptiBond Universal, Kerr™ Corporation, West Collins, Orange, CA). The composite compule was placed in a sonically activated handpiece, and the speed of composite ejection was adjusted to speed 3. The compule's tip was then placed at the bottom of the cavity floor, and the composite was ejected in a steady, continuous stream to fill the cavity. The composite was then packed with a ball burnisher, and any excess composite was removed. Finally, curing for 20 seconds was done.

After applying and curing the adhesive (G-Premio Bond, GC Company, Tokyo, Japan), Group 5 (BEG) was restored with fiber-reinforced resin composite Ever X posterior. A conventional incremental technique was used in the same way followed in group 3 (NCG). All specimens were finished and polished using Sof-Lex™ discs (3M ESPE, *USA)* with an aluminum oxide coating of four descending grits. In group 6 (IGG) restored with Grandio blocs, each prepared tooth was scanned for the optical impression using Omnicam intraoral camera of CEREC system software version 4.60 (Sirona Dental Systems GmbH, D-64625 Benshein, Germany). The optical impression was checked carefully. The margin was drawn, and the final design was developed and checked for any corrections. Following the design step of checking the margins, uniformity, and contour of the restoration and ensuring that all parameters were met, the selected block Grandio Blocs (VOCO GmbH, Germany, Cuxhaven) of the required size (14) was inserted into the spindle of the milling chamber of the CEREC milling machine (MCLX) and fixed with the set screw. The milling process was fully automated. After completing the milling process, the restoration was separated from the block and checked against their corresponding prepared teeth. All restorations were polished according to the manufacturer's recommendations using polishing kit DIACOMP PLUS (EVE Ernst Vetter GmbH, Germany). The fitting surface of milled restorations was treated with the CoJet® system utilizing 30μm silica-coated alumina powder, followed by 60 seconds of silanization with Bis-Silane (Bisco) and 5 seconds of air drying. After actively applying Futura bond D.C. adhesive with a micro-brush, it was light-cured for 20 seconds. Dual-cured universal, self-adhesive resin cement (Bifix SE, Voco) was then used for cementation and light-cured for 40 seconds from all surfaces after removing excess cement.

Thermocycling of specimens:

After storage for 24 hours, all specimens were thermo-cycled in a thermo cycle machine between 5±2 °C and 55±2 °C with a 30-second dwell time at each temperature, following a regimen of 5000 cycles, which represents six months of clinical function. [18] Within 24 hours of thermocycling, the specimens were subjected to compressive axial loading for fracture resistance until fracture in a computer-controlled universal testing machine (LRX-plus, LLOYD instruments Ltd., Fareham, U.K.) at a crosshead speed of 1 mm/min. The maximum breaking loads were recorded in Kilo Newton (Kn) by the computer connected to the loading machine [19]

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics Version 2.0 for Windows. Data were presented as mean and standard deviation (S.D.). The significance level was set at $P \leq 0.05$. Kolmogorov-Smirnov and Shapiro-Wilk tests were used to assess data normality. Multiple comparisons between study groups were performed using One-Way ANOVA, followed by Tukey's post-hoc test for pairwise comparisons

RESULTS

One-Way ANOVA followed by Tukey's post-hoc test showed a statistically significant difference between the different study groups ($P<0.001$) as shown in ***Table 2 and Figure 1***. Positive control, Grandio blocs (IGG), and Ever-X- posterior (BEG) groups had considerably higher mean values for maximum load. The mean value for the Sonic-fill (BSG) group did not differ significantly from the mean values for the IGG and BEG groups. The Ceram-X-one (NCG) group showed a significantly lower mean value than the positive control, IGG a BEG, and BSG groups, but a higher one compared to the negative control group. However, the negative control produced the significantly lowest mean value among all study groups.

TABLE (2): Mean ± S.D. and P-value for the effect of restoration type on fracture resistance of MOD cavities in maxillary premolars (Newtons).

Restoration type	Maximum load (Newtons)
Sound Teeth (Positive Control)	992.84 ± 117.16[a]
MOD Cavity (Negative Control)	459.52 ± 90.66[d]
NCG	707.07 ± 80.34[c]
BSG	825.99 ± 60.68[b]
BEG	910.00 ± 67.30[ab]
IGG	926.46 ± 83.25[ab]
P-value	<0.001*

: significant at $P \leq 0.05$

Means with different superscript letters are statistically significantly different at $P \leq 0.05$.

