Effect of Resin Restorative Material Type and Layering Techniques on the Fracture Resistance of Maxillary Premolars

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Abstract

Objectives: This study aimed to evaluate the fracture resistance of premolar teeth with standardized mesio-occluso-distal (MOD) cavities, restored using various techniques (layering techniques and composite-resin restorations)

Materials and Methods: Seventy intact maxillary premolars with standardized MOD cavities were randomly divided into seven groups (n=10): G1 control intact teeth; G2: MOD cavities left unrestored; G3: restored using an incremental technique with nanohybrid resin composite (Neo Spectra ™ ST, Dentsply Sirona); G4: restored in bulk using a flowable composite (SDR Flow+, Dentsply Sirona); G5: bulk-filled with a multihybrid composite (Tetric N Ceram, Ivoclar); G6: restored using an incremental technique with SDR Flow+ & Tetric N Ceram; and G7: restored incrementally with SDR Flow+ & Neo Spectra ™ ST. After 24 hours of storage at 37°C, the specimens were tested for fracture resistance using a universal testing machine, applying force through a 4 mm diameter steel sphere at a crosshead speed of 5 mm/min until fracture occurred. Statistical analysis was performed using the D'Agostino-Pearson test, Kruskal–Wallis test, and Mann–Whitney U tests at a 5% significance level to identify differences among groups.

Results: A significant variation in mean fracture resistance was observed among the tested groups. Groups G1, G6, and G7 demonstrated the highest mean fracture resistance, followed by groups G3 and G5, which showed no significant difference from each other. The lowest mean fracture resistance was recorded in groups G2 and G4.

Conclusions: Using a bulk-fill flowable composite as a lining beneath resin composite layering enhances fracture resistance. Additionally, bulk-fill flowable resin composites should be overlaid with a methacrylate-based resin composite.

Keywords: BULK FILL, RESIN COMPOSITE, FLOWABLE COMPOSITE, LAYARING TECHNIQUE, FRACTURE RESISTANCE

1. Introduction

Composite restorations have gained significant popularity over the past decade due to the growing demand for esthetic dental treatments and a greater focus on conserving tooth structure. They are now an integral part of routine dental practice. However, occlusal wear, secondary caries, and fractures remain the primary reasons for failure in composite restorations [(1)]. Fracture resistance is a critical property of dental materials, relying on their ability to resist crack propagation from internal flaws. Such cracks may lead to microscopic fractures at the restoration margins or result in the bulk fracture of the filling [(2)].

Recent studies have addressed concerns regarding the weakening of teeth following MOD cavity preparations and the role of restorative materials and techniques in enhancing the remaining tooth structure [(3, 4)]. Research suggests that cavity preparation significantly reduces tooth strength, particularly in MOD cavities, due to the loss of marginal ridges and the fatigue of brittle tooth structures caused by microcrack propagation under repeated occlusal forces [(5,6)]. Additionally, cusp fractures in teeth with wide cavities often result from occlusal loads that exert forces pushing the cusps apart [(7, 8)]. Consequently, reinforcing these teeth is crucial for ensuring adequate fracture resistance.

The clinical performance of modern dental composites has steadily improved over the past decade, offering sufficient strength for broader applications in posterior restorations with reliable longevity. Despite these advancements, the relatively high brittleness and low fracture toughness of current resin composites remain significant limitations for stress-bearing posterior restorations.

Clinical strategies have been proposed to enhance the fracture resistance of composites, including the incremental filling technique, which reduces the configuration factor (C-factor = bonded surface area/non-bonded surface area [(9-13)]. Additionally, employing an intermediary resin with low viscosity and a low modulus of elasticity, acting as an elastic buffer, has been suggested as a solution to this issue [(14-16)]. Flowable composites are one such material offering expanded applications in restorative dentistry. While the first-generation flowable composites were primarily used as liners due to their low modulus of elasticity, second-generation flowable composites have been developed as bulk-fill bases. These materials are marketed for use as liners in Class I and II restorations beneath conventional resin-based materials, with a reported depth of cure exceeding 4 mm [(17-22)]. However, studies evaluating their properties, particularly in stress-bearing areas, remain limited. This study aimed to examine the impact of layering techniques and the use of bulk-fill flowable composites on the fracture resistance of restorations. The research hypothesis proposed that no significant difference in fracture resistance among restored teeth when comparing different layering protocols.

