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Evaluation of fracture resistance in simulated immature teeth using resilon and ribbond as root reinforcements – An *in vitro* study

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Abstract – *Background/Aim*: To compare the reinforcement and strengthening ability of resilon, gutta-percha, and ribbond in endodontically treated roots of immature teeth. *Material and Methods*: Sixty five freshly extracted human maxillary anterior teeth were prepared with a Peeso no. 6 to simulate immature teeth (Cvek's stage 3 root development). After instrumentation, each root was irrigated with sodium hypochlorite and with ethylene diamino tetra acetic acid to remove the smear layer. To simulate single visit apexification technique a 4–5 mm white Pro Root mineral trioxide aggregate plug was placed apically using schilder carrier. The teeth were divided into three experimental groups and one control group. Group I – control group (root canals instrumented but not filled); Group II – backfilled with thermoplastisized gutta-percha using AH plus sealer; Group III – reinforced with Resilon using epiphany sealer; Group IV – reinforced with Ribbond fibers using Panavia F luting cement. A Universal Testing Machine was used to apply a load, at the level of the lingual cementoenamel junction with a chisel-shaped tip The peak load to fracture was recorded and statistical analysis was completed using student's *t*-test. *Results*: Values of peak load to fracture were 1320.8, 1604.88, 1620, and 1851newtons for Group I to Group IV respectively. The results of student's *t*-test, revealed no significant difference ($P > 0.05$,) between Group II and Group III. Comparison between Group IV and Group III and between Group IV and Group II revealed highly significant difference ($P > 0.001$). *Conclusions*: Teeth reinforced with Ribbond fibers using Panavia F luting cement showed the highest resistance to fracture. Resilon could not strengthen the roots and showed no statistically significant difference when compared with thermopasticised gutta-percha in reinforcing immature tooth when tested with universal testing machine in an experimental model of immature tooth.

Traumatic dental injuries are a common cause of tooth damage and loss in the young and adolescent age group. Common injuries to permanent teeth results from falls, traffic accidents, violent acts and participation in various sports. Previous research indicates that the most common site of dental impact injuries in the developing dentition is the maxillary anterior teeth (1, 2). These injuries can result in pulp necrosis of immature permanent teeth having incomplete root development and thin-weak root walls.

Advantages of single step apical barrier placement technique include shorter treatment time, development of a good apical seal, and mineral trioxide aggregate (MTA) induced hard tissue deposition periradicularly (3, 4).

The thin dentinal walls at the cementoenamel junction, however make them prone to fracture from secondary injuries (i.e., mastication or minor trauma), often leaving them non-restorable. It has been shown that, despite successful endodontic treatment, 28–77% of these teeth-depending on the stage of root development, will fracture during or after treatment. Because of this many clinicians view the procedure as having a poor prognosis for teeth arrested in the early stages of development (5). The remaining root walls, which are thin, particularly in the cervical region, present a very serious clinical problem. For this reason, the use of reinforcement in these weak roots would be advantageous.

Studies vary with regard to which material would best reinforce and seal the remainder of the root after an apical barrier of MTA or an apexification procedure with calcium hydroxide (6–11). Historically, the prognosis for restored thin-walled teeth was considered guarded. Taking advantage of advances in restorative technologies, adhesive materials and techniques for the intraradicular reinforcement of roots with thin walls have been used. Favorable clinical results with resin reinforcement and dowel and cores in structurally weakened teeth have been reported by some clinicians (8).

Several materials have been used with the aim of increasing the resistance of endodontically treated teeth. Studies have verified a resistance increase of the dental structure when the root canal was filled with composite resin (12). Different postsystems like para-post, flexi-post and prefabricated posts combined with polyethylene and composite were used to strengthen the endodontically treated teeth (12). Glass ionomer cement was also used as an auxiliary way to help teeth strengthening (12).

Gutta-percha has been historically the easiest and most predicatable root canal-filling material to use. With advent of technology research focused on developing a material which binds to the dentin of root canal. The recent introduction of Resilon (Pentron Clinical Technologies LLC, Wallingford, CT, USA) as an alternative root filling material offers the promise of adhesion to root dentine. As this filled polycaprolactone polymer contains a blend of dimethacrylates, the manufacturers claim it bonds well to methacrylate-based resin sealers (13).