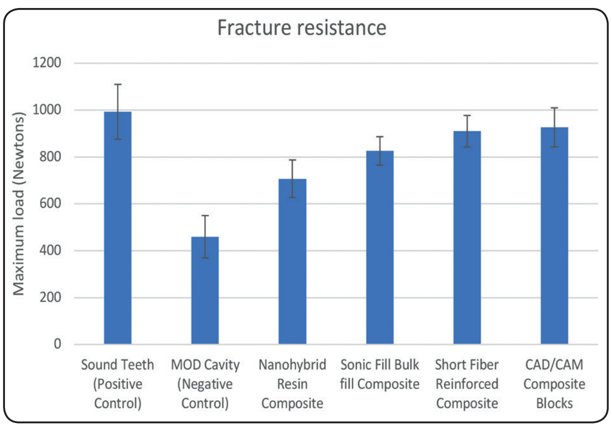

Fig. (1): Bar chart illustrating the effect of restoration type on fracture resistance of MOD cavities in maxillary premolars.

DISCUSSION

The restoration of weakened maxillary premolar teeth is one of the most challenging and controversial topics in operative dentistry. Adhesive restorations have considerable advantages in treating these weakened teeth due to their ability to distribute functional stresses throughout the restorative material and tooth interface and the potential to support the fragile and unsupported tooth structure. [20, 21] There are contradictory opinions regarding the most suitable restorative materials for restoring these teeth and achieving this goal. In the present study, different restorative materials systems were used to restore MOD cavities in maxillary premolar teeth, and their fracture resistance was evaluated.

New technologies for resin-based composite material were introduced in the dental market as bulk-fill composites that could be inserted in 4 to 5 mm thick increments in one increment, mainly in the posterior areas. Manufacturers claimed that both the physical and mechanical properties have been improved to withstand the higher masticatory stresses. Moreover, the risk of air voids entrapment or moisture contamination has been reduced by shortening the treatment period. Hence, SonicFill TM and everX-Posterior® composites were used in this study because both were reported to have the best mechanical properties in their respective categories and are based on different technology. [22, 23]

SonicFill™ RBCs system is a reliable and fast technique for posterior restoration, which does not require any additional capping layer. This sonically filled composite involves using a specially designated handpiece that dispenses the composite while applying sonic energy vibration.

The manufacturer claimed that this vibration reduces the material viscosity by 84%, resulting in a more flowable consistency that facilitates adaptability during application. Consequently, it allowed the filling of cavities up to 5 mm of depth in one bulk increment. [16]

Another breakthrough is using micro-glass fibers to strengthen composites, creating a fiber-reinforced substructure that improves their mechanical properties. The Ever X-Posterior fiber-reinforced composite is composed of PMMA, bis-GMA, TEGDMA, and HEMA. It is reinforced with short E-glass fibers randomly dispersed in numerous directions within a semi-interpenetrating resin matrix. [9]

Furthermore, one Nano-ceramic, which is recommended for incremental packing technique, was selected to be compared to the two bulk-fill composite materials evaluated in this study to analyze both the incremental and bulk-fill placement techniques. Ceram.X® one composite is a nanoceramic composite composed of a combination of conventional filler (1 μm), nanofillers (10 nm), and, most importantly, organically modified ceramic nanoparticles (2-3 nm). This combination of fillers based on nanoceramic technology has positively improved the mechanical properties of this material. [24]

On the other hand, an indirect CAD\CAM composite restorative material was selected to be compared to the previously mentioned direct composite materials to have more comparable data between direct and indirect restorative protocols in restoring MOD cavities in upper premolar teeth. Moreover, it was reported that the modulus of elasticity of resin composite CAD/CAM blocks is close to that of enamel and dentine when compared to CAD/CAM ceramic blocks, implying that resin composite CAD\CAM blocks are closer to the tooth structure stiffness, leading to higher flexibility and fracture toughness of those type of blocks. [25] Grandio blocs are nano-hybrid composite CAD/CAM blocks that contain 86 % wt. inorganic fillers in a polymer matrix and 14% UDMA+DMA. They are recommended for the fabrication of inlays and onlays restorations. Grandio blocs were chosen for their higher filler loading. [26]

In this study, maxillary premolar teeth were chosen to be evaluated because they were reported to be the second most prone teeth for vertical fractures due to their complex anatomy. [27] All premolars used in this study were extracted from patients aged 15 to 30 years old, and examined using 10X magnification, were free from caries and visible cracks, so as not to affect the inherent fracture resistance of the tooth structure. Moreover, premolars in this study received MOD cavity design to weaken the remaining tooth structure and increase the risk of cuspal fracture.

The cavity widths were also standardized to be within 5% of one another to standardize the amount of remaining tooth structure that consequently affects the fracture resistance of the restored teeth. On the other hand, the cavity depth was chosen to be 4 mm to evaluate the manufacturers' claim of applying bulk-fill composite up to 5 mm in one step. [28, 29]

According to the monoblock concept, a monoblock unit can bond strongly to available interfaces and the substrate. The successful binding effect of the adhesive joint that brings tooth structure together helps in favorable stress distribution and higher fracture resistance. Accordingly, the adhesive, which the manufacturer recommends for each tested resin-based composite material, was used to provide the required monoblock restoration to successfully function as a mechanically homogenous unit.