2. Materials & methods:

In this in vitro study, seventy recently extracted sound maxillary premolar teeth were collected, ensuring they were free from caries, hypoplastic defects, fractures, or cracks. The maximum bucco-palatal width of each tooth was measured using a digital micrometer gauge (ESSENTRA, Ontario, Canada) with a tolerance of 10 µm. The teeth were distributed into seven groups (n=10) so that the variance in mean bucco-palatal width among groups was less than 5% [(23-26)]. Prior to cavity preparation, the teeth were stored in a saline solution containing 0.1% thymol at 4°C. To simulate the periodontium, the root surfaces were coated with a 0.2–0.3 mm layer of melted wax to a depth of 2 mm below the cementoenamel junction (CEJ). The teeth were then positioned crown-up with their long axis vertical and fixed in chemically activated acrylic resin (Acrostone, Egypt) within cubic copper molds. The acrylic resin extended to within 2 mm of the CEJ. The specimens were randomly divided into seven groups, summarized as follows: Group 1 consisted of sound, unprepared teeth, while standardized Class II MOD cavities were prepared for Groups 2 through 7. Group 2 specimens were left unrestored for testing without restoration. The composition and properties of the restorative materials used (VOCO, Germany) are detailed in Table 1.

2.1 Cavity preparation:

Standardized MOD cavities were prepared in specimens from Groups 2 through 6 using a high-speed air/water-cooled handpiece equipped with a straight fissure carbide bur (size 010, ELA, German). The cavity dimensions were maintained at 4 ± 0.2 mm for pulpal depth from the tip of the palatal cusp and 3 ± 0.2 mm for the bucco-palatal width. The proximal walls were parallel, and the occlusal isthmus width was set at one-third of the intercuspal distance and no beveling was performed on the cavity margins. Digital caliper and periodontal probe were used as a guide to standardize all cavity dimensions.

2.2 Adhesive application:

After cavity preparation, the surfaces were pretreated for bonding using universal adhesive system (Prime & bond universal, Dentsply Sirona, Germany) following the manufacturer's instructions. First, the MOD cavity was air-dried for 30 seconds before applying a 37% phosphoric acid etching gel (Fine each 37 SPIDENT To. Ltd, Korea) for 30 seconds, followed by rinsing with water for 10 seconds. After a brief 3-second air-drying, one layer of the adhesive were applied using a sponge micro brush, left to flow for 10 seconds, and then light-cured for 20 seconds with a LED light-curing unit (3M ESPE, Germany) operating in standard mode at a light intensity of 1200 mW/cm².

2.3 Resin composite layering protocols:

The resin composites used to fill the MOD cavities included a nanohybrid composite (Neo Spectra ™ ST, Dentsply Sirona, Germany), a multi-hybrid bulk-fill composite (Tetric N Ceram, Ivoclar Vivadent AG, Liechtenstein), and a flowable bulk-fill resin composite (SDR flow+, Dentsply Sirona, Germany). To simulate clinical conditions, "Tofflemier" metal matrix bands and a matrix holder were utilized. Relating to the layering protocol, the cavities to be restored (Groups 3 till 7) were randomly assigned and filled with resin composites using one of the following techniques:

Group 3 (incremental filling): The universal nano-hybrid restorative material (Neo Spectra ™ ST) was applied in two horizontal incremental layers, each with a thickness of 2 mm. Each layer was light-cured at a right angle from the occlusal surface for 20 seconds.

Group 4 (bulk filling): In Group 4 (bulk fill with flowable resin composite), the flowable bulk-fill resin composite (SDR Flow+) was injected to fill the entire cavity (4 mm deep) and then light-cured from the occlusal surface for 40 seconds.

Group 5 (bulk filling), regular bulk-fill resin composite (Tetric N Ceram) was placed in a single increment (4 mm thick) and light-cured for 40 seconds from the occlusal surface.

Group 6 (incremental filling with flowable liner), the first layer was a 2 mm thick layer of flowable bulk-fill resin composite (SDR Flow+), light-cured for 20 seconds, followed by a 2 mm thick incremental layer of regular bulk-fill resin composite (Tetric N Ceram), light-cured for 20 seconds.

Group 7 (incremental filling with flowable liner), the first layer was a 2 mm thick layer of flowable bulk-fill resin composite (SDR Flow+), light-cured for 20 seconds. The remaining 2 mm was filled with universal nanohybrid restorative material (Neo Spectra ™ ST) and light-cured for 20 seconds.

