Effect of different bonded base materials on the fracture resistance and failure mode of complex cavity of endodontically treated premolars. (An in Vitro Study)

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Abstract

Objective: The aim of this study was to evaluate the effect of different bonded base materials on fracture resistance of endodontically with complex cavities, and the assessment of the mode and type of fracture of each experimental group.
Materials and Methods: Fifty freshly extracted, intact, non-carious human maxillary second premolar teeth with similar anatomic characteristics were selected, the teeth were classified according to their mesiodistal and buccolingual dimensions into five groups. Endodontic treatment performed for all the groups except Group 1
Group 1 intact teeth (control group).
Group 2 unrestored teeth with endodontic treatment.
Group 3 endodontically treated as in group 2 and restored with (smart dentine replacement) SDR bulk-fill.
Group 4 restored with Vertise flow self-adhering flowable composite with optibond technology.
Group 5 endodontically treated as in group 2 and restored with GC EQUIA Fill.
The cavities in group 3,4 and five were then filled with Filtek Z250XT composite.
Fracture resistance testing: All specimens were subjected to axial compressive loading until fracture in Hydraulic Universal Testing Machine (WDW 2006, China). The force required fracturing each tooth was recorded in kilo-Newtons. Assessment of fracture type and mode: After using ink perfusion of each sample for 5 min. Macroscopic fracture patterns were observed.
Results: the results showed that the mean fracture load values were (1.94, 1.61, 1.79, 1.91 and 1.89 Kn) for each group from group1 to group 5 respectively. The mean fracture load value recorded by each material (group3, 4 and 5) was near the mean value of the sound intact tooth (group 1) which means that all of the bonded base materials used in this study can improve the fracture resistance of the endodontically treated teeth to a great extent. Although the group 4 (self-bonded Vertise flow base material) showed the highest value of the other materials (group 3 and 5), there were no significant statistical differences.
Conclusion: The results predict that the three types of bonded base materials can increase the fracture resistance of the endodontically treated teeth to different extents depending on their bonding mechanisms and physical characteristics
Keywords: *Fracture resistance, Fracture mode, Endodontic treatment*

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Introduction:

Root canal treatment should not be considered complete until the permanent coronal restoration has been placed [(1)]. Root-filled posterior teeth are more susceptible to fracture than teeth with intact pulps, because of the removal of tooth structure during the restorative and root canal procedures[(1, 2)]. Root canal treatment changes the actual composition of the remaining tooth structure[(3)]. The combined result of these insults is the common clinical finding of increased fracture susceptibility in teeth with no pulps[(1)]. Restoration of root filled teeth is an important step that complements a technically sound root canal treatment. Fracture of unsupported tooth structure can lead to restorative difficulties and occasionally requires the extraction of the tooth[(4, 5)].

Increased use of composite resin materials for the restoration of the posterior dentition has drawn attention to technological advances in this field. A stable and durable adhesion between the dental restorative materials and tooth substrates are important for both a mechanical and aesthetic perspective[(6)]. Such materials despite sealing the margin, but studies have also shown that the use of adhesive materials can minimize the weakening effect of preparation designs[(7, 8)].

The choice of materials selected for the coronal restoration of endodontically treated teeth has a significant role in tooth longevity. Recently, SDR restorative material is used as a base for class I and class II restorations. It has handling characteristics typical of the flowable composite materials, but can be placed in 4 mm increments with minimal polymerization stress. It is designed to be overlaid with methacrylate based universal posterior composite replacing missing occlusal enamel[9].

EQUIA is also a unique restorative system which unites a new generation of glass particles (EQUIA Fil Capsules) and a highly filled resin coating material (EQUIA Coat) EQUIA can be used in the following indications: Stress-bearing Class I, limited-size Class II, Class V and deciduous teeth restorations; root caries, repair of old restorations and core build-ups. This self-adhesive, nano-filled resin coating, which provides a high hydrophilicity combined with an extremely low viscosity, accounts for the perfect seal of a GIC surface. Compounded nanofillers are thereby intended to protect the system against abrasive wear; this is of importance for the first months until the GIC is completely matured and able to withstand the intraoral stresses[10].Vertise™ Flow is the first self-adhering light-cured resin composite used for direct restorations. It incorporates the OptiBond® adhesion technology eliminating the different steps of etching, rinsing, priming and bonding. Consequently, the working time is shortened and made easier, and can be applied in various clinical situations for pediatric and conventional dentistry[11].

Aim of the study:

- Evaluation of the effect of different bonded base materials on fracture resistance of endodontically treated teeth with complex cavities.
- Assessment of the mode and type of fracture of each experimental group.