The more accurately a test simulates the clinical condition, the more likely the results are clinically relevant. Adding moisture and controlled temperature to the environment is important when measuring the fracture resistance of direct resin-based composites. That is why thermocycling wad performed for all the restored specimens.

All the restored groups showed lower fracture resistance mean values than the intact sound group (positive control group) in this study. It could be attributed to the inability of available restorative materials to fully restore lost mechanical properties, which might result from the heterogeneity between the tooth structure and the restorative material, multiple interfaces, and all faced challenges during adhesion. [30, 31] On the other hand, regardless of the resin-based composite material used, all restored groups had significantly greater mean values for substantial fracture resistance mean values than the prepared but unrestored teeth (negative control). It could prove that adhesive restorations could partially restore the lost tooth stiffness. [32] The findings of this study have shown that CAD/CAM composite blocks, short fiber-reinforced composite, and sonic fill bulk-fill composite yielded much higher maximum load mean values than Ceram.X® one. In contrast, these groups revealed no significant difference between each other. Thus, the null hypothesis was rejected because the different restorative protocols did affect the fracture resistance.

According to the literature review, it was reported that both filler loading and the elastic modulus of the restorative material are considered key factors affecting mechanical properties of composites.

The variation in strength between different composites may be explained due to the differences in the chemical composition of their matrix, filler content, filler size, and loading. The increase in the filler loading is directly proportional to an increment in fracture and compressive strength. [33, 34] The filler loadings of the Grandio blocs and Sonic-fill were found to be within the same range of 86% and 83% wt, respectively, which may explain why the fracture resistance mean values did not differ much between them. Moreover, it was revealed that the filler weight percentages of CAD/CAM composite blocks have a considerable role in mechanical properties than their microstructural constituents do. Further, CAD/CAM composites combine the strength of ceramic blocks with a lower modulus of elasticity of composite, resulting in a reduced hardness that may also explain the higher fracture resistance of Grandio blocs in this study. [35,36]

According to the manufacturer, Sonic activation significantly reduces the viscosity of the SonicFill™ composite dramatically up to 87%. It can be due to the presence of special rheological modifiers that react to sonic activation delivered through the SonicFill™ handpiece during its placement, leading to better adaptation to the cavity walls and a reduction in the frequency and size of critical voids. Sonicfill resin exhibits a low polymerization shrinkage of only 1.6%, decreasing gap formation and the risk of cracking that leads to fracture. [37]

Although both Ever X posterior and Ceram.X® one composites had filler loadings of 77% and 76% wt, respectively, the results of this study showed that Ceram X had the lowest significant fracture resistance mean values. It could be because their chemical compositions are diverse.

Ever X posterior containing E-glass fibers of 1–2 mm in length impregnated within the nanohybrid composite could be used in 4 mm increment. The e-glass fibers presented in EverX post short fiber-reinforced composites enhance the fracture resistance of restored teeth through transferring the subjected stresses from the resin polymer matrix to the fibers, hence preventing the crack propagation. Moreover, the e-glass fibers are incorporated in this resin composite in a random orientation, reinforcing the restoration in multiple directions and enhancing its strength.[38]

On the other hand, Ceram.X® one RBCs can be considered a Nanoceramic composite with pre-polymerized fillers (a trimodal resin composite) based on the modified version of the polysiloxane matrix. The filler system is a blend of three different filler types: the spherical, pre-polymerized SphereTEC™ fillers (≈15 µm), non-agglomerated bariumaluminium- borosilicate glass fillers (1.1- 1.5 µm), and meth-acrylate functionalized silicone dioxide nano-filler (10 nm).

Ceram.X® one RBCs compositions with a lower filler loading may have a lower significant fracture resistance due to incorporating pre-polymerized filler particles. Traditionally, mechanical properties are generally inferior with resin composite materials containing pre-polymerized particles. It may be owing to the unfavorable stress transfer between the resin matrix and filler particles. [39, 40]

CONCLUSION

Based on the findings and limitations of this study, it can be concluded that the fracture resistance of maxillary premolars with MOD cavities is highly dependent on the restorative material used. Accordingly, selecting the appropriate restorative material when restoring such cases could reinforce the restored tooth to a value close to that of the sound tooth. On the other hand, further clinical studies are required to evaluate the clinical performance of the tested restorative materials in clinical situations.

Clinical significance

Developing a clear restorative protocol and evaluating the efficacy of restorative materials for deficient maxillary premolars with varying remaining tooth structures to improve their fracture resistance under occlusal load.

Conflicts of interests

All authors declare no conflict of interests.

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