ORIGINAL RESEARCH

A comparative evaluation of fracture resistance of endodontically treated teeth, with variable marginal ridge thicknesses, restored with composite resin and composite resin reinforced with Ribbond: An *in vitro* study

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ABSTRACT

Background: The anatomic shape of maxillary premolars show a tendency towards separation of their cusps during mastication after endodontic treatment. Preservation of the marginal ridge of endodontically treated and restored premolars can act as a strengthening factor and improve the fracture resistance.
Objectives: To evaluate the effect of varying thickness of marginal ridge on the fracture resistance of endodontically treated maxillary premolars restored with composite and Ribbond reinforced composites.
Materials and Methods: One hundred and twenty, freshly extracted, non carious human mature maxillary premolars were selected for this experimental *in vitro* study. The teeth were randomly assigned in to twelve groups (n = 10). Group 1 received no preparation. All the premolars in other groups were root canal treated. In subgroups of 3 and 4, DO cavities were prepared while MOD cavities were prepared for all subgroups of group 2, the dimensions of the proximal boxes were kept uniform. In group 3 and 4 the dimensions of the mesial marginal ridge were measured using a digital Vernier caliper as 2 mm, 1.5 mm, 1 mm and 0.5 mm in the respective subgroups. All samples in groups 2.2 and all the subgroups of 3 were restored with a dentin bonding agent and resin composite. The teeth in group 2.3 and all subgroups of 4 were restored with composite reinforced with Ribbond fibers. The premolars were submitted to axial compression up to failure at 45 degree angle to a palatal cusp in universal testing machine. The mean load necessary to fracture was recorded in Newtons and the data was analysed.
Results: There was a highly significant difference between mean values of force required to fracture teeth in group 1 and all subgroups of group 2, 3 and 4 (i.e., $P < 0.01$)
Conclusion: On the basis of static loading, preserving the mesial marginal ridge with thicknesses of mm, 1.5 mm, 1 mm and 0.5 mm, composite restored and Ribbond reinforced composite restored maxillary premolars can help preserve the fracture resistance of teeth.

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The restoration of endodontically treated teeth is an important aspect of dental practice that involves a range of treatment options of variable complexity. Root canal treatment should not be considered complete until the final coronal restoration has been placed. Endodontically treated teeth are weak because of loss of tooth structure caused by caries, access cavity preparation, and instrumentation of the root canal. The likelihood of survival of a pulpless tooth is directly related to the quantity and quality of the remaining dental tissue.[1]

The traditional method of restoring non-vital teeth is the post and core restoration, full crown or a cast inlay that protects the cusps. Teeth weakened by restorative procedures should be reinforced by restorative materials to strengthen the remaining tooth structure.

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The true breakthrough in the restoration of endodontically treated teeth has been the introduction of adhesive bonding, propelled by the development of efficient dentinal adhesives. Resin-based restorations replace the tooth's rigidity which is lost during cavity preparation, and provide splinting of cusps. This can increase the fracture resistance of non-vital teeth.[1,2]

The development of fiber-reinforced composite (FRC) technology has led to substantial improvement in the flexural strength, toughness, and rigidity of dental resin composites. FRC technology has increased the use of composite resin materials in extensive preparations.

In this study, it was hypothesized that creating an elastic layer under a composite restoration using a leno-woven ultra high molecular weight (LWUHMW) polyethylene fiber ribbon and/or flowable composite would increase the fracture strength of endodontically treated teeth with mesio-occluso-distal (MOD) cavity preparations and in class II cavities with variable marginal ridge thicknesses.

In this study, it was also hypothesized that composite resin restorations also strengthen the endodontically treated teeth.

AIMS AND OBJECTIVES

- To evaluate the effect of different thicknesses of marginal ridge on the fracture resistance of endodontically treated maxillary premolar restored with composite resin and Ribbond reinforced composite resin.
- To evaluate the strengthening effect of composite resin and composite reinforced with Ribbond on endodontically treated maxillary premolars.

