FRACTURE RESISTANCE OF MUTILATED MAXILLARY PREMOLARS RESTORED WITH DIFFERENT DIRECT & INDIRECT RESTORATIONS

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Introduction:

Restoring mesio-occluso-distal (MOD) cavities in premolar teeth is often regarded as a challenging procedure, as the loss of marginal ridges significantly weakens the remaining tooth structure and greatly reduces its fracture resistance under occlusal stresses.(1,2) Adhesive techniques are commonly used to strengthen weakened teeth, enhancing the stiffness of the restored tooth structure and protecting it from fractures during clinical use.

It is well established that the most clinically significant challenge of direct resin-based composite materials is polymerization shrinkage and the associated stresses. Numerous efforts have been made to address this critical issue.[3] The majority of these efforts focus on minimizing shrinkage stresses, such as through the incremental layering technique and, more recently, the development of novel bulk-fill resin-based composite (RBC) materials. Manufacturers have introduced bulk-fill RBCs designed for placement in a single 4-mm increment, with enhanced physical and mechanical properties to withstand higher masticatory stresses. [4,5,6]

Manufacturers have made several efforts to enhance the bulk-fill category, including modifying monomers, developing specialized application instruments, and incorporating fibers into the material for added reinforcement. One such product from this category is SDR, a high-viscosity bulk-fill resin composite that transitions to low viscosity when subjected to sonic vibration. This innovation provides dentists with the advantages of high strength for restoring extensive cavities, improved adaptation, and a greater depth of cure. (7,8)

Another recently popularized bulk-fill category is short fiber-reinforced composite resin, which incorporates randomly oriented short glass fiber fillers. These fibers offer multidirectional reinforcement, making this material particularly suitable for use in high stress-bearing areas. (9)

The substantial advancements in resin-based composites over the past decade have extended to CAD/CAM systems, resulting in a notable increase in the use of CAD/CAM technology and the adoption of indirect CAD/CAM composite blocks for restoring weakened teeth. CAD/CAM composites offer several advantages over ceramics, including lower hardness, which reduces wear on opposing enamel, easier fabrication and repair, and improved marginal quality. However, limited research has been conducted on CAD/CAM composite blocks to assess their mechanical properties and clinical performance.(10,11)

Unfortunately, there remains ongoing debate regarding the optimal restorative protocol and the performance of restorative materials for treating weakened maxillary premolars with varying amounts of remaining tooth structure to enhance their fracture resistance under occlusal loads. Consequently, evaluating the impact of different restorative protocols on the fracture resistance of maxillary premolar teeth with MOD cavities, particularly after thermo-cycling, could provide valuable insights. Accordingly, the null hypothesis of this study posits that the various restorative protocols would have no effect on the fracture resistance of maxillary premolar teeth with MOD cavities.

Materials and Methods:

Study materials

Three direct resin-based composites as follows: bulk-fill resin composite, SDR (DENTSPLY SIRONA, De Trey, Konstanz, Germany) , Short fiber-reinforced composite, everX-Posterior (GC, Tokyo, Japan), and Nano-ceramic resin-based composite, Ceram.X Spectra St (DENTSPLY SIRONA, De Trey, Konstanz, Germany) and one type of indirect Nano hybrid CAD\ CAM composite blocks resin based composite block Brilliant Crios (Coltene, Whaledent GmbH, Langenau, Germany) were used in this study. The materials 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 t-test was set at 95% using a two-tailed significance level of 5%. A sample size of 8 premolars per group was estimated to detect an effect size of 2.07. Sample size was increased by

30% to 10 premolars per group, for a total of 60 premolars per 6 groups, in order to compensate for pre-test failures.

Samples selection

Sixty maxillary premolars extracted for periodontal reasons were collected. Teeth were scraped of any residual tissue, washed under running tap water and then examined microscopically under x10 magnification. 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 digital caliper to have average dimensions (7 ± 0.5 mm) mesio-distal width, and of bucco-lingual width (8mm ± 0.5mm). Any premolars with other dimensions than previously stated were excluded. The selected teeth were stored then at room temperature in distilled water containing 0.2% sodium azide for less than 3 months. [12, 13]

Sample grouping

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

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

Group 2 (NG): premolars with cavity preparation but kept unrestored to act as negative control

Group 3(NCG): specimens that were restored with nano-ceramic resin composite Ceram.X Spectra St (DENTSPLY SIRONA, De Trey, Konstanz, Germany).

