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Fracture resistance of simulated immature maxillary anterior teeth restored with fiber posts and composite to varying depths

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Abstract – *Background*: Traumatized immature teeth present a unique challenge during treatment, both endodontically as well as restoratively. Hence, the purpose of this study is to evaluate the type and depth of restoration that would be effective in simulated immature maxillary anterior teeth in terms of fracture resistance and mode of failure. *Materials and methods*: Seventy-five extracted human maxillary anterior teeth were used in this study that was standardized to a length of 13 mm. Instrumentation of the canals was performed after which a Peezo no. 6 was taken 1 mm past the apex to simulate an incompletely formed root. MTA apexification was simulated after which all the teeth were mounted and a 3-mm-diameter engineering twist drill extended the preparation 3 and 7 mm below the facial cemento–enamel junction (CEJ) to simulate Cvek's stage 3. These teeth were divided into seven different groups: Group 1: Negative control: intact teeth; Group 2: Positive control: 3 mm, no restoration; Group 3: Positive control: 7 mm, no restoration; Group 4: 3-mm composite; Group 5: 3-mm quartz fiber post; Group 6: 7-mm composite; Group 7: 7-mm quartz fiber post. Fracture resistance was performed at 130° to the long axis of the tooth with a chisel-shaped tip at the cingulum with a cross-head speed of 5 mm min^{-1}, and the maximum load at which the fracture occurred was recorded. *Results*: Group 1 that was the negative control showed the highest fracture resistance. Among the experimental groups, 4 and 5 showed the highest fracture resistance, which were significantly different from groups 6 and 7, respectively. *Conclusions*: Within the limitations of this *in vitro* study, it can be concluded that using either dual-cure composite or a quartz fiber post with composite resin to a depth of 3 mm would significantly strengthen the roots in immature teeth.

Traumatic dental injuries to the permanent dentition are extremely common. Previous studies have demonstrated that the evidence of trauma to the permanent dentition especially the permanent incisors varies in different countries and ranges from 3.9 to 58.6% (1). In cases of traumatized immature teeth, endodontic treatment is necessary. However, these immature teeth present a unique challenge endodontically as well as restoratively due to open apices and thin dentinal walls (2). The thin dentin walls predispose these teeth to a higher incidence of root fractures (3). Root fractures commonly occur in the cervical third and have been shown to have a rate of about 28–77% depending on the stage of root development (4).

From an endodontic standpoint, there are currently few options to treat the immature apex, which include mineral trioxide aggregate (MTA) apexification and pulp revascularization (5). Revascularization has shown great potential for clinical success (6, 7) but has yet to be evaluated over the long term, and may not be successful in every case. When revascularization is not an option or has not been successful, other procedures like apexification with MTA have been carried out. Apexification has demonstrated high clinical success with 84% of the cases healing at 30.9 months (8).

From the restorative standpoint, it is important to consider the predisposition of incompletely formed teeth to fracture. Previous studies have demonstrated that posts may increase the fracture strength of mature teeth and have noted different failure patterns between metal, zirconium, and fiber posts (9). Other studies that have looked at MTA apexification in immature teeth restored with fiber posts have demonstrated that the predisposition to root fracture in the cervical third may be augmented by the choice of restorative materials (10, 11). The best current evidence from recent publications recommends restoration of immature incisors with fiber posts surrounded by dual-cure composite resin (11, 12).

It is imperative that clinicians consider the restorative prognosis and the predisposition to fracture before restoring these immature teeth. Some previous research has shown that a greater post length imparts greater fracture resistance in mature teeth (13); hence, some clinicians may elect to proceed with a MTA apexification followed by placement of a post. No studies thus far have looked at the differences in fracture resistance of simulated immature maxillary anteriors restored with dual-cure composites vs those restored with quartz fiber posts. The purpose of this study is to evaluate the type and depth of restoration that would be effective in simulated immature maxillary anterior teeth in terms of fracture resistance and mode of failure. Hence, the null hypothesis was that the type and depth of the restoration would have no effect on the fracture resistance and mode of failure of the teeth.