Purpose of the study

The purpose of this study was to analyze the fracture resistance of endodontically treated maxillary premolars with different thicknesses of mesial marginal ridge, which are restored with composite resin and Ribbond-reinforced composite resin.

MATERIALS AND METHODS

One hundred and twenty freshly extracted human mature maxillary premolar teeth with approximately similar dimensions and without any defects were selected. The teeth were cleaned of debris and soft tissue remnants and were stored in physiological saline at room temperature until required.

Inclusion criteria

Maxillary premolars without any defects, extracted for orthodontic reasons (within a 6-month period).

Exclusion criteria

Teeth affected by caries, developmental anomalies, trauma, fracture, and dehydration were excluded.

The teeth were randomly assigned in the following groups of 10 teeth each [Table 1].

Except for group 1, standard access cavities were prepared.

In groups 2 through 4, root canal treatment was performed and obturation was done.

In groups 2.1, 2.2, and 2.3, class II MOD cavities were prepared with gingival cavosurface margin located 1.5 mm above the cemento-enamel junction (CEJ) using 245 carbide bur (MANI, Tokyo, Japan). The dimensions of the mesial and the distal box were approximately the same; a buccolingual width of 3 mm at gingival floor and convergence of the buccal and lingual walls toward occlusal were insured. The cavosurface angle in all walls was approximately 90°.

In the remaining groups, class II disto-occlusal (DO) preparations were prepared in the same manner as that of the MOD group and the mesial ridge was preserved for 2 mm, 1.5 mm, 1 mm, and 0.5 mm in the respective groups. The thickness of the mesial marginal ridge was measured with a digital Vernier caliper within 0.01 mm tolerance.

After completion of the cavity preparation, all the prepared teeth were etched with 35% phosphoric acid (Prime Dental Products, Mumbai, India) for 15 s, rinsed for 10 s, and dried with air, leaving a shiny hydrated surface of moist dentin.

Table 1: Study groups

Group		No. of samples
1	Intact teeth, no treatment	10
2.1	MOD cavities non-restored	10
2.2	MOD cavities restored with resin	10
2.3	MOD cavities with Ribbond-reinforced composite	10
3	Teeth restored with composite resin	
3.1	Class II DO cavities with 2-mm-thick mesial marginal ridge	10
3.2	Class II DO cavities with 1.5-mm-thick mesial marginal ridge	10
3.3	Class II DO cavities with 1-mm-thick mesial marginal ridge	10
3.4	Class II DO cavities with 0.5-mm-thick mesial marginal ridge	10
4	Teeth restored with composite resin reinforced with Ribbond	
4.1	Class II DO cavities with 2-mm-thick mesial marginal ridge	10
4.2	Class II DO cavities with 1.5-mm-thick mesial marginal ridge	10
4.3	Class II DO cavities with 1-mm-thick mesial marginal ridge	10
4.4	Class II DO cavities with 0.5-mm-thick mesial marginal ridge	10

DO=Disto-occlusal, MOD=Mesio-occluso-distal

In groups 2.2, and 3.1, 3.2, 3.3, and 3.4, Adper single Bond (3M ESPE) was applied. Then using a Tofflemire Retainer and an ultrathin matrix band, the teeth were restored with A2 shade resin, Filtek Z-100 (3M ESPE), using an oblique layering technique.

In groups 2.3, and 4.1, 4.2, 4.3, and 4.4, after the bonding procedures as in group 3, the cavity surfaces were coated with flowable composites. A piece of LWUHMW polyethylene fiber 2 mm in width was cut and coated with adhesive resin. Excess material was removed and the fiber was embedded inside the flowable composite (Filtek Z-250 3M ESPE) in a buccal to lingual direction. After curing for 20 s, the cavities were restored with composite as described above for group 3.

Forty-eight hours after restoration, finishing was done with Super snap polishing kit (Shofu, Higashiyama-ku, Kyoto, Japan) under air–water spray, followed by polishing a green abrasive impregnated rubber point. Then the teeth were stored in an incubator.