Group 4 (BSG): specimens that were restored with bulk fill composite, SDR (DENTSPLY SIRONA, De Trey, Konstanz, Germany).

Group 5 (BEG): specimens that were restored with short fiber-reinforced composite, everX-Posterior (GC, Tokyo, Japan).

Group 6 (IBG): specimens that were restored with Nano hybrid CAD\ CAM composite blocks resin based composite block Brilliant Crios (Coltene, Whaledent GmbH, Langenau, Germany).

Specimens' preparation:

For simulation of periodontium, the roots of teeth were embedded in melted wax (Cavex, Holland B.V) except for a 2 mm of root length away from cemento-enamel junction to form a uniform coat of about 0.5 mm around root. The tooth was then mounted in self-cure acrylic resin surrounded by Specially designed cylindrical Teflon mold for having 2cm length and 2cm diameter. Accurate centralization of the teeth in self-cure acrylic resin was done using a specially designed centralizing metal device to ensure that the long axis of each tooth was mounted perpendicular to the cylinder base. The teeth were removed from the casted acrylic block after its complete setting, wax spacer was removed and replaced by light body poly-vinyl siloxane material (Speedex, Coltene Whaldent AG, Attstatten, Switzerland) then teeth were re-inserted in the mold. (14)

Cavity preparations:

All groups except for positive control group (PG) were prepared to receive standardized class II MOD cavities using high speed round-end parallel diamond bur (Frank FG SF, Germany, SF-21, D.836. 014.FG) under copious cooling with water and air. (15)A new bur was changed every three preparations. a waterproof marker (Faber Castell, Germany) was used to draw outline form design of MOD class II cavity on the tooth and dimensions were measures using digital caliper as follow; buccolingual width = 3 mm and occluso-cervical depth = 4 mm from the cusp tip as reference point and with no proximal steps. The walls of the cavities of the direct restorations were prepared to be parallel and all internal line angles were rounded. While the cavity walls for the indirect restorations were prepared with occlusal divergence of about 6-10 degrees. Cavity dimensions were rechecked using periodontal probe (CP-15 Periodontal Probe, Medentra) and the same digital caliper (Bacolis Digital Clipper, Stainless Haredned, Generic) after preparation. (16,2)

Restorative procedures

All tested materials were placed according to the manufacturer's instructions using their recommended adhesives of the same company. 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 and the enamel margin of all specimens were selectively etched using 37% phosphoric acid for 30 seconds then rinsed with both air and water for 60 seconds and air dried. The adhesive was then applied on both enamel and dentin and polymerized using LED light-curing unit unit (3M, ELIPRA DEEPURE, L1007-240V INT) operating in standard mode at light intensity 1200 mW/cm². (17)

In Group 3 (NCG) restored with Ceram.X Spectra St, a conventional incremental technique was used after curing of 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. Afterwards the second increment was placed and cured.

In Group 4 (BSG) restored with SDR Bulk-fill composite, bulk-fill technique was used after curing of the adhesive (Prime & Bond Universal Adhesive, Dentsply Sirona, Ballantyne). The tip of the sringe was then placed at bottom of cavity floor and then the composite ejected to fill the cavity in a steady, continuous stream. A ball burnisher were then used to pack the composite and excess composite was removed. Finally curing for 20 seconds was done.

In Group 5 (BEG) restored with fiber reinforced resin composite Ever X posterior, after application and curing of the adhesive (G-Premio Bond,GC Company, Tokyo, Japan). A conventional incremental technique was used in the same way followed in group 3 (NCG). Finally, all specimens were finished and polished using Sof-Lex™ discs (3M ESPE, *USA)* with aluminum oxide coating of four descending grits.