In all groups, post-curing was done on the buccal and lingual surfaces for 40 seconds after the matrix band was removed. Ten minutes after the restorative procedure, the restorations were finished with a finishing bur and polished with rubber cups using a low-speed handpiece (Sirona T4 line B 40, Jerman). The specimens were then stored in distilled water at 37°C for 24 hours

Table 1- Brand names, product description and chemical composition of the used materials

Brand Name	Material Category	Composition
Neo Spectra™ ST	Nano hybrid	Organically modified ceramic-Methacrylate modified polysiloxane dimethacrylate resins, Ethyl-4 (dimethylamino) benzoate and Bis(4-methyl-phenyl) iodoniumhexafluorophosphate. Filler load: 78–80% by weightSpherical, pre-polymerized SphereTEC fillers (d3,50 ≈ 15 µm), non-agglomerated barium glass and ytterbium fluoride (≈0.6 µm)
Tetric N Ceram Bulk Fill	Multi hybrid	Barium glass, Prepolymer, Ytterbium trifluoride, Mixed oxide Bis-GMA, DMA
SDF Flow+	Flowable bulk fill	Modified urethane dimethacrylate resin, ethoxylated bisphenol-A dimethacrylate (EBPADMA), triethyleneglycol dimethacrylate (TEGDMA)
Prime & bond universal	Universal adhesive system	PENTA (dipentaerythritol pentacrylate phosphate), 10-MDP (10-methacryloyloxydecyl dihydrogen phosphate), Active GuardTM Technology crosslinker

2.4 Measurement of fracture resistance:

The fracture resistance test was performed using a universal testing machine (Instron, Model 3345, England). A 4 mm diameter steel sphere was applied to the inclined planes of the buccal and lingual cusps of the tested teeth at a cross-head speed of 5 mm/min until fracture occurred. The force applied was recorded in Newtons as the fracture resistance.

2.5 Statistical Analysis

Data were presented as mean, standard deviation (SD), and the minimum and maximum values. The normality of the data was assessed using the D'Agostino-Pearson test for normal distribution. Since fracture resistance exhibited an abnormal distribution, the Kruskal-Wallis test was used, followed by paired group comparisons using the Mann-Whitney U test at a 5% significance level to analyze the effect of the packing protocol on fracture resistance. Statistical analysis was performed using IBM® SPSS® Version 23 for Windows (SPSS Inc., IBM Corporation, NY, USA).

3. Results

The mean loads (N) required to induce fracture in each group are shown in Table 2 and illustrated in Figure 1. According to the table, a significant difference in mean fracture resistance was found between the tested groups ($p \leq 0.001$). Groups G1 (998.64±127.17 N), G6 (1033.55±53.19 N), and G7 (1002±866.12 N) exhibited the highest mean fracture resistance, with no significant difference between them. These were followed by Group G3 (831.02±50.81 N) and Group G5 (864.34±64.22 N), which also showed no significant difference between each other. The lowest mean fracture resistance was observed in Groups G2 (465.55±32.76 N) and G4 (483.49±65.22 N), with no significant difference between them.

Table 2: Mean, standard deviation (SD), minimum and maximum of fracture resistance and results of Kruskal–Wallis test for the effect of packing protocol.

		Group							p-value
		G1	G2	G3	G4	G5	G6	G7	
Fracture resistance (N)	Mean	998.64^{a}	465.55^{c}	831.02^{b}	483.49^{c}	864.34^{b}	1033.55^{a}	1002^{a}	≤0.001*
	SD	118.65	92.76	65.21	69.66	57.22	96.13	108.33	
	Minimum	887.80	299.80	744.20	381.30	739.10	928.20	887.90	
	Maximum	1230.30	595.60	916.60	593.80	938.20	1211.70	1220.20	

SD: standard deviation. Means with the same letter within each row are not significantly different at p=0.05.