Finally, teeth from all the groups were submitted to a thermocycling regimen of 500 cycles between 5°C and 55°C water baths. The dwell time was 30 s, with a 10-s transfer time between baths.

Each tooth was vertically positioned with its root embedded into a plastic cylinder of self-curing acrylic resin up to 1 mm below CEJ. Subsequently, universal testing machine was used to conduct a fracture test at a crosshead speed of 2 mm/min. The lingual cusp of each specimen was submitted to axial compression up to failure at an angle of 45° to the palatal cusp and 150° to its longitudinal axis in universal testing machine (Mechatronic, Ichalkaranji, India) [Figure 1]. The forces required to produce fracture were recorded in Newton, mean values of force were calculated [Graph 1, Tables 2 and 3] and statistically analyzed [Table 4].

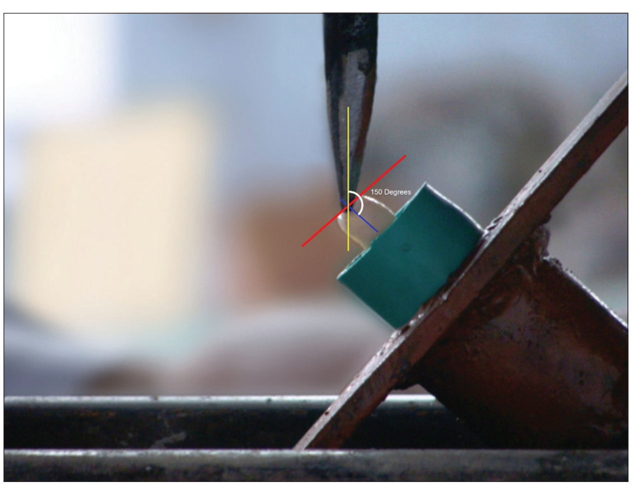


Figure 1: Premolar mounted on the universal testing machine; the lingual cusp of each specimen is submitted to axial compression up to failure at an angle of 45° to the palatal cusp and 150° to its longitudinal axis

RESULTS

By applying Student's unpaired "*t*" test to the above table, it is seen that there is a highly significant difference between mean values of force required to fracture in group 1 and all subgroups of groups 2, 3, and 4 (i.e., $P < 0.01$).

DISCUSSION

This study examined the fracture resistance of endodontically treated maxillary premolars, the anatomic shape of which creates a tendency toward separation of their cusps during mastication. In addition, loss of tooth structure during endodontic access and cavity preparation procedures makes these teeth even more prone to fracture.

Endodontic access to the pulp chamber destroys the structural integrity provided by the coronal dentin of the pulpal ceiling, allowing greater flexion of the tooth under function. Root canal procedures alone reduce tooth stiffness by only 5%, whereas tooth structure removal in an MOD preparation reduces tooth stiffness by 50%.[3]

The general effect of MOD intracoronal cavity preparations is the creation of long cusps. Thus, the restorative material

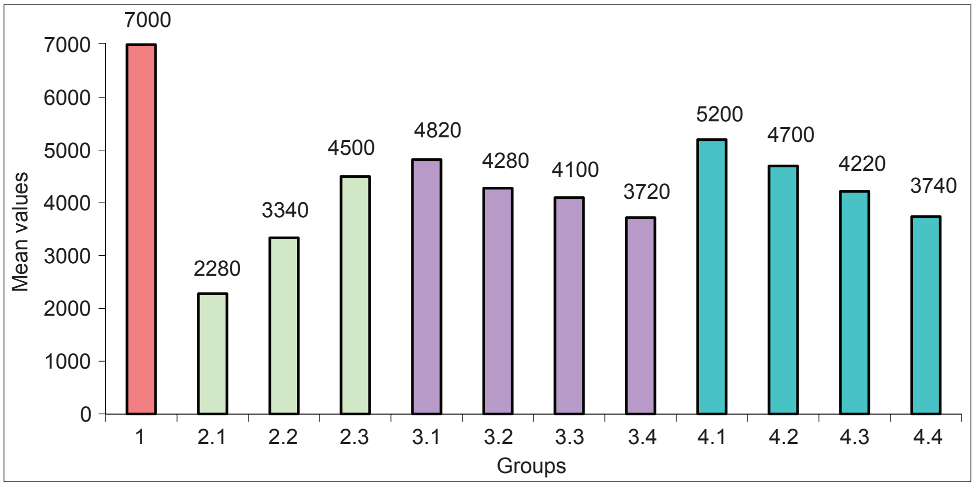
Table 2: Force required (*N*) to fracture teeth