Materials and methods

Preparation of samples

Fracture resistance of the teeth was evaluated based on the protocol from Hemalatha et al. (14). Seventy-five extracted human maxillary anterior teeth were used in the study and were stored in one part full-strength bleach diluted with nine parts of water initially, followed by storage in water. The teeth were measured with digital calipers, ensuring mesiodistal and buccolingual width at the cemento–enamel junction (CEJ) would fall within ± 25% of the group mean. Only intact teeth without fractures, caries, or pulpal obliterations were included. All roots were standardized to 13 mm in length from the facial CEJ with a slow-speed disk. Access and instrumentation of the canal were performed with K-files, Gates Glidden burs, and Peezo reamers (Roydent, Johnson City, TN, USA) until a Peezo no. 6 passed 1 mm past the apex. All teeth were irrigated with 5 ml 6% sodium hypochlorite (NaOCl), 5 ml 17% EDTA, and 5 ml 0.9% saline. After this irrigation procedure, MTA apexification was simulated. 4–5 mm of MTA (Tulsa Dental, Tulsa, OK, USA) was condensed to form an apical plug and allowed to set for 72 h at 37°C in 100% humidity. The teeth were attached on a surveyor and mounted vertically in clear orthodontic resin (Patterson Dental, St. Paul, MN, USA) inside a half-inch diameter PVC ring to 2 mm apical to the facial CEJ to simulate the relation between the tooth and the bone (Fig. 1a). After mounting the teeth in resin, a 3-mm-diameter engineering twist drill with water irrigation extended the preparation 3 and 7 mm below the facial CEJ to simulate Cvek's stage 3 (15) (Fig. 1b). A final irrigation was performed as mentioned above, and the teeth were divided into the following groups according to the depth of post/restorative material placement and the type of material used:

Group 1: Negative control: intact, virgin teeth (n = 5).
Group 2: Positive control: 3 mm, no restoration (n = 5).
Group 3: Positive control: 7 mm, no restoration (n = 5).
Group 4: Experimental group: 3-mm composite (n = 15).

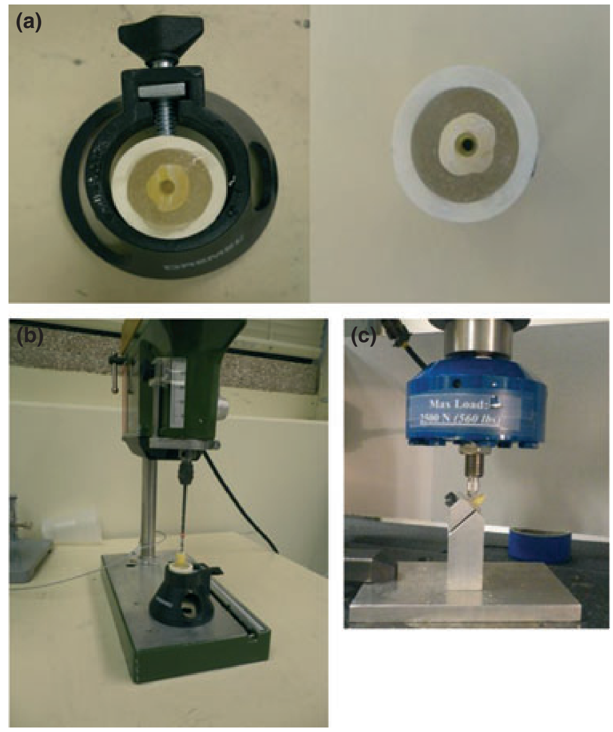

Fig. 1. (a) Teeth were mounted vertically in clear orthodontic resin inside a half-inch diameter PVC ring 2 mm apical to the facial CEJ to simulate the relation between the tooth and bone. (b) A twist drill was used to extend the preparation 3 and 7 mm below the facial CEJ to simulate Cvek's stage 3 of root development. (c) Fracture resistance was performed on an Instron machine at 130° to the long axis of the tooth.

Group 5: Experimental group: 3-mm quartz fiber post (n = 15).
Group 6: Experimental group: 7-mm composite (n = 15).
Group 7: Experimental group: 7-mm quartz fiber post (n = 15).

Groups 1–3 were the controls and used only five teeth each to obtain the baseline results to compare the data with the experimental groups. Groups 4–7 were etched for 30 s and rinsed with water. Optibond (Kerr Corporation, Orange, CA, USA) was placed, thinned with air, and then light-cured for 20 s. The quartz fiber post (DT Light posts, size 3) (Bisco Dental, Schaumburg, IL, USA) in groups 5 and 7 was measured and trimmed with a diamond disk, and then cemented with a dual-cure composite resin build-up material (Biscore; Bisco Dental). Groups 4 and 6 were restored completely with the same dual-cure resin. Finally, the dual-cure composite was used to seal the access.