In group 6 (IBG) restored with Brilliant Crios CAD/CAM composite blocks, each prepared tooth was scanned using the omnicam intraoral camera of the CEREC system scanner (CEREC SW5, Dentsply Sirona, York, Pennsylvania, USA) to obtain optical impressions. The scanning time of each specimen was standardized by the operator to be between 25-35 seconds. The optical impressions were checked to avoid incomplete image that would affect the final design of the restorations and then sent to the lab for designing. Restorations were designed using Exocad software (Exocad GmbH, Darmstadt, Germany).The composite restorations thickness was checked by the software in order to standardize the thickness of all specimens. After successful design of the restoration; checking the margins, checking restoration uniformity and contour, the selected Brilliant Crios CAD/CAM composite blocks were inserted in the spindle of the milling chamber of the In Lab MC X5 milling machine and fixed with the set screw then milled and checked for accuracy and seating on their specimens**.** All composite specimens were polished according to the manufacturer's recommendations using a Vita Enamic polishing kit of varying grit sizes, starting with the largest grit-sized tips and ending up with the smallest.

The fitting surfaces of the CAD\CAM composite restorations were treated as follows; sandblasted for 20 seconds by 29 µm Aluminum Oxide particles at 0.2 MPa air pressure using an Aquacare Twin Dental air abrasion unit (Velopex Int, Medivance Instruments Ltd, London, UK). The restorations were cleaned by ultrasonic cleansing unit for two minutes. Then were Rinsed for 20 seconds and air dried for 10 seconds. Silane coupling agent was applied and left for 1 minute then airdried A thin coat of the universal adhesive prime and bond was actively applied using 1.5 mm green fine type micro brush and left for 20 seconds. It was then air thinned for 10 seconds and cured for 20 seconds using a light-emitting diode (LED) polymerization unit (3M, ELIPRA DEEPURE, L1007-240V INT).

After storage for 24 hours, all specimens were thermo-cycled in thermo cycle machine between 5±2°C/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 after 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, UK) with crosshead speed 1mm / 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 was presented as mean and standard deviation (SD). 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.

Table 1: Materials description, composition and manufacture

Material	Description	Composition	Manufacturer
SDR	Nanohybrid bulkfill composite material	**Matrix**: Glass, oxide, chemicals (10–30%), 3-trimethoxysilylpropyl 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	DENTSPLY SIRONA, Trey, Konstanz, Germa
everX-Posterior	short-fiber reinforced resin composite	**Resin matrix:** Semi-interpenetrating polymer network (semi-IPN): netpoly(methyl meth'acrylate)-inter-net-poly(bis-glycidyl-A-dimethacrylate): Bis-GMA, TEGDMA, and PMMA **Fillers**: E-glass fiber, barium borosilicate	GC, Tokyo, Japan
Ceram.X Spectra St	Nanohybrid composite material	Matrix: (methacrylate-, acid-modified methacrylate-, inorganic	DENTSPLY SIRONA, Trey, Konstanz, Germa

		polycondensate- or epoxide based) modified version of the polysiloxane. it is combined with a well-established *poly*-urethane-methacrylate as well as bis-EMA and TEGDMA. **Fillers:** 77-79 weight	
Brilliant Crios	Nano-ceramic hybrid CAD / CAM composite	Dental glass Bariumglass Size < 1.0 µm, Amorphous silica SiO2 Size < 20 nm, Resin matrix Cross- linked methacrylatesand Inorganic pigments such as ferrous oxide or titanium dioxide	Coltene, Whaledent GmbH, Langenau, Germany

Results:

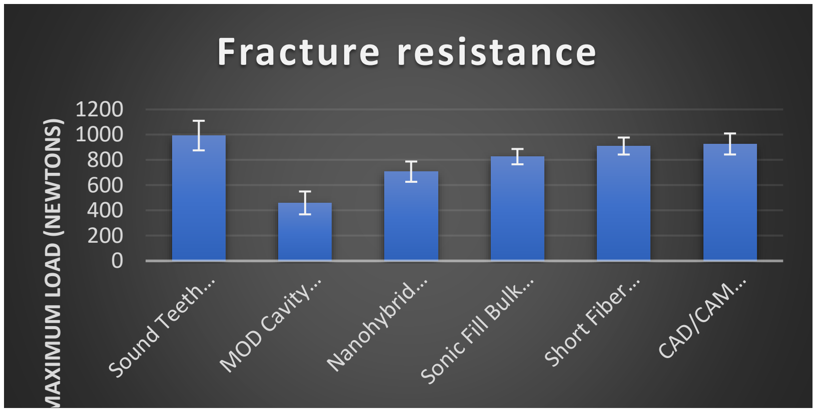
One-Way ANOVA followed by Tukey's post-hoc test showed that there was a statistically significant difference between the different study groups (P<0.001). Positive control, Grandio blocs (IGG) and Ever-X- posterior (BEG) groups yielded the significantly highest maximum load mean values. Mean value of Sonic-fill (BSG) group did not differ significantly from those of IGG and BEG groups. Mean value of Ceram-X-one (NCG) group was significantly lower than those of positive control, IGG a BEG and BSG groups; but significantly higher than that of negative control group. While the negative control produced the significantly lowest mean value among all study groups.

