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Fracture resistance of root filled molar teeth restored with glass fibre bundles

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Abstract

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Aim To evaluate the effect of unidirectional or woven glass fibre tapes inserted into MOD cavity preparations on the fracture resistance of root filled molar teeth.

Methodology Extracted human molar teeth were randomly divided into six groups ($n = 15$) : G1 – sound teeth, control; G2 – MOD cavity preparation; G3 – MOD + root canal treatment (Endo); G4 – MOD + Endo + composite resin restoration (Resin); G5 – MOD + Endo + unidirectional fibre (UF) + Resin; G6 – MOD + ;Endo + woven fibre (WF) + Resin. The teeth were subjected to a compressive fracture test in a universal testing machine. After testing, two failure modes were classified: pulp chamber floor or cusp.

Results The highest and the lowest mean fracture strengths were found in sound teeth (G1) (4960N) and MOD + root canal treatment (G3) (612.84N), respectively, with significant differences from the other groups ($P < 0.05$). The remaining groups had statistically similar means. In G5 and G6, there was a tendency for fracture to occur in the pulp chamber floor compromising tooth integrity.

Conclusions The insertion of glass fibres into MOD cavity preparations and restoring them with composite resin was not different than molar teeth filled with composite resin only in terms of fracture resistance. Fibres placed into MOD cavities do not reinforce teeth.

Keywords: composite resin, endodontic therapy, fracture resistance, glass fibre, molar teeth.

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Introduction

Root canal treatment is considered complete after placement of the final restoration, which is inserted to recover strength, aesthetics, protect the remaining tooth structure and avoid microleakage (Oliveira *et al.* 1987). An ongoing change in the restorative paradigm of endodontically treated teeth has allowed more conservative techniques to be developed, with the aim of maintaining the integrity of the tooth. The acid-etch technique (Buonocore 1955) and the development of composite resin have enabled the use of the adhesive technique to re-establish the tooth structure in a more conservative manner.

However, the fatigue process that occurs over time compromises the longevity of the resin bond strength (Perdigao 2007). Nevertheless, the use of materials that reinforce the tooth, for example fibre-reinforced composites (FRC), has good mechanical properties and can be tailored to specific needs, enabling preservation of tooth structure and using minimal invasive preparations and adhesive techniques (Bell 2007). The advancements made with polyethylene fibres, already used for reinforcing fixed bridges and for splinting teeth, may be an opportunity that seems interesting for the internal strengthening of large MOD restorations in root filled teeth.

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According to Vallittu (1999), continuous unidirectional fibres give strength, stiffness and anisotropic mechanical strength to the composite in the direction of the fibres. The reinforcing efficiency of unidirectional fibres can be obtained in one direction. Continuous bidirectional fibres (woven, weave) have reinforcing fibres in two directions, thus reinforcing the polymer equally in two directions. Woven fibres add toughness to the polymer, act as crack stoppers and are especially suitable in cases where the direction of the load is unknown or where there is no space for unidirectional fibres. The use of woven fibres gives so-called orthotropic properties in a plane. If the fibres are oriented randomly as in a fibre mat or as in chopped short FRCs, the mechanical properties are the same in all directions and are so-called isotropic three-dimensionally (38%) in two dimensions and (20%) in three dimensions (Bell 2007).

Belli *et al.* (2005) placed polyethylene fibres with flowable resin inside MOD cavities and observed higher fracture strength values than those obtained in teeth restored with composite resin only. However, the restorative technique proposed by these authors did not recompose the fracture strength of a sound tooth and may conversely compromise the distribution of occlusal forces. Siso *et al.* (2007) affirmed that the presence of large restorative procedures with excessive masticatory stress associated with excursive lateral contacts implies an increase in susceptibility to tooth fracture. Therefore, the study of possible restorative materials, which are capable of predictably restoring root filled teeth to their original strength, instead of the placement of full coverage restorations, could provide patients with economic and health benefits.

The aim of the present study is to evaluate the fracture strength molar teeth with MOD cavity preparations with or without root canal treatment, either associated with or without glass fibres (woven or unidirectional).

The null hypothesis of the present study is that the insertion of glass fibres, either woven or unidirectional, inside the MOD cavity preparation of root filled molars re-establishes fracture resistance equivalent to that of a sound tooth.

