Evaluation of the Fracture Resistance of Premolars with Extensive and Medium Cavity Preparations Restored with Direct Restoring Systems

Abstract

Context: Studies have been conducted to measure the fracture resistance of restored teeth with the current restorative materials. However, most of those studies disregard the cavity size as an influencing variable. Aims: To evaluate the fracture resistance of prepared and restored maxillary premolars with medium and large preparations. Materials and Methods: Seventy superior and sound premolars were randomly divided: G1 (control) – sound tooth; G2, G3, and G4 received a Class II mesial-occlusal-distal (MOD) preparation with an occlusal box width 1/3 of the intercuspal distance, and were restored with Filtek Z350 XT, IPS Empress Direct, and Charisma Diamond, respectively; G5, G6, and G7 received a Class II MOD preparation with an occlusal box width 2/3 of the intercuspal distance, and were restored with Filtek Z350 XT, IPS Empress Direct, and Charisma Diamond, respectively. After storage in water, at 37°C, the specimens were subjected to a fracture test under compression in a universal testing machine where the loads were applied vertically and at a speed of 0.5 mm/min. Statistical Analysis Used: Data were analyzed with two-way ANOVA and Tukey’s multiple comparison post hoc test (P < 0.05). Results: G1 presented a fracture resistance significantly higher (P = 0.005) than any other experimental groups. Among the experimental groups, only G5 showed a significantly low fracture resistance (P = 0.019) when compared to the other groups. For the other resins, the change in intercuspal distance from 1/3 to 2/3 the intercuspal distance did not significantly reduce the fracture resistance (P > 0.05). Conclusions: The cavity preparation weakens the remaining tooth structure; however, its resistance could be partially restored using direct adhesive restorations.

Keywords: Adhesive restorations, composite resin, fracture resistance

Introduction

Recent studies have evaluated topics related to the weakening of the tooth structure when performing mesial-occlusal-distal preparations (MOD) and also issues regarding the effect of adhesive restorations in strengthening the remaining dental tissue.[1-6] Some studies claim that the strength of a tooth decreases proportionally to the amount of dental tissue removed, especially in relation to the vestibu–palatal width of the occlusal box preparation.[7,8] Furthermore, when a significant amount of the dental structure is lost, there is an increase in fragility and susceptibility to fracture.[7,9,10] Soares et al.[7] argued that the application of a load on the teeth with large restorations produces a wedge effect between the palatal and buccal cusps, leading to a reduction of fracture resistance and a higher occurrence of catastrophic fracture.

Adhesive restorative systems have been developed, over the years, to improve their mechanical properties and ability to bond to dental structure. With improved bond strength, they can provide a higher resistance for restored teeth and can decrease the amount of healthy dental tissue that is removed during cavity preparation.[11] Therefore, an improvement in adhesive restorative systems may offer a higher preservation of dental structure.

The evolution of restorative materials began when the particle filler size was reduced, beginning with macroparticles, evolving to the hybrid resins, and reaching nanometric dimensions, which are found in the current composite resins. Even with the improvement in the clinical performance of the latest dental composites, direct adhesive restorations are still indicated for restoring small and medium cavities.[12] Although the indirect restorations are considered the

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gold standard to restore large defects, a recent clinical trial evaluated the direct use of composite resins for wide cavity restorations and obtained satisfactory results.\(^1\)[3]

Several studies\(^1\)[2,4,6] have been conducted to measure the fracture resistance of restored teeth with the current restorative materials. However, most of those studies disregard the cavity size as an influencing variable. Thus, the aim of this current research was to evaluate and compare the fracture resistance of solid maxillary premolars with premolars containing restored and unrestored medium and large cavity preparations. It is important to emphasize that, although there are previous studies that used the compression test, the present study evaluated materials that had not yet been evaluated regarding this property.

The null hypothesis was that there would be no significant differences in fracture resistance of the restored and solid maxillary premolars, independent of the preparation size and restorative system used.

**Materials and Methods**

After approval from the Human Research Ethics Committee, 70 sound, human premolars, with similar dimensions, were selected and analyzed with a magnifying glass, under proper lighting, to ensure the absence of cracks and caries lesions. All teeth were stored in water at 37°C and 100% humidity until the beginning of the experiment. The teeth were cleaned by removing dental calculus and performing prophylaxis. Each tooth was then fixed up to 2 mm below the cementoenamel junction in a 25-mm diameter polyvinyl chloride cylinder containing autopolymerizing acrylic resin to stabilize the tooth and facilitate its handling during the experiment.