Materials and method:

In this study, 50 freshly extracted, intact, non-carious human maxillary first premolar teeth (for the orthodontic purpose) with the age ranges between 18-25 years were selected. Soft tissue and debris on the teeth were removed using a manual scaler, and stored in distilled water at room temperature until the time of use. The teeth were classified according to their mesiodistal and buccolingual dimensions to reduce the influence of size and shape variations in the results[5].

Sample grouping:

Fifty maxillary premolar teeth were divided randomly into five groups of 10 teeth. Standardized extensive class II MOD cavities were prepared for all of the teeth and were endodontically treated except the teeth which were saved as a control group.

Group 1 intact teeth (control group).

Group 2 unrestored teeth with endodontic treatment.

Group 3 endodontically treated as in group 2 and restored with SDR bulk-fill flowable composite as a base up to 1mm below the cavity margin.

Group 4 endodontically treated as in group 2 and restored with Vertise flow self-adhering flowable composite (Kerr Italia, S.r.l.) with optibond technology as a base up to 1mm below the cavity margin.

Group 5 endodontically treated as in group 2 and restored with GC EQUIA FiL (GC CORPORATION TOKYO, JAPAN) as a base up to 1mm below the cavity margin. Then the remaining part of cavities were filled with Filtek Z250XT nanohybrid composite (3M ESPE, U.S.A.).

Cavity preparation:

All the teeth, except for group 1 which remained as the intact (control group), received MOD (Mesial-Occlusal-Distal) cavity preparation by the aid of a modified dental surveyor with no proximal steps and flat floor[12]. The MOD cavities were prepared with ISO 14 burs. The buccolingual width of the occlusal isthmus was one-third of buccolingual cusp tips width, and the buccolingual width of the approximal preparations was one-third of the buccolingual width of the crown. Cavity floor was prepared (1 mm) coronal to the CEJ. The cavo-surface margins were prepared at 90. The buccal and lingual walls of the cavity were prepared parallel (non-undercut)[5].

Endodontic treatment:

Endodontic access cavities were then prepared, any access cavity wider than the dimension of the cavity (1/3 the intercuspal distance) was discarded. The canals were instrumented by stainless steel K-files starting from size #15 to file size #40 using crown down technique (Mani, Inc, Tochigi, Japan) and canals filled with gutta-percha (SPI Dental Mfg. Inc., Inchon, Korea) and AH 26 root canal sealer (Dentsply DeTrey, Konstanz, Switzerland) using a hot lateral condensation technique.

Restorative procedure:

Group 3 (Bulk-fill SDR)

In this group, teeth were restored with bulk-fill SDR (Dentsply-Detrey). A self-etch adhesive (Adper Easy Bond) was used for bonding the restorative material to the cavity walls. The SDR restorative material was placed in the cavity up to 1mm below the cavity margin and cured according to the manufacturer instructions for 20 seconds by LED curing device (LITE Q, Monitex). As the cavity was filled with the bulk-fill flowable base, the restoration was completed by replacing the remaining part of the cavity (1mm) with one increment of Filtek Z250 XT Nano Hybrid Composite.

Group 4 (Vertise flow self-adhering flowable composite)

In this group, the cavities were washed thoroughly with water spray and air dried at maximum air pressure for 5 seconds. Then Vertise Flow dispensed to the preparation with a dispensing tip. A thin layer (<0.5 mm) of Vertise Flow was brushed onto entire cavity with moderate pressure for 15-20 seconds. Light cured for 20 seconds; then the cavity is filled with additional increments up to 1mm from the cavo-surface margin (following the manufacturer instructions). Then the restoration was completed by replacing the remaining part of the cavity (1mm) with one increment of Filtek Z250 XT Nano Hybrid Composite.

Group 5 GC EQUIA Fill:

GC cavity conditioner was applied to the cavity for 10 seconds, rinsed and gently dried. The GC EQUIA capsule was mixed for 10 sec (working time is 1min. 15sec .from start of mix), then inserted into the cavity up to 1mm below the cavity margin. After that the cavities were restored with one increment of 1mm thickness of Filtek Z250 XT Nano Hybrid composite and cured by LED curing device (LITE Q, Monitex).

Then the final restorations were finished and polished according to the manufacturer instructions.

Teeth mounting:

The restored teeth were stored in 100% humidity at 37°C for seven days. Cylindrical molds (20 mm diameter and 40 mm length) were prepared using the elastomeric impression material. The self-cure acrylic resin was used to fill the mold, and the teeth mounted to a level 1mm apical to the cementoenamel junction [(5)].