Resilon when used according to manufacturer's instructions with a dual cure, resin-based sealer, Epiphany (Pentron Clinical Technologies LLC) reportedly forms a 'mono-block' in the canal. Teeth obturated with these materials have been shown to be more resistant to vertical root fractures than teeth obturated with gutta-percha (14).

Ribbond-A ribbon reinforcement material, (Ribbond Inc., Seattle, WA, USA) has been available commercially since 1992. Ribbond is a spectrum of 215 fibers with a very high molecular weight. These fibers have a very high coefficient of elasticity (117 GPa); this means an excellent resistance to stretch and distortion. They also have a very high resistance to traction (3 GPa), as a result of their 'closed stitch' configuration, and a good adaptability (15).

The purpose of this *in vitro* study was to evaluate the ability of two recently developed materials namely Resilon and Ribbond in reinforcing the root canal walls of simulated immature teeth.

Material and methods

Ninety freshly extracted human maxillary anterior teeth were collected for this *in vitro* study, and were stored in saline. The teeth were obtained from local dentists who had extracted them because of periodontal reasons. The faciolingual dimension of each tooth was measured with Vernier calipers (Mitutoyo, Kawasaki, Japan) at the facial cementoenamel junction (CEJ). The mean values obtained were 6.68 mm for mesiodistal and 6.40 mm for buccolingual direction. Samples presenting a difference of 20% from the above mentioned mean values were discarded leaving a total of 65 incisors. All teeth were radiographed to exclude teeth with fracture lines, caries and calcifications.

Immature teeth model preparation

The root of each tooth was standardized to a length of 13 ± 1 mm as measured from the apex to the facial CEJ by cutting off the root end with corborundum disk (Dentorium, New York, NY, USA) mounted on straight handpiece (NSK, Tokyo, Japan).

Coronal access was made using No 4 round diamond bur (Mani, Tochigi, Japan) using a high speed handpiece, (NSK) under water coolant and access was widened using Ex24 bur (Non end cutting tapered fissure) (Mani). The dental pulp was removed by using barbed broaches (Pulpadent, Zurich, Switzerland) and hedstroem file no. 45 (Mani).

The canal was instrumented to ISO no 80 K file (Mani). To simulate immature teeth the canals were instrumented with Peeso reamers (No1-6) (Mani) until a no. 6 Peeso (1.7 mm) could be passed 1 mm beyond the apex(Fig. 1a). After instrumentation, each root was irrigated with 5 ml, 3.0% sodium hypochlorite (Comdent, Mumbai, India) and 5 ml, 17% EDTA (ethylene diamino tetra acetic acid) (Canalarge, Aman Int., Ahmedabad, India) to remove the smear layer. Five milliliter of 0.9% normal saline (Fresenius Kabi, Pune, India) in 5 cc irrigation syringe with 23 gauge needle (Becton, Mumbai, India) was used as a final rinse.

Calcium hydroxide dressing (Prime Dent, Mumbai, India) was placed in the canals of all teeth and they were temporized using a cotton pellet and Cavit (3 M ESPE AG, Seefeld, Germany) for 7 days to simulate the disinfection procedure. Then all teeth were stored at 37°C and 100% humidity.

After 7 days the calcium hydroxide was removed by flushing the prepared canals with 5 ml, 3.0% sodium hypochlorite and 5 ml, 17% EDTA. Five milliliter of 0.9% normal saline in 5 cc irrigation syringe with 23 gauge needle was used as a final rinse.

To simulate single visit apexification technique a 4–5 mm white Pro Root MTA plug (Dentsply India Pvt Ltd, Delhi, India) was placed apically using schilder pluggers (Dentsply Caulk, Milford, DE, USA). The MTA Plug was condensed with a hand plugger. All teeth were placed in flower arrangement sponge prior to placing MTA, to aid in handling, setting and to prevent MTA extrusion. The teeth were taken out after 72 h and radiographed to check the accuracy of MTA plug.