The specimens were randomly divided into seven groups \((n = 10)\), 10 specimens were kept completely intact for the control group (Group G1), and 60 specimens were prepared with a Class II MOD cavity. The preparations were carried out by a single operator and were standardized to simulate medium and large cavities using 3127 and 3131 diamond burs (KG Sorensen, Cotia, SP, Brazil) in a high-speed handpiece and under constant irrigation, respectively. The dimensions of the cavities were standardized as follows: Occlusal box that is 2 mm deep (in relation to the bottom of the groove), an occlusal box width that was 1/3\(^{\text{rd}}\) the intercuspal distance for the medium cavities and 2/3 the intercuspal distance for large cavities, and an axial wall height of 1.5 mm and 2 mm width at the gingival wall [Figure 1].

The prepared teeth were divided into six groups, based on the cavity size and restorative material used:

- **Group G2**: The teeth were prepared 1/3 of the intercuspal distance and restored with Filtek Z350 XT (3M ESPE, Saint Paul, MN, USA)
- **Group G3**: The teeth were prepared 1/3 of the intercuspal distance and restored with IPS Empress Direct (Ivoclar Vivadent, Schaan, Liechtenstein)
- **Group G4**: The teeth were prepared 1/3 of the intercuspal distance and restored with Charisma Direct (Ivoclar Vivadent, Schaan, Liechtenstein)
- **Group G5**: The teeth were prepared 2/3 of the intercuspal distance and restored with Filtek Z350 XT (3M ESPE)
- **Group G6**: The teeth were prepared 2/3 of the intercuspal distance and restored with IPS Empress Direct (Ivoclar Vivadent)
- **Group G7**: The teeth were prepared 2/3 of the intercuspal distance and restored with Charisma Diamond (Heraius Kulzer)

After distribution, the adhesive procedures were initiated with acid etching, using 37% phosphoric acid (Power Etching, BM4, Palhoça, Brazil) for 30 s on the enamel and 15 s on dentin. The specimens were rinsed with abundant water for 60 s and dried using compressed air, while protecting the dentin with cotton to avoid dehydration. The adhesive was applied uniformly on enamel and dentin, following the manufacturer’s recommendations based on the experimental group [Table 1].

The restorations were initiated along the proximal walls and were performed in three increments. The first increment was horizontal and the others were oblique. The rest of the cavity was filled with two oblique increments that were no more than 1.5 mm thick, with dentin resin and two more increments of enamel resin. Each increment of resin was photoactivated for 20 s at an intensity of 850 mW/cm\(^2\) (Translux Power Blue, Heraeus Kulzer, Hanau, Germany), and the final photoactivation was performed under a layer of oxygen blocking gel (KY, Johnson and Johnson) for 20 s, on each side.

The finishing and polishing was performed 24 h after the final photopolymerization, using a sequence of abrasive discs (Sof-Lex Pop-On, 3M ESPE, Saint Paul, MN, USA) in descending order of granulation on the mesial and distal faces and rubber tips (Astropol, Ivoclar Vivadent, Schaan, Liechtenstein) on the occlusal face.

After 15 days of storage in water at 37°C and 100% humidity, the specimens were subjected to a fracture endurance test.
under compression. A universal testing machine (Instron 4444, Instron Corp., Canton, Mass) was used for this testing, in which the specimens were fixed to a testing device, which was positioned in the testing machine. The active tip of the testing machine had a metal sphere with a 6-mm diameter, which was placed at the center of the occlusal surface of each specimen, touching only the tooth structure. Axial loading was applied at a speed of 0.5 mm/min until specimen fracture. The force at the moment of specimen fracture was recorded. The data obtained were tabulated, and the remnants and fragments were stored in a dry container.

The fractured specimens were analyzed to determine the failure modes, and were assigned to 1 of 4 categories, using a modified classification system based on the one proposed by Burke:[19] 1 = fracture involving a small portion of the coronal structure; 2 = fracture involving a small portion of the coronal structure, but requiring an increase in cavity preparation during the repair procedure; 3 = fracture involving the tooth structure with root involvement, which can be restored in association with periodontal surgery; and 4 = severe root and crown fracture, which determine tooth extraction.

After confirming the normality of the data distribution using the Shapiro–Wilk test (P > 0.05), the parametric two-way ANOVA test (variance analysis of two factors) was performed by considering the following variables: intercuspal distance (1/3 or 2/3) and composite resin (Filtek Z350 XT, Empress Direct, or Charisma Diamond). Furthermore, it was possible to investigate the interaction of these factors. As a consequence of the significance (P < 0.05) in the interaction of variables, the Tukey’s test was performed to visualize the differences between means. The significance level for the test was 95%.

Results

The fracture resistance values for comparisons among the experimental groups and the control group are shown in Table 2.