Fracture resistance testing:

All specimens were subjected to axial compressive loading until fracture in a computerized Hydraulic Universal Testing Machine (WDW 2006, China). A steel bar (8 mm in diameter) was placed at the center of the occlusal surface and applied in parallel to the long axis of the tooth, and the slopes of the tooth cusps were contacted (not the restoration)[(13)]. The force required fracturing each tooth was recorded in kilo-Newtons.

Assessment of fracture type and mode:

After using ink perfusion of each sample for 5 min. Macroscopic fracture patterns were observed. Photographs were taken using a digital camera to determine the type of fracture[(14)]. Also, the type of failure was determined and categorized as favorable and unfavorable fractures. The unfavorable fracture was denoted if the fracture line was below the CEJ extending to the radicular portion. On the other hand, the favorable fracture was denoted if the fracture line above the CEJ[(9)].

The mode of failure was assessed into an adhesive mode in which the failure occurs at tooth\restoration interface, and cohesive mode in which the failure occurs within the restoration, and the mixed mode of failure, in which the failure was both adhesive and cohesive. Stereomicroscope at a magnification of 20× used for the examination of the mode of failure[(15)].

Statistical analysis:

The read data were statistically analyzed using one-way ANOVA test and LSD test with the aid of IBM SPSS Statistics 22.

Results:

The descriptive statistics of the sample has been summarized in Table 1; the results of the fracture test show that the mean fracture load values were (1.94, 1.61, 1.79, 1.91 and 1.89 Kn) for each group from group1 to group 5 respectively, Table1, Figure 1. So the result is showing that the most group that resist the fracture force is the intact tooth (1.947 Kn), and the weakest group to resist the fracture force is Group 2 the endodontically treated unrestored teeth (1.618 Kn).

Table 2 and three are showing the significance of relation (*p*-value) and the least significant difference LSD; the results are showing that there are no significant differences among the groups

Another test performed in this study was the fracture type of the samples during force application the most favorable type of fracture found in group 4 (Bulk-fill SDR**)** while the least favorable type was found in group 2 (unrestored teeth with endodontic treatment). Table 4 showing the type of fractures of all the group

Discussion:

In the current in-vitro study the fracture resistance and the fracture pattern of endodontically treated premolars with extensive class II (MOD) cavities restored with different types of bonded base materials have been evaluated. Maxillary first premolars were chosen because the cuspal inclines make them more susceptible to force that may result in cusp fracture [(17)]. Standardized mesio-occlusal distal (MOD) cavities were prepared to simulate what is often clinically seen. Preparation of MOD cavity will create long cusps; thus, a restoration is needed that can replace the tooth structure, increase the fracture resistance of residual tooth and promote effective marginal sealing [(18)]. Different kinds of materials and combinations of materials have been used for this purpose. Each specimen was subjected to axial compressive loading until causing fracture using a universal testing machine. The applied force speed was 0.5 mm/min. It was stated that lower speeds are accompanied by greater plastic deformation and, thus, higher fracture resistance measurements will be recorded [(19)]. The choice of load direction (parallel to the long axis of the tooth) was also designed to reproduce physiological function and to obtain a degree of non-axial loading through existing occlusal contact variations[(15)]. In which during function the dental occlusion generates non-axial forces resolved into their vectors along the cuspal side. So the load was applied along the long axis to distribute stresses equally between the residual dental tissues and the restorative material simulating a physiologic occlusion [(20)].

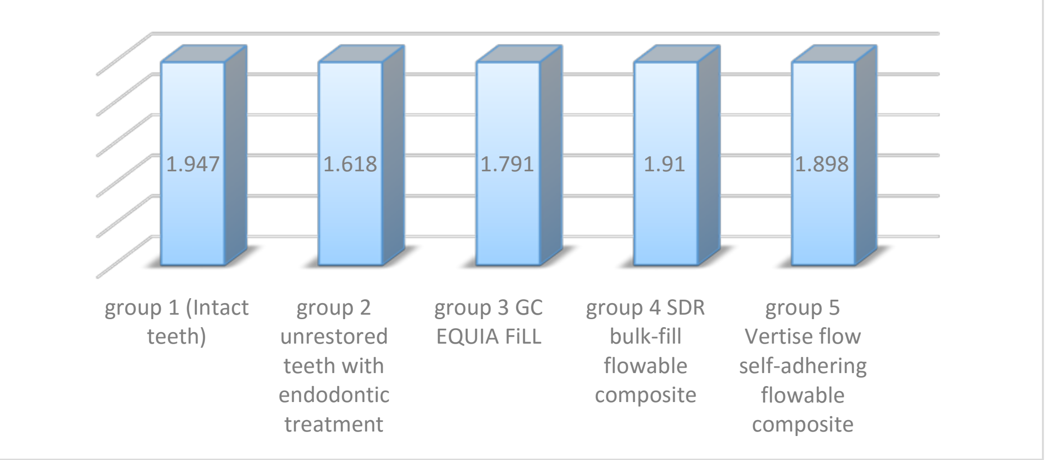

Figure 1: Showing the mean of the fracture force (KNt) for each group

Table 1: Showing descriptive statistics of the sample fracture load means.