Fracture testing

Specimens were stored at 37°C in 100% humidity until testing. Fracture resistance was performed (14) on an Instron machine (Instron, Norwood, MA, USA) at 130° to the long axis of the tooth with a chisel-shaped tip at the cingulum with a cross-head speed of 5 mm min^{-1} (Fig. 1c). The maximum load at which the samples fractured was recorded in newtons (N).

Statistical analysis

SigmaPlot 11.0 (Systat Software, Inc. San Jose, CA, USA) was used for all the statistical testing. Data were analyzed by one-way analysis of variance (ANOVA) to determine differences among treatments, with further pairwise multiple comparisons made with the Tukey post hoc test. Differences with P values (*) < 0.05 were considered significant.

Results

The mean fracture values for all groups are shown in Table 1. The control group had fracture strength of 1665 N. The mean fracture strengths for the 3-mm composite and post group were similar at 1442 N and 1415 N, respectively. However, as the lengths increased to 7 mm, the fracture values decreased. The mean fracture values for 7-mm composite and post group were also similar at 1033 N and 1086 N, respectively. The results demonstrated that the 3-mm composite group showed better results than any of the experimental groups. However, none of the groups were close to the negative groups.

Table 2 lists the failure patterns of the different groups. As can be seen from the results, the teeth that had posts failed, but the fragments did not separate, which was possibly because the posts held the fragments together.

Table 3 lists the comparison between the various experimental groups and the negative control (group 1). All groups were statistically different from the positive controls, groups 2 and 3 (data not shown). There were statistically significant differences between the control group and the 7 mm experimental groups. Furthermore, as can be seen from Table 3 and Fig. 2, the differences between the 3 mm and the 7 mm groups were also significant (0.015 and 0.047 for the composite and the post groups, respectively). This demonstrated that the 3 mm group had higher fracture resistance compared to the 7 mm group.

Table 1. Mean fracture values for all groups measured in Newtons along with their standard deviations

Group	*N*	Characteristics	Mean ± SD (*N*)
1	5	Negative Control	1665 ± 467
2	5	Positive control 3 mm	725 ± 257
3	5	Positive control 7 mm	738 ± 269
4	15	3-mm composite	1442 ± 369
5	15	3-mm post	1415 ± 307
6	15	7-mm composite	1033 ± 350
7	15	7-mm post	1086 ± 195

Table 2. Typical failure patterns of the different groups

Group	Characteristics	Typical failure pattern
1	Negative control	Across the acrylic
2	Positive control 3 mm	Across the acrylic
3	Positive control 7 mm	Across the acrylic
4	3-mm composite	Across acrylic/through composite, or 3 mm below CEJ
5	3-mm post	Failed, but segments did not separate
6	7-mm composite	Across acrylic/through composite
7	7-mm post	Failed, but segments did not separate

Table 3. Comparison between the various experimental groups and the negative control (group 1)

Comparison	*P*-value
Control (Group 1) vs 3-mm composite	0.744
Control (Group 1) vs 3-mm post	0.656
Control (Group 1) vs 7-mm composite	0.009*
Control (Group 1) vs 7-mm post	0.021*
3-mm composite vs 3-mm post	0.913
7-mm composite vs 7-mm post	0.993
3-mm composite vs 7-mm composite	0.015*
3-mm post vs 7-mm post	0.047*

**P*-value of < 0.05 was considered significant.

Discussion

Fracture of teeth with incompletely formed dentin walls/roots is a major concern after endodontic and restorative procedures are completed. A number of previous studies have concentrated on increasing fracture resistance of teeth using various techniques. Some studies evaluated the fracture strength of immature incisors after using different obturation materials and fiber posts (2). Others have shown that flowable composite and hybrid composites increase fracture resistance compared to gutta percha and Resilon (16–18). Goncalves et al. (19) used a technique to cure various composite resins with a translucent curing post and then cemented a titanium post in place of the curing post. They found that this technique significantly increased the fracture resistance of weakened roots to the level of the post. Hence, our study looked at two different methods of restoration with either a composite resin alone or a quartz fiber post placed with composite resin. Based on the data obtained, we can reject the null hypothesis,