It can be observed that the control group showed a significantly higher fracture resistance (P = 0.005) when compared to the experimental groups. Among the experimental groups, only G5 (Filtek Z350 XT (3M ESPE) + distance 2/3) showed significantly lower fracture resistance (P = 0.019) when compared to the others. For Empress Direct (Ivoclar Vivadent) and Charisma Diamond (Kulzer), the intercuspal distance increased from 1/3 to 2/3 did not significantly reduce (P > 0.05) the resistance to fracture (G1 > G4 = G2 = G7 = G3 = G6 > G5).

The mode of fracture of each specimen is shown in Table 3. A higher number of samples in the groups restored with extensive cavity preparations showed Type III and IV patterns of fracture. The specimens with extensive cavity preparations showed a more severe fracture mode when compared with specimens restored with medium cavity preparations.

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Table 1: Adhesive and restorative procedures for each experimental group

| Group | Adhesive and restorative procedures |
|-------|-------------------------------------|
| G1    | -                                   |
| G2    | Adhesive: Single bond 2 (3M ESPE, Saint Paul, MN, USA) |
| G5    | Application of two consecutive layers of adhesive on dentin and enamel<br>Application of a saturated brush with material, and agitating it on the surface for 15 s<br>Drying for solvent evaporation<br>Photopolymerization for 20 s<br>Restorative material: Filtek Z350 XT (3M ESPE) |
| G3    | Adhesive: Tetric N-Bond (Ivoclar Vivadent, Schaan, Liechtenstein) |
| G6    | Application of a thick layer of adhesive on dentin and enamel<br>Gentle rubbing a saturated brush on the dentin for 10 s<br>Drying with a gentle stream of air for solvent evaporation and removal of excess<br>Photopolymerization for 20 s<br>Restorative material: IPS empress direct (Ivoclar Vivadent) |
| G4    | Adhesive: Gluma 2 bond (Heraeus Kulzer, Hanau, Germany) |
| G7    | Application of adhesive layer on dentin and enamel<br>Wait for 15 s<br>Drying with a gentle stream of air for solvent evaporation, until there is no more liquid movement<br>Photopolymerization for 20 s<br>Restorative material: Charisma diamond (Heraeus Kulzer) |

Table 2: Fracture resistance means (Newton) for the six experimental groups and the control group

| Intercuspal distance | Composite resin |
|----------------------|----------------|
|                      | Filtek Z350 XT (3M ESPE) | Empress direct (Ivoclar Vivadent) | Charisma diamond (Kulzer) |
| 1/3                  | 1106.93±345.40 Bb | 917.56±97.05 Bb | 1212.35±324.20 Bb |
| 2/3                  | 721.26±212.10 Cc | 881.91±195.40 Bb | 928.96±229.50 Bb |
| Control (sound teeth)| 1637.7±246 Aa | | |

*Means followed by the same lowercase letters, in the rows, do not differ (P>0.05), *Means followed by the same capital letters, in the columns, do not differ (P>0.05)
Table 3: Mode of fracture of restored specimens

| Group | Type 1 | Type 2 | Type 3 | Type 4 |
|-------|--------|--------|--------|--------|
| G2    | 1      | 3      | 4      | 2      |
| G3    | 0      | 4      | 3      | 3      |
| G4    | 3      | 4      | 2      | 1      |
| G5    | 1      | 2      | 3      | 4      |
| G6    | 1      | 2      | 5      | 2      |
| G7    | 0      | 1      | 6      | 3      |

Discussion

The removal of dental structure has a direct correlation with a decrease in fracture resistance, teeth with large MOD cavities are severely weakened due to the loss of reinforcing structures (such as the marginal ridge), and they become more susceptible to fracture.\[10\] When these preparations are restored with adhesive materials, there is full or partial recovery of fracture resistance.\[8,14\] According to Mondelli et al.,\[10\] preparations with an occlusal isthmus width greater than half of the intercuspal distance require indirect restorations. However, a 5-year clinical study found no advantage in postpolymerized and semidirect inlays when compared with direct restorations performed incrementally with the same composite resin.\[15\] This conclusion is consistent with other studies that were unable to detect differences between direct and indirect restorations with composite resin.\[15,16\]

Furthermore, the adhesive materials used with direct composite restorations have significant advantages. They are performed in a single session; they require less reduction of the dental structure; they preserve healthy tissue and eliminate the need of a dental laboratory, all of which reduce the cost for the patient.\[4,9\] A 12-year clinical study found high rates of clinical success for large restorations when using direct composite resin involving three, four or five surfaces.\[13\] It is likely that the success of these materials in large cavities is because there is constant improvement in their mechanical properties.