All teeth were mounted in a self cure acrylic (Dentsply India Pvt Ltd) cylinder of 1 inch diameter and 2 inch height using a surveyor (Ney, Dentsply Ceramco Avenue York, PA, USA) to ensure straight line access. Teeth

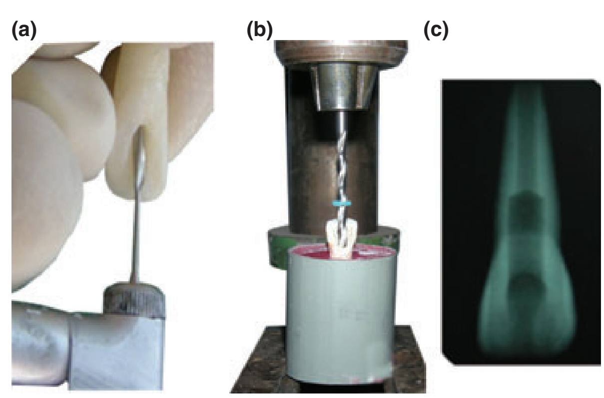

Fig. 1. Immature tooth model preparation (a) Instrumentation with Peeso reamers. (b) Engineering twist drill of 3 mm diameter to extend the preparation of the canal. (c) Radiograph showing finished immature tooth model.

were placed to leave a gap of 2 mm between the top of acrylic and the facial and lingual CEJ to simulate the physiologic spacing found clinically between the bone crest and the CEJ (14). An engineering twist drill of 3 mm diameter was used with water coolant to extend the preparation of the canal 3 mm below the facial CEJ (Fig. 1b). The 3 mm diameter was chosen to approximate Cvek's stage 3 of root development, since at this stage the root-to-canal ratio, in a mesiodistal dimension at the CEJ, is roughly 1:1 (5).

After instrumentation, each root was irrigated with 5 ml, 3.0% sodium hypochlorite and 5 ml 17% EDTA. Five milliliter of 0.9% normal saline in 5 cc irrigation syringe with 23 gauge needle was used as a final rinse.

All specimens were buccolingually and mesiodistally radiographed to check the thickness of remaining dentin (Fig. 1c). The teeth were divided into three experimental groups and one control group using a randomized-stratified design. Five teeth were instrumented but not obturated which served as a control group and the remaining sixty teeth were assigned to three experimental groups based on the obturating material to be used.

Group I – Control group ($n = 5$). Instrumented, not obturated.

Group II – Backfill with thermoplastisized gutta-percha and AH Plus sealer ($n = 20$). Thermoplastisized gutta-percha (E & Q Plus System, Meta Biomed Co. Ltd, Cheungju, Korea) with epoxy-resin-based sealer, AH Plus (Dentsply Maillefer, Konstanz, Germany) was used for obturation of canal. The sealer was mixed according to manufacturer's instructions and applied to the canal walls using a paper point. The excess gutta-percha was seared off at the CEJ level and vertically compacted using a hand plugger.

Group III Obturated with Resilon and Epiphany sealer ($n = 20$) Custom made Resilon gutta-percha cone was used with resin-based Epiphany root canal sealant. Resilon primer was introduced into the canal using special applicator brushes. Thirty seconds later, dry paper points were used to wick out the excess primer from the canal. The Resilon master point was generously coated with Epiphany sealer and seated into the canal. The excess Resilon gutta-percha was seared off at the CEJ level and vertically compacted with hot instrument. The material was light-cured for 30 s to facilitate setting.

Group IV Backfill with dual cure Panavia F luting cement reinforced with Ribbond fibers ($n = 20$). ED Primer (Kuraray, Osaka, Japan) was used according to the manufacturer's instructions for the treatment of root canals. The two paste adhesive cement Panavia F (Kuraray) was mixed according to instructions of the manufacturer and loaded into the root canal. After the two paste adhesive cement was placed into the canal space, a 3-mm-wide piece of Ribbond fiber was cut to a length equal to twice the depth of each canal preparation. The Ribbond fiber was coated with the bonding agent (Bond I, Pentron Technologies LLC) and excess removed. The Ribbond material was handled with cotton pliers only. Using pluggers, the Ribbond strip was shaped into a 'V' and inserted to the depth of the canal with the width in a facio-lingual direction. Some of the dual cure cement was displaced as the ends of the 'V' were pushed even with the cavo-surface margin.