Materials and methods

The local research ethics committee approved the protocol of this study. Ninety sound human maxillary molar teeth were extracted for therapeutic reasons, cleaned and then disinfected in 0.5% chloramine solution for 48 h. Teeth were stored in distilled water at 4 °C until use. The buccal–palatal and mesio-distal dimensions were recorded for each tooth using a digital pachymeter (Mitutoyo, Suzano, SP, Brazil) at the most prominent point of the surface, as described by Mondelli *et al.* (1998) and Beltrao *et al.* (2009). Teeth were also inspected using loupes (Bioart, São Paulo, SP, Brazil) to detect the presence of flaws or fractures. The average buccal–palatal and the mesio-distal mean widths were 10.71 ± 0.63 mm and 9.30 ± 0.55 mm, respectively. The selected teeth were randomly divided into 6 groups, as described in Table 3 ($n = 15$ per group).

Teeth were embedded in self-curing acrylic resin (Jet; Clássico Prod. Odont., Rio de Janeiro, Brazil), using a PVC cylinder (3 cm in height and 2 cm in diameter), up to 2 mm below the cementoenamel junction.

MOD cavity preparation and root canal treatment

A special device positioned over an optical microscope body was created to standardize the movements during MOD cavity preparation (Fig. 1). The methodology for

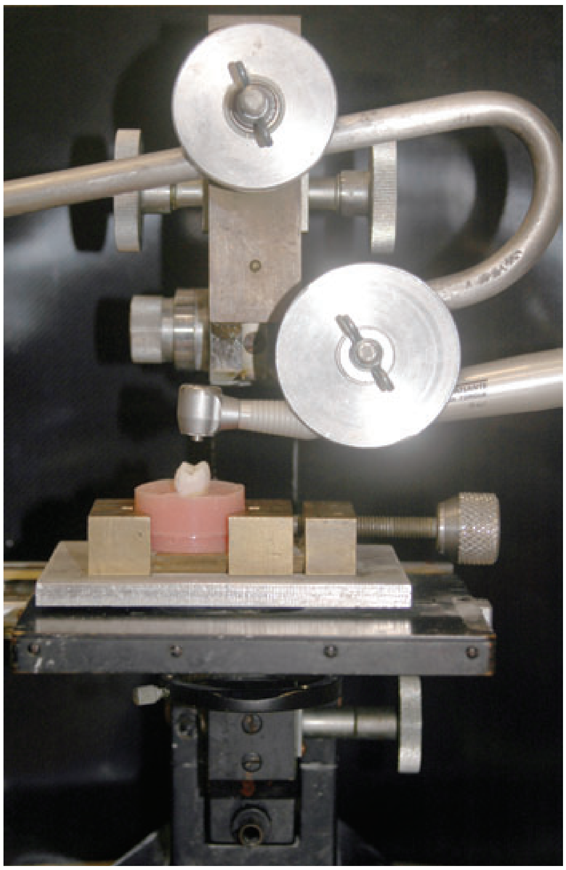

Figure 1 Cavity preparation device.

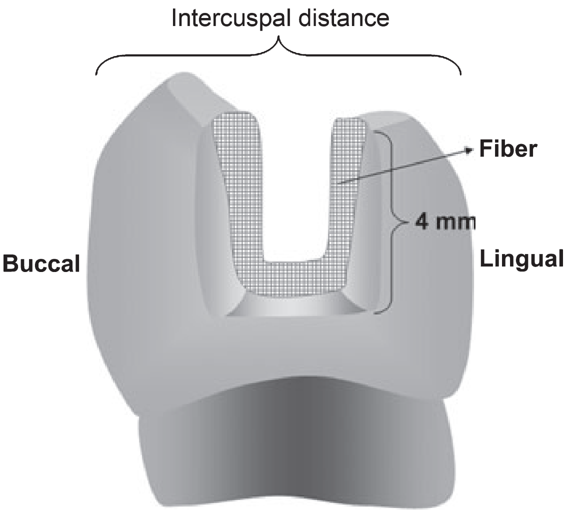

Figure 2 Cavity preparation used in the experiment.