In turn, the compression fracture test is a method used to assess the maximum resistance of a restored tooth and can be performed to quantify the influence of different factors involved in restorative procedures. The magnitude of tooth deformation depends on several factors, influencing preparation design, the type and manner of load application, the substrate mechanical properties, and the restorative material.\[17\]

The compression test usually produces loads that exceed the load limit exerted by the normal movements of the oral cavity. Nevertheless, the test reproduces some real situations, such as when an individual chews a solid material of reduced dimensions, in which the force is distributed over the occlusal surfaces of the posterior teeth. However, the clinical situation mostly focuses on a single tooth.\[17,9,18,19\]

In the present study, a vertical force along the long axis of the tooth was utilized to uniformly apply the force. The load application was performed at a constant speed using a metal sphere with a 6-mm diameter, which only contacted the dental structure. This procedure produces stress along the adhesive interface.\[18\]

The null hypothesis, which states that there would be no significant difference in the value of fracture resistance of sound and restored maxillary premolars, regardless of the size of preparation and restorative system used, was rejected, as both the restorative material and the preparation size had fracture resistance values that were significantly lower than the control group. The control group, which was composed of sound teeth, showed the highest average value for fracture resistance (1637.70 N). Previous studies have presented a wide variation of fracture resistance of sound teeth (882–1742 N), most likely due to the variation in morphology of these teeth, the method of samples storage, or the preparation and speed of load application that were used in each work. Intact teeth have presented greater values of fracture resistance when compared to prepared teeth in several studies.\[1,2,6,7,11,20-22\] These results are in accordance with the results obtained in the present research.

Indeed, sound teeth are usually resistant to chewing stress because the cusps and marginal ridges form a continuous circle of dental structure.\[7,8\] However, teeth with an MOD cavity suffer a significant reduction in fracture resistance due to the loss of the marginal ridge, and the occurrence of microfractures caused by occlusal forces. Occlusal loads tend to force the cusps in opposite directions, causing cuspal fracture from fatigue.\[3,7,8\]

From the current results obtained, it can be concluded that all of the experimental groups achieved satisfactory results, with the exception of G5, which presented the lowest mean values of fracture resistance (721.26 N), and which differed significantly from the other restored groups. Still, G5 presented a resistance value that could support physiological chewing forces, which range from 8 to 880 N.\[23\] It should be emphasized that these large forces are exerted only in cases of trauma or masticatory accidents. These results are in agreement with those performed by other studies,\[11,22\] who concluded that there was a partial reinforcement of restored teeth when using composite resin when compared to intact teeth. However, some studies have presented different results, reported no significant differences in the fracture resistance between sound teeth and teeth restored with composite resin.\[5,9\]

It is worth mentioning that the restorative material made no significant difference in the fracture resistance of premolars with wide preparations. This result is consistent with Moosavi et al.,\[1\] who also found no difference in the fracture resistance of restored cavities with two different types of restorative composites. On the other hand, Casselli et al.\[24\] suggested that an indirect method should be used to restore wide preparations, although they suggest using resins indicated for direct restorations. This method has the potential of improving the degree of conversion of these
materials, and it is less expensive than using a composite resin indicated for an indirect technique.

Even with all the limitations of a laboratory test, it can be seen that a direct composite resin restoration is capable of restoring the fracture resistance of teeth with a moderate MOD preparation to fracture resistance values of a sound tooth. However, the composition of the restorative material has an important influence on the fracture resistance for more extensive preparations. In relation to this current research, the nanoparticle resin showed significantly lower values of fracture resistance when compared to nanohybrid composite resins. However, large cavities restored with nanohybrid resins demonstrated values of fracture resistance statistically similar to the medium-sized restorations.

One of the limitations of this in vitro study is that the compression test does not simulate the functional environment of the oral cavity, and an aging simulation of the sample was not performed by thermocycling. Furthermore, the results of the compression test do not account for all factors that may contribute to the failure of a restoration. Thus, other in vitro tests, such as an analysis of stress distribution and fatigue testing, must be performed to determine the longevity of direct resin restorations.

Conclusions

Based on the results of the present study, it can be concluded that sound teeth that received MOD preparations and composite restorations significantly reduced the fracture resistance of maxillary premolars. All the groups that were prepared and restored did not reestablish the fracture resistance of sound teeth, although they presented values of fracture resistance that were good enough to withstand clinically demonstrated chewing forces. In terms of fracture resistance, there was no significant difference between restored teeth with medium and large cavity preparations, except when using a nanoparticle composite resin, which had a statistically significantly lower value of fracture resistance for large preparations.

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Conflicts of interest

There are no conflicts of interest.

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