A second piece of Ribbond fiber, which had been prepared in the same manner, was then shaped into a 'V' and inserted into the canal to the same depth. The width of the second 'V' was placed in a mesiodistal direction and thus perpendicular to the first strip. The ends of the Ribbond fiber were then packed below the cavo-surface margin, and additional dual cure cement was used to fill the void resulting from Ribbond fiber placement. The restoration was light-cured for 40 s.

In groups II, III and IV, the access openings were filled using composite resin (Charisma, 3 M ESPE, St Paul, MN, USA) according to manufacturer's instructions. The specimens were then stored in 100% humidity at 37°C until fracture resistance testing. A jig was fabricated to fit each tooth/acrylic cylinder in the testing machine. A Universal Testing Machine (Fuel Instruments & Engineers Pvt Ltd Inchalkarnji, Maharashtra, India) was used to apply a load to each specimen at a crosshead speed of 5.0 mm min^{-1} (Fig. 2a).

The specimens were fixed in the jig and the load was delivered at 130° to the long axis of the tooth in a linguo-labial direction at the level of the lingual CEJ with a chisel-shaped tip. (Fig. 2b) The peak load to fracture was recorded and statistical analysis was completed using student's *t*-test.

Results

All 65 teeth tested showed horizontal fractures through the cervical portion of the root. In group I the fractures extended through the empty, instrumented canal space. In group II, group III and group IV the fractures extended through the gutta-percha, Resilon, and Ribbond, respectively. The control group exhibited lowest load value to fracture and group IV exhibited the highest load value to fracture. The mean peak load required to cause cervical root fracture in all five groups is presented in Fig. 3.

The results of student's' *t*-test (Table 1), revealed no significant difference ($P > 0.05$,) between group II and group III. Comparison between group IV and group III and between group IV and group II revealed highly significant difference ($P > 0.001$).

(a) (b)

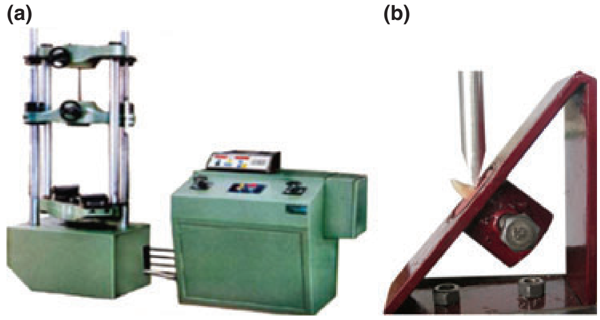

Fig. 2. (a) Universal testing machine (UTM). (b) Triangular device used for fixation and positioning of specimens on UTM.

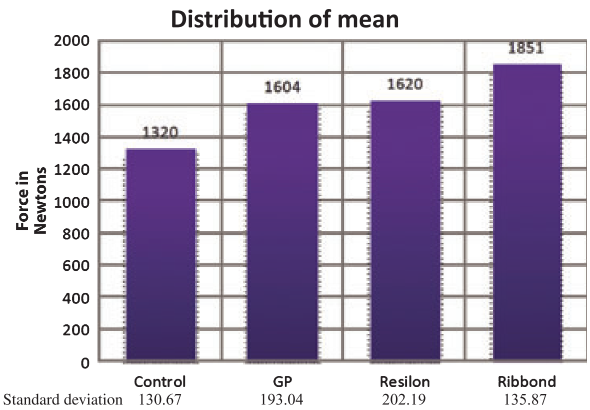

Fig. 3. The mean peak load required to cause cervical root fracture.

Table 1. The results of student's *t*-test

Group	'*t*'-value	Significance
GP vs resilon	0.2543	*P* > 0.05, NS
Ribbond vs resilon	4.2406	*P* < 0.001, HS
Ribbond vs GP	4.667	*P* < 0.001, HS

NS, not significant; HS, highly significant.