Mean ± SD 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}
IBG	926.46 ± 83.25^{ab}
P-value	<0.001*

**: significant at P≤ 0.05*

Means with different superscript letters are statistically significantly different at P≤ 0.05.



Discussion:

Restoring weakened maxillary premolar teeth is among the most challenging and debated topics in operative dentistry. Adhesive restorations offer significant benefits for treating these weakened teeth, as they can effectively distribute functional stresses across the restorative material-tooth interface while providing support to fragile and unsupported tooth structures. [20, 21] Questions and differing opinions persist regarding the selection of the most appropriate restorative materials for achieving optimal outcomes in restoring these teeth. In this study, various restorative material systems were utilized to restore MOD cavities in maxillary premolar teeth, and their fracture resistance was evaluated.

New resin-based composite technologies, such as bulk-fill composites, have been introduced to the dental market. These composites can be placed in 4 to 5mm thick increments, typically in posterior areas. Manufacturers assert that the physical and mechanical properties of these composites have been enhanced to endure higher masticatory stresses. Additionally, the risk of air void entrapment or moisture contamination is minimized, thanks to reduced treatment times. Regarding that, in this study both SDR RBCs and everX-Posterior ® RBCs were selected, as it was reported that both revealed the best mechanical properties among their category and both are based on different technologies. [22, 23]

SDR RBCs system is a reliable and fast technique for posterior restoration which does not require any additional capping layer. The manufacturer claimed that this vibration reduces the material viscosity by 84%, similar to a flowable consistency, which facilitates its adaptation during application. This allowed the filling of cavities up to 5 mm of depth in one bulk increment. [16]

Another innovation is reinforcing of composite with micro-glass fibers, a fiber-reinforced substructure to enhance their mechanical properties. Ever X-Posterior fiber reinforced composite based on short E-glass fibers randomly dispersed in multiple directions in a semi interpenetrating resin matrix resin matrix consists of PMMA, bis-GMA, TEGDMA and HEMA. (9)

Furthermore, one Nano-ceramic that is recommended to be applied in incremental packing technique was selected to be compared to the two bulk-fill composite materials evaluated in this study to compare both the incremental and bulk-fill placement techniques. Ceram.X Spectra St

RBCs is a New *SphereTEC* filler technology uses granular spherical fillers together with an optimised resin matrix system nanoceramic composites that consists of a combination of conventional filler (1µm), nano fillers (10nm) and most importantly organically modified ceramic nano particles (2-3nm). This combination of fillers based on nanoceramic technology has positively improve the mechanical properties of this material. (24)

On the other hand, an indirect CAD\CAM composite restorative material was selected to be compared with the previous mentioned direct composite materials in order to have more comparable data between both 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 are close to that of enamel and dentine in comparison to CAD/CAM ceramic which means 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) The *CAD/CAM reinforced composite blocks* have superior flexural strength and a shock-absorbing effect that reduces stress transmission. While the use of ceramics for indirect CAD/CAM restorations is well established due to their superior aesthetic and mechanical qualities, ceramics are brittle materials that are prone to failure in the presence of flaws. Resin-based composites have lesser elastic modulus and hardness values, making them easier to mill and adjust intra-orally, less prone to fracture and chipping, and less wear on opposing teeth .(26)

Premolar teeth are an intriguing choice because they have a significant number of fractures in clinical situations. Due to their anatomy, which includes an unfavorable crown-to-root ratio and a cuspal inclination that makes them prone to fracture under occlusal forces, maxillary premolar teeth are more vulnerable to fracture than other posterior teeth. Premolar buccal cusp fractures are more common than palatal cusp fractures, according to study who reported that a high percentage of fractures up to 60% occur on the non-functional buccal cusp whereas 40% of fractures occur on the functional palatal cusp. Between 300 and 600 Newtons of force are applied to the posterior part of the oral cavity during mastication. Therefore, for long-term success and the preservation of tooth structure, achieving ideal fracture resistance in restorations placed in that area is essential. (27). This is why this study was implemented on premolars. The age range was from 16 to 25 to avoid presence of wear signs and cracks in the selected teeth. Moreover, premolars in this study were received MOD cavity design in order to weaken the remaining tooth structure and increase risk of cuspal fracture. The cavities width was also standardized to be within differences of a maximum 5% to standardize the amount of remaining tooth structure that consequently affect the fracture resistance of the restored teeth. While 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)