Group	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10
1	6600	6200	5800	7200	7800	8000	8400	7600	6600	5800
2.1	3000	3200	1800	2400	1600	1200	1800	2000	2800	3000
2.2	3600	4200	4200	1800	3000	2400	3000	3800	4000	3400
2.3	3600	2400	3000	6600	3600	6000	5800	4800	4400	4800
3.1	4000	6000	6400	5400	5400	6000	4800	4200	4600	5200
3.2	3800	4200	5200	4800	5600	5400	5000	4600	4400	4000
3.3	4800	4800	3200	4600	4200	3800	3800	4000	4400	4600
3.4	5400	3600	4800	3800	3800	2400	3600	3800	3200	3000
4.1	4800	4800	4800	5400	6600	4400	3800	4400	4200	5000
4.2	3600	3600	4800	4200	3400	5400	4000	3600	3600	4800
4.3	4200	3400	3800	4200	4600	4800	5400	3600	4800	4000
4.4	4800	4800	4200	3000	4200	3600	3000	3400	3000	3200

T=Tooth no

Table 3: Mean and SD values of force required to fracture the teeth

Group	Mean±SD
1	7000.00±885.44
2.1	2280.00±658.48
2.2	3340.00±754.00
2.3	4500.00±1296.91
3.1	4820.00±729.10
3.2	4280.00±587.87
3.3	4100.00±646.53
3.4	3720.00±688.18
4.1	5200.00±785.95
4.2	4700.00±574.46
4.3	4220.00±493.56
4.4	3740.00±810.18



Graph 1: Mean values of force required to fracture the teeth

Table 4: Comparison of mean values of force required to fracture in group 1 and groups 2.1, 2.2, 2.3, 3.1, 3.2, 3.3, 3.4, 4.1, 4.2, 4.3, and 4.4

Mean±SD	Mean±SD	Student's unpaired "*t*" test value	"*P*" value	Result/significance
Group 1 7000.00±885.44	Group 2.1 2280.00±658.48	13.53	<0.01	Highly significant
	Group 2.2 3340.00±754.00	9.95	<0.01	Highly significant
	Group 2.3 4500.00±1296.91	5.03	<0.01	Highly significant
	Group 3.1 4820.00±729.10	8.98	<0.01	Highly significant
	Group 3.2 4280.00±587.87	8.36	<0.01	Highly significant
	Group 3.3 4100.00±646.53	8.09	<0.01	Highly significant
	Group 3.4 3720.00±688.18	9.25	<0.01	Highly significant
	Group 4.1 5200.00±758.95	4.88	<0.01	Highly significant
	Group 4.2 4700.00±574.46	6.89	<0.01	Highly significant
	Group 4.3 4220.00±493.56	8.67	<0.01	Highly significant
	Group 4.4 3740.00±810.18	8.59	<0.01	Highly significant

By applying Student's unpaired "*t*" test to the above table, it is seen that there is a highly significant difference between mean values of force required to fracture in group 1 and all subgroups of groups 2, 3, and 4 (i.e., $P<0.01$)

used must not only replace the lost tooth structure but also increase the fracture resistance of the tooth and promote effective marginal sealing.[4]