Discussion

Teeth with incomplete root formation, pose a special challenge to dentists all over because of large open apices, divergent root walls and thin dentinal walls that are susceptible to fracture and frequent periapical lesions.

The use of reinforcement in these weak roots is necessary for these reasons. There are few studies in the literature that give the importance and value to the resistance to fracture in traumatized and endodontically treated immature permanent teeth, and therefore there is little information about the variables that can increase the resistance of those teeth to new fractures (16).

Choice of material

These materials were chosen because Resilon is a new material that has been introduced for the obturation of endodontically treated teeth. Resilon is a synthetic polycaprolactone polymer based on the polymers of polyester. This material contains dimethacylates and can bond to methacrylate-based resin sealers. One of the main claims of those advocating the use of Resilon is its ability to produce a bonded mono-block filling. This is created by the adhesion of the Resilon cone to the resin-based sealer, which adheres to the dentinal wall and penetrates the dentinal tubules. Shipper et al. referred to this bonded root canal-filling as the Resilon 'Monoblock' System (17).

Ribbond material is composed of preimpregnated, silanized, plasma treated, leno-woven, ultra high molecular weight polyethylene fibers. Leno-weave is a special pattern of crosslinked, locked-stitched threads which increase the durability, stability and shear strength of the fabric. The open and lacelike architecture of the leno-woven ribbon allows it to adapt closely to the contours of the teeth (18).

In the present study, stage 3 root development was selected for the model because it is the stage at which the root-to-canal ratio in a mesiodistal dimension at the CEJ is roughly 1:1. Because the mature maxillary central incisor model does not allow for the degree of apical closure or the fraction of final root length to be used as determinants, the root-to-canal ratio provided a consistent parameter for preparation. An effort was made to standardize the preparation of each specimen so that parameters such as absence of craze or fracture lines, canal preparation centering (by using a surveyor), placement of the applied load, embedment of the teeth in acrylic leaving 2 mm gap between top of acrylic and the facial and lingual CEJ, and dimensions of the canal preparation were similar, leaving tooth restoration as the only variable.

The reasons for leaving a gap of 2 mm between the top of the acrylic and the facial and lingual CEJ were:

1 To simulate the physiologic spacing found clinically between the bone crest and the CEJ and
2 To expose the portion of the tooth that was likely to fracture when horizontal forces were placed on the crown.

To simulate immature teeth the canals were instrumented with Peeso reamers (1–6) until a no. 6 Peeso could be passed 1 mm beyond the apex to simulate open apex. Preparation of the immature canal space was done with a 3 mm diameter engineering twist drill in a drill press to simulate stage 3 of Cvek's classification. Each specimen block was fixed in a jig that ensured a loading angle of 130° degrees to the long axis of the tooth. This angle was chosen because it simulates the average angle of contact between maxillary and mandibular incisors in a class I occlusion (9).

The experimental model was quite successful in providing a repeatable system for each trial. All fractures passed through the cervical area of the root. Each tooth in experimental groups 2, 3 and 4 also fractured through the respective restorative materials at the point where the fracture extended through the prepared canal space.

The depth of the preparation to a minimum of 3 mm below the facial CEJ was adequate, because all of the fractures in the experimental groups extended through the filling materials in cervical area during strength testing. Also, the failure of the restorative materials occurred concomitantly with fracture of the teeth. Thus the load at the point of fracture directly reflected the strength of the tooth and the restorative material at the fracture site. In our study, the mean load to fracture of resilon and gutta-percha group was higher than the control group but there was no statistically significant difference between the resilon and gutta-percha group.

The ability of Resilon to reinforce the tooth has not been conclusively proved. Teixeira et al. (19) have showed that the teeth obturated with Resilon/Epiphany exhibited greater resistance to vertical root fracture compared to similar teeth filled with gutta-percha.

Williams et al. (20) reported that Resilon and gutta percha, both materials had cohesive strengths and moduli of elasticity values that are too low to reinforce the roots of endodontically treated teeth. They believed that the stiffness of Resilon is much too low to allow that material to strengthen roots and if an endodontic filling material is to reinforce or strengthen endodontically treated teeth, the material should have physical properties at least equal to that of dentin.