Groups	N	Mean	Std. Deviation	Std. Error Mean
group 1	10	1.9470	.53635	.16961
group 2	10	1.6180	.41553	.13140
group 3	10	1.7910	.15380	.04864
group 4	10	1.9100	.45729	.14461
group 5	10	1.8980	.44221	.13984

Table 2: Showing the result of ANOVA test for the fracture force among and between the groups

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.711	4	.178	1.001	.417
Within Groups	7.998	45	.178		
Total	8.709	49			

Intact teeth (Group 1) presented the highest mean fracture load (1.1235 Kn). A statistically high significant difference with other groups existed, this is due to the existence of the palatal and buccal cusps with intact mesial and distal marginal ridges which form a continuous circle of the dental structure, reinforcing the tooth[21] On the other hand, prepared unrestored teeth with endodontic treatment (Group 2) show the least mean fracture resistance value (1.618 Kn) with a

Table 3: Showing the result of the lsd test (least significant difference) for the fracture force applied between different sample groups

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
1	2	.32900	.18854	.088	-.0507	.7087
	3	.15600	.18854	.412	-.2237	.5357
	4	.03700	.18854	.845	-.3427	.4167
	5	.04900	.18854	.796	-.3307	.4287
2	1	-.32900	.18854	.088	-.7087	.0507
	3	-.17300	.18854	.364	-.5527	.2067
	4	-.29200	.18854	.128	-.6717	.0877
	5	-.28000	.18854	.144	-.6597	.0997
3	1	-.15600	.18854	.412	-.5357	.2237
	2	.17300	.18854	.364	-.2067	.5527
	4	-.11900	.18854	.531	-.4987	.2607
	5	-.10700	.18854	.573	-.4867	.2727
4	1	-.03700	.18854	.845	-.4167	.3427
	2	.29200	.18854	.128	-.0877	.6717
	3	.11900	.18854	.531	-.2607	.4987
	5	.01200	.18854	.950	-.3677	.3917
5	1	-.04900	.18854	.796	-.4287	.3307
	2	.28000	.18854	.144	-.0997	.6597
	3	.10700	.18854	.573	-.2727	.4867
	4	-.01200	.18854	.950	-.3917	.3677

Table 4: The distribution of the fracture type among the groups

Group	Fracture type: Favorable No.	%	Unfavorable No.	%	Total
group 1	7	70%	3	30%	10
group 2	0	0%	10	100%	10
group 3	6	80%	4	20%	10
group 4	10	100%	0	0%	10
group 5	2	20%	8	80%	10

significant difference when compared with the other groups, this is due to the type and quality of the remaining tooth structure, especially the cusps and marginal ridges which form a circle of dentin and enamel, which has an influence on fracture resistance. Due to endodontic treatment with MOD cavity preparations, the strength of the tooth was considerably reduced; therefore, when forces are applied they act as a wedge between the buccal and lingual cusps of non-restored teeth; thus, decreasing the mean fracture resistance values and promoting more catastrophic types of fractures [10, 19, 22].

It is clearly seen that all restored teeth displayed improved fracture strength than the prepared but unrestored teeth group with endodontic treatment which presented (1.618 Kn) mean value, this may be due to the ability of adhesive restorations to transmit and distribute functional stresses through restorative material-tooth interface due to mechanical interlocking of resin with peritubular/intertubular dentin and hybrid layer formation, with the potential to reinforce the weakened tooth structure[21].

Teeth restored with SDR as a base material (group 3) showed a mean fracture load value of (1.791 kn), which shows an increase in strength comparing to the (group 2) the unrestored teeth. These findings may be due to the elastic buffer effect of using a low-viscosity flowable composite. It was determined that polymerization shrinkage and the concomitant stresses upon the restoration-tooth interface have an influence on the outcome of extensive composite resin restorations, in which the shrinkage stress generated by a subsequent layer of higher modulus resin composite can be absorbed by an elastic intermediary layer, thereby reducing the stress at the tooth-restoration interface manifested clinically as a reduction in cuspal deflection[23]. This group is the least resistant to fracture than the other restored groups with no statistically significant differences.