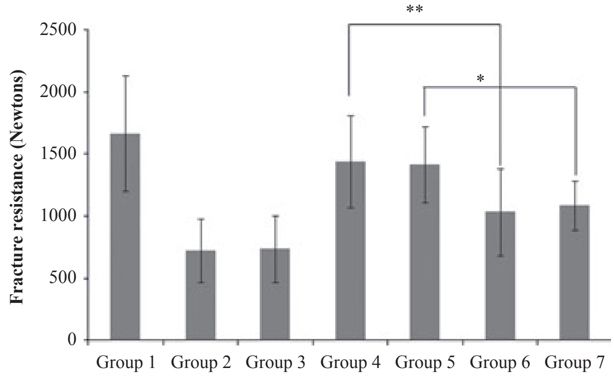

Fig. 2. demonstrates the average load to failure in newtons (N) for all the groups with 95% confidence intervals. Differences between groups 4 and 6 and groups 5 and 7 that were statistically different are shown in the figure at $P \leq 0.05$ (** and * respectively).

because the results demonstrate that the presence of the quartz fiber post had no effect on the fracture resistance of immature maxillary anterior teeth. The findings of this study are most similar to those of Carvalho et al. (20) where they compared composite cured with a transilluminating posts to cosmopost zirconium fiber posts in simulated immature bovine incisors. They concluded that the light-cured composite resin exhibited the same resistance to fracture as the cemented zirconium fiber post, and these groups were better than the control groups. The use of the quartz fiber post in the current study can be best attributed to the similar modulus of elasticity between the quartz fiber post and the dual-cure composite resin. Chuang et al. (21) noted that composite resin cores (7 GPa) with quartz fiber posts (11 GPa) have similar elastic modulus to dentin (18.6 GPa).

The depth of post placement in mature teeth has been studied extensively *in vitro*, with studies either favoring the placement of longer posts or showing no difference in post length (21–24). Büttel et al. (25) found that longer posts exhibited higher fracture resistance, but post fit did not have a significant effect. Cecchin et al. (13) investigated the length of fiber post placement in sheep incisors that were standardized to 17 mm, at depths of 4, 8 and 12 mm. They concluded that a post length of 8 mm, which was slightly over half the length of the tooth, was ideal because it did not remove excessive tooth structure. Based on the results from that study, we tested the 7 mm depth in our study, which was also slightly over half the length of the tooth and the 3 mm depth according to Hemalatha et al. (14), both to simulate Cvek's stage 3 of root development (15). Furthermore, some previous studies have looked at these different post lengths but did not compare the composite with fiber posts in immature teeth (13, 25). The teeth used in this study were not obturated prior to placing the posts or restorations as previous publications showed no increase in fracture resistance of the obturated teeth (14).

The results demonstrated that there was no difference in the fracture resistance of the unrestored 3 and 7 mm negative controls, but both the 3 mm restored groups had a significantly higher fracture resistance than both the 7 mm groups. One explanation for this could be the fact that posts changed dentin stress considerably under compression (26) and that the highest stress concentration was associated with the apical termination of the post (27). Another logical explanation for immature teeth could be that because the root is thinner apically, the presence of restorative material simply distributed the forces to the thinner areas, which is in contrast to fully formed roots.

Furthermore, the composite resin groups performed better than the post group although these differences were not statistically significant. The presence of a quartz fiber post did not significantly affect fracture resistance compared to dual-cure composite resin. It has been previously shown that roots reinforced with composite posts and restorations had more resistance as compared to the group without any root reinforcement (28). Based on these findings, dual-cure composite resin or quart fiber posts placed 3 mm apical to the CEJ impart greater resistance to fracture in simulated immature maxillary anterior teeth than those 7 mm apical to the CEJ, but all four experimental groups performed better than the positive controls, which were left unrestored. Hence, clinicians could use either composite resins or quartz fiber posts with composite resins up to 3 mm as methods to restore immature teeth.

These findings are novel and in contrast to prior conclusions for mature teeth, which have thicker dentin walls and completely formed roots. Based on the results from this study, it could be concluded that after revascularization or apexification procedures are performed, the clinician could restore these teeth with a composite restoration or a fiber post with resin to a depth of 3 mm. Another important consideration, which may be especially useful in immature teeth, in children, is the ease of delivery of restorative material in which case again the clinician could use only a dual-cure composite or a post with composite to 3 mm to increase the fracture resistance.

Conclusions

Within the limitations of this study, it can be concluded that using either dual-cure composite or a quartz fiber post with composite resin to a depth of 3 mm would significantly strengthen the roots in immature teeth. This methodology could be specifically recommended for immature teeth that have excessively thin and weakened dentinal walls and would need some type/method of reinforcement to prevent fractures.

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