cavity preparation was the same as described by Beltrao *et al.* (2009). The MOD cavity preparation was cut with a number 2143 diamond bur (KG Sorensen, São Paulo, SP, Brazil) at high speed under air–water spray and changed after five cavities. To standardize the cavities and internal angles, the high-speed device was adapted to an optical microscope base with movements in the X and Y coordinates. The bucco-palatal width was measured with a digital caliper and corresponded to two-thirds of the distance between the mesio-buccal and palatal cusps. A depth of 4 mm was determined for cavity preparation. The width of the occlusal box was the same as for proximal cavities. The finished cavity preparation presented a buccal and lingual wall with a mesial to distal box and rounded internal angles defined by the diamond bur (Fig. 2). One operator prepared all the cavity preparations. A 40/41d chisel was applied in the superficial concave angle to regularize the enamel prisms.

After MOD preparation, root canal treatment was performed according to the crown-down technique (Dulaimi & Wali Al-Hashimi 2005). Next, the root canals were filled with gutta-percha and the sealer Endofill (DentsplyMaillefer, Petrópolis, RJ, Brazil). The sealer was mixed according to the manufacturers' instructions and placed into the root canal using a lentulo spiral. The gutta-percha master points were placed into the root canal to full working length. Lateral compaction was performed using a size 25 finger spreader (Dentsply Maillefer) to a level approximately 1 mm short of the working length and ISO size 25, 30 accessory cones (Dentsply Latin America, Petrópolis, RJ, Brazil) coated with sealer were inserted into the canal until the spreader could penetrate no more than 2–3 mm. The excess material was removed with a heated instrument and then compacted vertically. Next, the pulp chamber was filled with the glass–ionomer Ketac Fil Plus (3M-ESPE, St. Paul, MN, USA). Etching with 35% phosphoric acid (Vococid; Voco, Cuxhaven, Germany) was then applied, first on enamel and then on dentine for 15 s. The cavity was then washed with water–air spray for 5 s, and the excess water was eliminated using cotton pellets. Two consecutive coats of the adhesive, Adper Single Bond 2 (3M-ESPE), were applied in the etched cavity. These coats received a brief 5 s air spray, and the adhesive was polymerized for 20 s using a halogen light (XL 3000; 3M-ESPE) with 600 mW cm^{-2} monitored by radiometer (Demetron, Orange, CA, USA).

Restorations with fibres

The fibres used in the current study were pre-impregnated by the manufacturer with silane, monomers and adhesive. The fibres were cut into 3-mm length and inserted into the cavity preparation with a tweezers in the buccal–palatal direction and polymerized for 40 s, in accordance with the manufacturer's instructions.

Restorative procedures

After fibre tape application, the MOD cavity preparation was restored with the composite resin, Filtek Z250 (3M-ESPE) (shade A3), which was inserted into the cavity using an incremental technique. The last two increments were inserted individually and formed an intercuspal angle of 90° to standardize the inclination of the cusps and make it easier to position the cylindrical bar exclusively on the tooth structure during the compression test. The increments were never positioned in simultaneous contact with the buccal and palatal walls, and each of them was polymerized for 20 s, in accordance with the manufacturers' instructions. The groups obtained (Table 1) were as follows:

Group 1 – sound teeth
Group 2 – cavity preparation (CP)
Group 3 – CP + root canal treatment (RC)
Group 4 – CP + RC + composite resin restoration (RR)
Group 5 – CP + RC + RR + woven fibre
Group 6 – CP + RC + RR + unidirectional fibre

After the restorative procedures, the specimens were then stored for 24 h in distilled water at 37 °C.

Mechanical test

Teeth were submitted to fracture testing using a universal testing machine EMIC DL-2000 (São José dos Pinhais, PR, Brazil) at a crosshead speed of 1 mm min^{-1} until fracture. A metal cylinder, 7.5 mm in diameter and 16 mm in height, was positioned on the inclined surfaces of the buccal and palatal cusps in the mesio-distal direction, touching only tooth structure. The data were recorded in Newtons (N), and the deformation and dislocation curves were interpreted using the Mtest software.

Failure mode

After mechanical testing, the specimens were visually inspected to determine the failure mode. These failures were classified according to the studies by Uyehara *et al.* (1999) and Beltrao *et al.* (2009) as follows: (i) pulp chamber floor and (ii) cusp. The pulp chamber floor fracture was considered when the tooth was divided into two parts, irrespective of whether it occurred in the bucco-palatal or mesio-distal direction. Cusp fracture was considered to occur when it was partially or totally involved, irrespective of its dislodgment.