Restorations that enhance structural integrity would be expected to increase the prognosis of endodontically treated teeth which are exposed to heavy masticatory loading forces. However, there is no consensus regarding the preferred type of final restoration for endodontically treated posterior teeth.[5] In the past decade, improved restorative adhesive bonding technique and materials have led some authors to suggest that endodontically treated teeth can be restored in a more conservative manner than was previously considered appropriate.[6] Numerous materials have been used as substitutes for natural dental tissues; amalgam and composite resins are the most commonly used. Amalgam does not adhere to dental structure, thus does not compensate for the loss of fracture resistance.[4] It has been found that amalgam restoration regained only 2% stiffness of the tooth structure.[3]

For these reasons, adhesive materials have been considered useful for tooth reinforcement. Denehy and Torney (1976) were the first authors to propose the use of adhesive materials to reinforce the dental structure and to offer support for enamel altered by cavity preparation.[1] The use of resin composites in restoring extensive cavities reinforces dental stiffness. It has been suggested that the adhesive nature of composites binds the cusps and decreases their flexion, which is the main cause of fractures in amalgam.[4] Adhesive restorations efficiently transmit and distribute functional stresses across the bonding interface to the tooth and reinforce weakened tooth structure.[7]

Reel *et al.* showed that maxillary premolars when restored with bonded composite resins were approximately100% stronger than unrestored premolars, but Joynt *et al.* reported a 23% increase in strength.[8]

However, separate studies have proposed that significant differences exist in fracture resistance between intact and restored premolars with resin composite and dentin-bonding agent, with intact teeth being superior. These differences in results could reflect the variation in type and size of teeth, preparation design, experimental material, loading speed, direction of load, and thermocycling.

In this study, the results showed that the difference in mean force required to fracture the teeth in group 1 (intact teeth) with group 2 (MOD cavities, unrestored), group 2.1 (MOD cavities restored with composite), and group 2.3 (MOD restored with Ribbond reinforced composite) were statistically significant.

The least fracture resistance was seen in group 2.1, which is in accordance with Linn and Master, who demonstrated that endodontically treated teeth with MOD cavities were severely weakened due to the loss of reinforcing structure, such as marginal ridges and pulp chamber roof, causing the tooth to become more susceptible to fracture. These findings are also supported by Belly and others, who reported that MOD cavity preparations reduced the fracture resistance of root-filled teeth.

Ultra high strength polyethylene (UHSPE) fibers with higher ribbon reinforcement material, Ribbond (Ribbond Inc., Seattle, WA, USA), have been available commercially since 1992. This material is composed of pre-impregnated, silanized, plasma-treated, leno-woven, ultra high molecular weight (UHMW) polyethylene fibers. Leno-weave is a special pattern of cross-linked, locked-stitched threads which increase the durability, stability, and shear strength of the fabric.[9]

Application of a fiber layer in a restorative material increases the load-bearing capacity of the restoration and prevents crack propagation from the restoration to the tooth.

The elastic modulus of UHMWPE fiber was previously shown to be 1397 MPa. However, in clinical conditions, UHMWPE fiber Ribbond is used in combination with flowable resin and an adhesive resin, resulting in the elastic modulus increasing to 23.6 GPa.[10] The higher modulus of elasticity and lower flexural modulus of the polyethylene fiber are believed to have a modifying effect on the interfacial stresses developed along the etched enamel/ resin boundary. Embedding an LWUHM polyethylene fiber into a bed of flowable resin under an extensive composite restoration increases both the fracture strength in root-filled premolars with class II DO and class II MOD cavities and the micro tensile bond strength to dentin. The development of FRC technology has increased the use of composite resin materials in extensive preparations.[11]

Comparing of the mean values of force required to fracture teeth in group 1 and the teeth in the remaining experimental groups, it can be concluded that there is a highly significant difference between mean values of force required to fracture teeth in group 1 and all subgroups of groups 2, 3, and 4 (i.e., $P < 0.01$).

The mean values of force required to fracture the teeth in groups 3 and 4 showed that as the thickness of mesial marginal ridge decreased, the force required to fracture the teeth also decreased, but the difference was statistically insignificant.