To reinforce roots, the modulus of elasticity would need to approximate that of dentin, which is, 14 000 MPa (13). Dentin has a tensile stress (cohesive strength) ranging between 36 to 100 MPa (21). Resilon's modulus was approximately 129 MPa (after 1 month in water) and gutta-percha was approximately 77 MPa. Resilon had yield strength of approximately 8 MPa and gutta-percha 6 MPa. Furthermore, when placed under tensile stress it elongated like gutta-percha as shown by the high maximum elongation values obtained (20).

The second reason for the poor results of Resilon could be the failure at the interface between Resilon and sealer and between sealer and dentin. The low shear strength of Resilon to a methacrylate-based sealer (Epiphany) compared with a composite control suggests that the amount of dimethacrylate incorporated in this filled polycaprolactone-based thermoplastic composite may not yet be optimized for elective chemical coupling to methacrylate resins (13).

The interfacial strength achieved with Resilon/Epiphany to intraradicular dentin is not superior to that of gutta-percha and a conventional epoxy-resin sealer (22). The results challenge the concept of strengthening root canals with the new root filling system. Although our study did not evaluate the type of failure in Resilon group, the low fracture load values when compared to Ribbond group could be attributed to the above factors. Previous studies on Resilon strengthening tested its ability to inhibit vertical root fractures. This was done by applying a force along the long axis of the tooth (19). Thus its low bond strength and high elasticity may not be as important as in this case where a horizontal force is applied 'through' the material.

Ribbond reinforced group showed highest values which could be attributed to the physical properties of Ribbond fibers and Panavia F dual cure cement. Apart from properties discussed before, ribbond fibers are translucent and assume the color of the resin to which they are added. Ribbond fibers easily absorb water because of the 'gas-plasma' treatment to which they are exposed. This treatment reduces the fibers superficial tension, ensuring a good chemical bond to composite materials (15).

The leno-weave of Ribbond reportedly resists shifting and sliding under tension more than a plain weave, minimizing crack propagation (18). This occurs by reducing the coalescence of microcracks within the resin matrix into cracks that could lead to failure of the restorative complex. This composite reinforcement fiber network provides an efficient transfer of stress within the internal frame work by absorbing the stresses that are applied to the restorative complex and redirecting those forces along the long axis of the remaining root structure, thereby minimizing the risk of root fracture (23).

A Finite Element Analysis model study found that the cement with elastic modulus similar to that of dentin could reinforce weakened root and reduce the stress in dentin. Thus, it may be a better choice for the restoration of weakened roots in clinical practice. Panavia F has modulus of elasticity same as that of dentin. It has been demonstrated that elastic modulus is one of the important parameters to evaluate property of the cements. When cement with an elastic modulus close to the dentin was selected, optimal combination and mechanical compatibility of the cement and dentin could be achieved; this enhanced the ability to resist external force together. Stress in dentin was reduced due to the cement sharing parts of the stress. Stress distribution in root could be improved and extension of high stress region could be prevented by selecting cements with elastic modulus close to that of the dentin, and thus further reduced root fracture incidence (24).

Our results were similar to results of a study done by Erdemier et al. (25), who reported highest fracture strength values with reinforcement of resin cement using a polyethylene fiber, when compared with other groups. This dual advantage, namely similar modulus of elasticity of Panavia F to dentin and better physical properties of Ribbond contributed to highest load to fracture values in this group.

Conclusion

The findings of the study showed that Ribbond in combination with Panavia F cement had the highest resistance to fracture; Resilon could not strengthen the roots and showed no statistically significant difference when compared with thermopasticized gutta-percha in reinforcing immature tooth when tested with a universal testing machine.

This study was carried out using simulated immature teeth and was an *in vitro* study; hence results could vary in '*in vivo*' conditions. Within the limitations of this study, it may be concluded that the placement of Ribbond with Panavia F cement substantially increased the fracture resistance of the thin-walled simulated immature roots.

Disclosure

The authors have no financial interest in any way with the products, materials, or suppliers used in this article.

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