Fracture mode

After failure, all specimens were visually inspected to evaluate the fracture finishing line. Two types of diagnoses were determined: unrestorable or restorable. A tooth was considered unrestorable when the fracture line occurred throughout the vertical extension of the pulp chamber floor, dividing the crown into two pieces. A tooth was considered restorable when the fracture line was partial, either vertically or horizontally, without dividing the crown into parts.

Statistical analysis

The data were recorded in Newton (N) and submitted to ANOVA and Tukey *post hoc* test with a 5% significance level ($P \leq 0.05$). The statistical analysis was performed using the software Statistix for Windows v. 8.0 (Analytical Software, Tallahassee, FL, USA).

Results

Fracture resistance test

The sound teeth in group G1 (control) and those in G3 (MOD + Endo) had the highest (4960 N) and the lowest mean (612.84 N) fracture strengths, respectively, and were significantly different from the other groups ($P \leq 0.05$) (Table 2).

Groups G2 (MOD without Endo), G4 (MOD + Endo + Resin), G5 (MOD + Endo + WF) and G6 (MOD + Endo + Resin + UF) had intermediate mean fracture strength values and did not differ significantly from each other; however, they were significantly different

Table 1 Distribution of Study Groups

Groups	Teeth (*n*)	MOD cavity preparation	Endodontic treatment	Composite resin	Glass fibre
G1	15	No	No	No	No
G2	15	Yes	No	No	No
G3	15	Yes	Yes	No	No
G4	15	Yes	Yes	Yes	No
G5	15	Yes	Yes	Yes	Yes (woven)
G6	15	Yes	Yes	Yes	Yes (unidirectional)

Table 2 Mean fracture strength values (N)

Groups	*n*	Mean (N)	SD	CV
G1 (control, sound teeth)	15	4960 A	1146.7	23.11
G2 (MOD without Endo)	15	1926.20 B	647.85	33.63
G3 (MOD + Endo)	15	612.84 C	133.45	21.77
G4 (MOD + Endo + Resin)	15	1813.9 B	798.91	44.04
G5 (MOD + Endo + Resin + WF)	15	2024.5 B	637.11	31.47
G6 (MOD + Endo + Resin + UF)	15	1879.1 B	571.41	30.41

*Means followed by the same letter show no statistical difference for Tukey ($P < 0.05$).
WF, woven fibre; UF, unidirectional fibre.

Table 3 Failure mode in the study groups

Groups	Pulp chamber floor (not restorable)	Cusp (restorable)
G1	53.3% (8)	46.7% (7)
G2	53.3% (8)	46.7% (7)
G3	86.7% (13)	13.3% (2)
G4	60.0% (9)	40.0% (6)
G5	93.3% (14)	6.7% (1)
G6	93.3% (4)	6.7% (1)

from the other two groups (G1 and G3) ($P \leq 0.05$) (Table 2).

Qualitative variables analysis

The results of the failure mode and diagnostic type are presented in Table 3. There was a high prevalence of cusp fractures in G2. There was a high prevalence of pulp chamber floor fracture in groups G3, G5 and G6.

Discussion

The initial null hypothesis of the present study was that the insertion of glass fibre tape either woven or unidirectional, inside the MOD cavity preparation of root filled molar teeth, could re-establish the fracture resistance equivalent to that of a sound tooth. According to the present results, the null hypothesis was rejected. Group G1 (control) had a mean fracture strength of 4260 N and G3 (MOD + Endo) 612 N, which were the highest and the lowest values, respectively, with a significant difference between them and in comparison with the other groups. These findings are in agreement with other studies; however, different mean values were found, probably because of the differences in the methodologies (Howe & McKendry 1990, Mondelli *et al.* 1998, Assif *et al.* 2003, Belli *et al.* 2005). Belli *et al.* (2005) also reported that root filled molars with MOD preparations had the lowest mean fracture strength values (376.51 N) when compared with sound teeth (1676 N).