The more closely a test simulates the clinical condition, the more likely the results are clinically relevant. Adding moisture and controlled temperature to the environment is found to be important when measuring the fracture resistance of direct resin-based composites.

In this study, all restored groups exhibited lower mean fracture resistance values compared to the intact, sound group (positive control group). This can be attributed to the inability of the available restorative materials to fully restore the lost mechanical properties. The disparity may be due to the differences between the tooth structure and the restorative material, the multiple interfaces involved, and the challenges encountered during the adhesion process. (30, 31) On the other hand, all restored groups, regardless of the type of resin-based composite material used, showed significantly higher fracture resistance mean values compared to the prepared but unrestored teeth (negative control). This suggests that adhesive restorations can partially restore the lost tooth stiffness. [32]The findings of this study have showed that CAD/CAM composite blocks, short fiber reinforced composite and bulk fill composite yielded the significantly higher maximum load mean values than Ceram.x spectra one while these groups showed no significant difference between each other. Thus, the null hypothesis was rejected, because the different restorative protocols did affect the fracture resistance.

A review of the literature reveals that both filler loading and the elastic modulus of the restorative material are crucial factors influencing the mechanical properties of composites. The variation in strength between different composites can be attributed to differences in the chemical composition of their matrix, filler content, filler size, and loading. An increase in filler loading is directly proportional to higher fracture and compressive strength. (33, 34) The filler loading of the composite blocs, Bulk-fill have showed to be within the same range which is 86%, 83% wt. respectively which may explain the no significant fracture resistance mean values between each other.

Moreover, it was reported that the filler weight percentages of CAD/CAM composite blocks have a considerable role in mechanical properties than do its microstructural constituents. Additionally, CAD/CAM composites combine the higher strength of ceramic blocks with lower modulus of elasticity of composite hence, lower hardness that may also explain the higher fracture resistance of Composite blocs in this study(35,36)

Bulk-fill resin has a low polymerization shrinkage of only 1.6% decreasing gap formation and the risk of cracking that leads to fracture. (37)

Although, the filler loading of both Ever X posterior and Ceram.x one RBCs have showed also to be in the same range which is 77% and 76% wt. respectively, the results of this study showed that Ceram X had the lowest significant fracture resistance mean values. This might be due to the difference in chemical composition between each other.

Ever X posterior, a short fiber-reinforced composite containing 1–2 mm long E-glass fibers embedded within the nanohybrid composite, can be used in 4 mm increments. The E-glass fibers in EverX posterior enhance the fracture resistance of restored teeth by transferring the stresses from the resin polymer matrix to the fibers, which helps prevent crack propagation. Additionally, the random orientation of the E-glass fibers within the resin composite provides reinforcement in multiple directions, improving the overall strengthening efficiency of the restoration.[38]

On the other hand, Ceram.X one RBCs can be considered as a Nanoceramic composite with pre-polymerized fillers (a trimodal resin composite) based on modified version of the polysiloxane comprising matrix. Since The filler system is a blend of three different filler types: the spherical, prepolymerized 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). The incorporation of pre-polymerized filler particles in Ceram.X® one RBCs formulations with its lower filler loading could have contributed to its lower significant fracture resistance. Traditionally, mechanical properties are generally inferior with resin composite materials containing pre-polymerized particles this may be due to the unfavorable stress transfer between the resin matrix and filler particles. (39, 40)

Conclusion:

Based on the findings of this study and within its limitations, it was concluded that The fracture resistance of maxillary premolars with MOD cavities is greatly influenced by the restorative material chosen. Therefore, selecting the appropriate material for restoration can strengthen the tooth to a level similar to that of a healthy, intact tooth. However, additional clinical studies are needed to assess the performance of these tested restorative materials in real-world clinical settings.

Conflicts of interests

All authors declare to have no conflict of interests.

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