In this study the results show that teeth restored with Vertise flow base material (group 4) gives the highest strength among all groups with the mean fracture load of (1.91 kn) which is near the strength of sound teeth in (group 1) the control group, and it is of greater strength comparing to the unrestored teeth. These results could be due to the bonding mechanism which is primarily based on the chemical bond between the phosphate functional group of GPDM (glycerol methacrylate dihydrogen phosphate) monomer and calcium ions of the tooth [24]. A micromechanical bond resulting from an interpenetrating network between Vertise Flow polymerized monomers and dentin collagen fibers also contribute to adhesion [12].

The present study shows that the teeth restored with glass ionomer Equia fill (group 5) the mean fracture load of (1.89kn) which is near the strength of the sound teeth group 1 and more resistant to fracture than the unrestored teeth with no statistically significant difference among the three groups of restored teeth. The explanation for these results may be due to the chemical adhesion of GIC to enamel and dentin is achieved by reaction of phosphate ions in the dental tissue with carboxylate groups from the polyacrylic acid. Electroneutrality is maintained by the displacement of calcium ions with the phosphate ions. However, surface conditioners, such as polycarboxylic, citric or phosphoric acids, have been found to improve bond strength. The conditioner acts as an etching agent which removes the smear layer from the dentin tubuli. The acids demineralize and penetrate a dentine surface layer to a depth of approximately one μm [25]. GIC bond directly to dentin and enamel, even in the presence of a smear layer and prepare for a chemical bonding. The bond strength has been increased to (11 Mpa) by treatment of the dentin with a polycarboxylic acid cleaning agent [26].

Fracture type:

Depending on the results of the current study, 70% of the samples in the control group (Group 1) showed favorable fracture type. However, the samples in the unrestored teeth (Group 2) showed unfavorable fracture type (100%). These results may be due to the existence of the palatal and buccal cusps with intact mesial and distal marginal ridges in the control group and the weakening effect of cavity preparation and endodontic treatment in unrestored teeth with endodontic treatment which was discussed previously.

In group 3 with SDR restoration, the teeth showed 80% unfavorable fracture type and 90% adhesive mode of failure. The severity of fracture type presented in this group may be the reason of low modulus of elasticity. In which the stresses in the compression test were transmitted to the adjacent tooth structure. This may in turn results in the concentration of stresses in the inner dentine and occurrence of unfavorable fracture. It was concluded that the higher the elastic modulus of the restorative material when the joint of restorative material / dental structure is stressed, the lower the deformation of dental structures. In contrast, the low elastic modulus of composite resin promoted less restoration stiffness and a greater distribution of stresses produced by the compression test to adjacent tooth structure which resulted in the catastrophic type of fracture [22].

Group 4 100% unfavorable type of fracture and 70% mixed mode and 30% adhesive mode of failure (adhesive and cohesive). The fact behind this result is that the Vertise flow as it is a micro-hybrid composite, and due to the fact that the micro-hybrid composite has an elasticity property, which makes the material capable of stress absorption.

In group 5 the teeth restored with glass ionomer shows 20% favorable type of fracture and 80% unfavorable type of fracture, with 60% mixed mode of failure. The mode of failure was 60% cohesive. Glass ionomer has poor mechanical properties such as low fracture strength, toughness, and modulus of elasticity [25]. In addition, the weakness appears to be in the matrix, which is prone to crack propagation. These reasons may be responsible for such results in this study [27]. Glass ionomer cement used as a base under either a resin or an amalgam restoration increased the resistance to fracture of endodontically treated premolars, but to a lesser degree than the use of the acid etch resin technique. The characteristics, which make GIC desirable are chemical bonding to enamel and dentin, a coefficient of thermal expansion, which is essential the same as that of tooth structure [28]

However, these findings should be supported by scanning electron microscope (SEM) to evaluate the failure point whether it is the restoration and bonding, bonding and the tooth or within the adhesive layer.

Conclusion:

Based on the results of the current study it can be concluded that the use of bonded base materials in combination with the permanent restoration can provide a high level of fracture resistance. And the self-adhesive flowable base material (Vertise flow) shows the highest fracture resistance than the Equia Fill and the SDR. So, direct composite restorations should be considered as a valid interim restoration for weakened endodontically treated teeth before cuspal coverage can be provided.

Further study for comparing the fracture resistance, in teeth restored with bonded base materials in combination with permanent restoration, and teeth restored directly with composite restoration, is needed to confirm these results.

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