Group G2 (MOD without Endo) demonstrated the difference between the presence and absence of the pulp chamber floor as a natural reinforcement. A significantly higher difference in resistance was found in G2 when compared with G3 (MOD + Endo), proving that the presence of a pulp chamber roof is a determining factor in the resistance of MOD preparations. No statistical difference was found in G2 and the other restored groups, permitting the speculation that a MOD-prepared tooth with a pulp chamber roof had the same compression strength as a MOD-prepared tooth with root canal treatment and restored with composite resin. This could have occurred because the volume of dentinal tissue present in the G2 cavity preparations, which in G3 was replaced by composite resin, with a modulus of elasticity of 20.13 GPa (Labella *et al.* 1999) was similar to that of dentine, 18 GPa (Ausiello *et al.* 2002).

The use of glass fibres follows the methodology proposed by Belli *et al.* (2005, 2006). In the former study, there was a significantly better result for MOD cavities in molars restored with polyethylene fibre and composite resin (1050 N) than in molars restored with composite resin only (575.40 N). This differs from the current results in which no significant difference was found between groups restored with composite resin only (G5 – 2024.5 MPa and G6 – 1879.1 MPa). In a previous study (Belli *et al.* 2006), a polyethylene fibre was inserted into a groove in combination with flowable resin that was cured for 20 s and covered with composite resin. In the present study, the fibre was positioned over the adhesive system after it was polymerized. This procedure was performed so as to be more realistic, considering the manufacturer's instructions and recommendations described for splinting and fragment bonding using fibres.

The current study also analysed qualitative and quantitative failures, using the association between failure mode and tooth diagnosis. This assessment reinforced the belief that restorative treatment with high resistance is not that important if the pulp chamber floor has been destroyed. The results showed that groups G5 and G6, which received the fibres, had 93.3% of pulp floor failures. Nevertheless, the use of fibres, either woven or unidirectional, did not improve the compression strength or the diagnosis. The authors of the present study believe that the fibres would act to protect the pulp chamber floor, because this pulp chamber floor, if lost, could condemn the tooth to extraction or to complex treatments with doubtful prognosis. It is also interesting to observe that preserving the pulp chamber roof protects the tooth from pulp chamber floor fracture, even in a large MOD cavity preparation.

The most intriguing data is that groups G5 and G6 had the greatest number of pulp chamber floor fractures, specifically the ones restored with fibre, in which fracture resistance values were inferior when compared with the groups restored only with resin, which presented a more aggressive fracture pattern. This could be related to the mechanical properties of the restorative materials. As these glass fibres have a high modulus of elasticity (Hirata 2002), there will be less elastic deformation during load application, and the compression tension will be transferred to the material located below the fibre, in this case, the adhesive system and glass ionomer. When these fibres are subjected to flexural tension, they do not rupture, but completely dissipate the force, deflecting it in the same direction as the applied force. When subjected to an extreme flexural force that leads to plastic deformation of the fibre, the resinous matrix around the fibre ruptures. As the adhesive has a low elasticity modulus, 4.5 GPa (Labella *et al.* 1999), it cannot dissipate the masticatory load, which will act directly on the thin pulp chamber floor, leading to crack formation. This also demonstrates a weak interaction between glass fibres and adhesive systems. A possible solution in this case could be the application of a non-cured coat of composite resin on the pulp chamber floor before fibre insertion to wrap it. This additional step would reinforce the composite resin and connect the pulp floor to the resin and fibre. However, the use of glass fibre as a reinforcement would lose its meaning, because it would not be possible to define whether the real contribution to increasing the fracture resistance comes from the composite resin, the glass fibre, or both.

This study corroborates the findings of Burke (1992), who affirmed that when cavity preparation has a buccal–palatal dimension of 2/3 or more of the intercuspal distance, it is possible to recover almost 60% of the fracture resistance of a sound tooth. When one considers the direct and indirect restorative techniques, it seems that no significant differences are found in the literature, because they have similar success rates (Santos & Bezerra 2005).

Conclusion

The use of woven or unidirectional glass fibres is not indicated as a reinforcement for teeth with MOD cavity preparations. This is not surprising as the cusp deflection strength occurs because of the adhesive system and composite resin and not by reason of the glass fibre, which is unable to strengthen the cusps. Moreover, the absence of the pulp chamber roof makes the tooth more susceptible to fracture.

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