On comparing the mean values of force required to fracture in group 2.1 and 2.2, 2.3 and other subgroups of groups 3 and 4, it is seen that there is a highly significant difference between the mean values of force required to fracture teeth in group 2.1 and other subgroups of group 2, and all subgroups of groups 3 and 4 (i.e., $P < 0.01$).

From the results, it is seen that the mean forces required to fracture teeth in all the subgroups of Ribbond-reinforced composites were greater than the respective subgroups of composite-restored teeth, confirming the reinforcing effect of LWUFMW polyethylene fiber.[11]

Considering the mean values of force required to fracture teeth in all experimental groups, it can be concluded that 0.5 mm thickness of marginal ridge is also of prime importance in restoring the endodontically treated maxillary premolars. For this reason, it can be recommended that if during cavity preparation in endodontically treated maxillary premolars, the remaining marginal ridge thickness is judged to be 0.5 mm, it should be retained. It improves the strength as well as esthetic appearance, since restoration of MOD cavities is more difficult than of DO cavities due to construction of the proximal contact and contour. In addition, the probability of overhang at the proximal margin has been shown to occur from 25% to 76% of time, and providing the proper anatomic form of MOD restorations in comparison with DO restorations is more time consuming.

Occlusion on a premolar is located on the cuspal tips and at the marginal ridge. Because occlusion takes place on the marginal ridge of a premolar, it is important to know the strength of the restored tooth with variable marginal ridge thickness.[1] Marginal ridge enamel is composed of gnarled enamel and is stronger.[12]

The results of this study support the idea that in endodontically treated maxillary premolars, when minimal dentin structure connects the buccal and the lingual walls of preparation, a method that could reinforce the tooth should be used. The ability to predictably restore an endodontically treated tooth to its original strength and fracture resistance without placement of a full coverage restoration could provide potential periodontal health and is economic to patients.[6]

In this study, each specimen block was fixed in a jig that ensured a loading angle of 150° to the long axis of tooth. This angle was chosen because it simulates the average angle of contact between maxillary and mandibular premolars in occlusion.

There are many differences between fractures that occur clinically and those induced by *in vitro* testing appliances. The force created intraorally during mastication varies in magnitude, speed, and direction, while the forces applied to the teeth in this study were constant in speed and direction. The masticatory forces could not be duplicated in the laboratory.[13]

The present study was carried out *ex vivo* and the test was performed 48 h after restorations were placed. In the current study, thermocycling was done to reproduce thermal stresses that occur in clinical situations; according to different studies, thermocycling can increase stresses and can have a weakening effect on the adhesive bond of teeth and consequently lead to a decrease in the fracture resistance of teeth. This means that the reinforcing effect of resin composite may be diminished under clinical conditions. In this study, fracture resistance measurement was used, and while it is the simplest to perform, it is a destructive test that may not always simulate *in vivo* conditions because the forces required to fracture specimens *in vitro* may not occur in the oral cavity.

Future studies are necessary to evaluate the effect of preserving the marginal ridge by using non-destructive testing techniques that allow samples to be used repeatedly. These techniques have the advantage of allowing the sequential testing of endodontic and restorative procedures on the same tooth. The relative effects of these procedures on tooth strength can then be assessed.

Further long-term clinical trials are needed to measure the performance of resin composite restorations *in vivo* and to evaluate bonding stability for longer periods due to the fact that the adhesive bond might fail under clinical situations.

SUMMARY AND CONCLUSION

Within the limitation of this *in vitro* study, the following can be concluded:

- MOD cavity preparations reduced fracture resistance of root-filled teeth.
- On the basis of static loading, preserving the mesial marginal ridge with thicknesses of 2 mm, 1.5 mm, 1 mm, and 0.5 mm, composite-restored and Ribbond-reinforced composite-restored maxillary premolars can help preserve the fracture resistance of teeth.
- Inserting an LWUHMW polyethylene ribbon fiber in root-filled premolar teeth with class II DO and class II MOD preparations significantly increased fracture strength.

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