**=Significant*

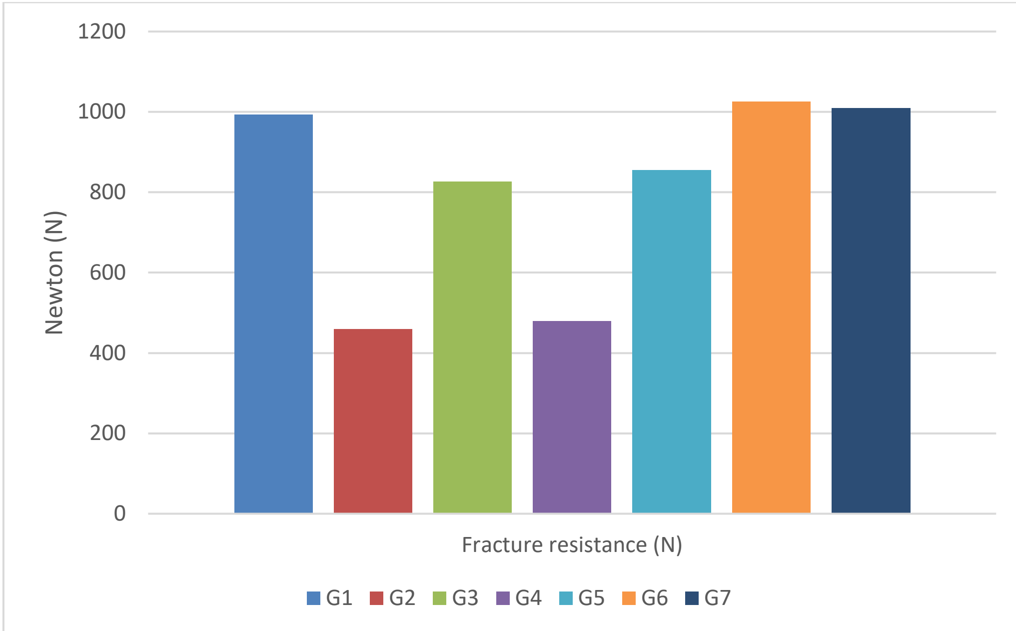

Figure 1: Histogram showing the mean Fracture resistance of different tested groups.

3. Discussion

Direct resin-based restorative materials are crucial in dentistry. However, several issues with resin-based composites are associated with polymerization shrinkage [18]. Additionally, technique sensitivity remains a significant concern for dentists striving to achieve successful outcomes. Although a new category of bulk-fill resin-based composites has been introduced, there is limited clinical and laboratory research exploring the performance of these materials. These studies gain an increased importance when the material is used in stress-bearing areas. Therefore, this study aimed to investigate the fracture resistance of bulk-fill composites, which, according to their manufacturers, can be placed in bulk. It also compared different layering protocols.

In the current study, MOD cavity designs were prepared in premolar teeth, as this type of preparation tends to weaken the remaining tooth structure and increases the risk of cuspal fractures. The bucco-palatal width was standardized in all teeth to within a maximum difference of 5% to ensure consistent comparisons within and between groups. It was expected that, regardless of the layering protocol used, restored teeth should exhibit higher fracture resistance values compared to prepared, unrestored teeth, as the modulus of elasticity in resin composites can restore fracture resistance and influence the mode of fracture [27]. These findings align with the present study, which observed the lowest fracture resistance values in the unrestored group.

The present results confirmed that different layering protocols for resin composites play a critical role in enhancing fracture resistance. In this study, the fracture resistance of groups restored with bulk-fill flowable composite as a base showed values closest to unprepared teeth and was significantly higher than groups without a flowable liner, consistent with findings from previous studies [28]. This flowable composite has a cushion effect and reduces polymerization shrinkage stresses from the overlying composite material due to its low modulus of elasticity and excellent ability to deform (29-31).

In the study, no statistically significant difference was found between the fracture resistance of bulk-fill with Tetric N Ceram and incremental filling with Neo Spectra™ ST. This may be due to the higher volumetric filler content in both Neo Spectra™ ST (71.4%) and Tetric N Ceram (70.1%), as compressive strength is closely related to filler content, with higher fracture resistance observed at around 50% filler content (20,32,33). Previous research has highlighted those variables such as the shape, size, content per volume/weight, and distribution of filler particles all influence the mechanical strength, elastic modulus, and hardness of resin composites (34,35).

Interestingly, when the bulk-fill flowable composite was used to restore the MOD cavities in a single 4 mm increment, the mean fracture resistance was significantly reduced. This finding aligns with the pioneering work of Versluis et al. (36), which supported the widely accepted idea that an incremental filling technique reduces polymerization stress. Additionally, placing a large increment simultaneously constrains both cusps during light curing, further limiting overall cuspal deflection (19,37,38). However, under the term "bulk-fill," bulk-fill flowable resin composites are primarily intended as base layers, which should ideally be covered by a 2 mm surface layer of methacrylate-based resin composite.

This study focused solely on premolar teeth, and fracture resistance was evaluated shortly after restoration. However, several variables in the oral cavity, such as thermal, chemical, and physical factors, as well as fatigue stresses and aging, may influence the induced fractures. Additionally, stresses in the oral cavity are cyclic and vary in speed, magnitude, and direction. Therefore, further studies are needed to assess the in vivo behavior of these materials and layering techniques under dynamic loading conditions.

4. Conclusions

Based on the findings of this study and within its limitations, the following conclusions can be listed:

- Fracture resistance of tooth structure was significantly enhanced with using bulk fill flowable composite as a base
- To maximize the effect of bulk fill flowable composite in enhancing fracture resistance, it should be covered with methacrylate-based resin composite

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