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Load Capability of Excessively Flared Teeth Restored with Fiber-reinforced Composite Posts and All-ceramic Crowns

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Clinical Relevance

The fracture resistance of excessively flared endodontically-treated teeth (ETT) without ferrule preparation is not acceptable. Adhesively luted FRC posts with 2 mm ferrule are recommended.

SUMMARY

This investigation evaluated the stabilizing effect of glass fiber reinforced posts (FRP) luted with self-adhesive universal cement on the fracture resistance of excessively flared endodontically treated teeth (ETT). Values were compared to teeth with no ferrule, 2 mm ferrule and resin cement for luting with 2 mm ferrule.

Thirty-two caries-free maxillary central incisors were randomly assigned to 4 groups (n=8) and endodontically treated. Two groups were flattened 2 mm above and 2 groups at the cemento-enamel junction (CEJ). The teeth received FRPs as follows: 1) post was cemented with self-adhesive cement (RelyX Unicem, 3M ESPE) (U), no ferrule (F) was prepared, root canal entrance was excessively flared with a remaining wall thickness of 0.5 – 0.75 mm (UNF/flared); 2) post was cemented with U, no F was prepared; 3) post was luted with U, F was prepared; 4) post was cemented with a resin cement (Panavia F, Kuraray, Japan), F was prepared. All specimens were built-up using a resin composite (Clearfil Core, Kuraray). All-ceramic crowns were adhesively luted (U). Specimens were exposed to thermo-mechanical loading and statically loaded until failure.

The mean fracture load values [N](SD) were: UNF/flared=68 (126); UNF=315 (136); UF=488 (72); PF=860 (190). All groups exhibited statistically significant differences regarding maximum fracture load (*p*<0.05).

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INTRODUCTION

The restoration of a tooth with excessively flared root canal entrances is clinically problematic with an endodontically-treated tooth (ETT). Flaring might be attributed to immature development of the root, serious structural damage by carious lesions, previous restoration with large post diameters or over-instrumentation during root canal treatment.[1] The fundamental importance of preserving the remaining tooth structure to provide strength and resistance to fracture after both endodontic therapy and post-space preparation has been previously reported.[2-3] Dentin wall thickness is stated to be directly proportional to the ability to withstand lateral forces.[4] Simulated immature teeth with excessively enlarged access cavities received a strengthening effect by using resin-modified glass ionomer cements and resin composite with and without cast posts and cores or prefabricated posts.[1,5-7] A relation of fracture load capability and the remaining buccal dentin thickness, in combination with endodontic posts, was described: 1 mm of remaining buccal dentin was judged to be inferior in terms of fracture resistance under horizontal impact to 2 or 3 mm dentin walls.[8-9] An additional metal collar in case 1 mm of dentin thickness remained and did not enhance the resistance to root fracture.[8] More than a 1-mm thickness of the buccal dentin wall on the level of the post channel is required to prevent root fracture, so that the addition of a 2 mm dentin ferrule improves fracture resistance.[9] While the presence of a 1.5- 2.0 mm ferrule preparation is well proven,[10] the importance of uniformity in ferrule height and configuration was recently stressed.[11] It is also important to consider the remaining dentin thickness. Under structurally weakened conditions, such as 1 mm or less of remaining dentin, a ferrule did not provide additional benefit for fracture resistance with adhesively luted posts.[1,9]

All of the above-mentioned studies, using root canal treated maxillary central incisors, were compressively loaded until failure; however, no clinical simulation in terms of fatigue was carried out. The benefit of glass fiber reinforced composite (FRC) posts, in combination with self-adhesive resin cement or well-suited resin cement, was not investigated to date. Therefore, this study was initiated to evaluate load capability of non-ferruled, thin-walled maxillary central incisors—teeth without compromised wall thickness and no ferrule preparation or teeth with ferrule preparation using self-adhesive cement. A well-tried resin material for the luting of endodontic posts served as the positive control in ferruled teeth. All teeth were restored with all-ceramic crowns and were subjected to thermo-mechanical loading (TML).

The null-hypothesis was that there would be no difference in load capability, irrespective of the remaining dentin thickness, ferrule preparation or luting cement used.

METHODS AND MATERIALS

The methodology of specimen preparation and loading was adopted from Butz and others.[12] Thirty-two caries-free, undamaged human maxillary central incisors were divided into 4 groups (n=8) on the basis of cervical size. To ensure an even size distribution within groups, mesio-distal (MD) and facial-lingual (FL) dimensions were measured at the level of the cemento-enamel junction (CEJ). A size assessment value was calculated from the product of MDxFL. Teeth of extreme size were excluded, and specimens were randomly distributed into test groups (Figure 2). All teeth were stored at room temperature in a 0.1% thymol solution. Root canals were enlarged to #60 (Antaeos, VDW, Munich, Germany) and rinsed with 2.5% sodium hypochlorite. Root canals were filled by lateral condensation with gutta-percha (Roeko, Langenau, Germany) and a sealer (AH 26, De Trey, Constance, Germany). The clinical

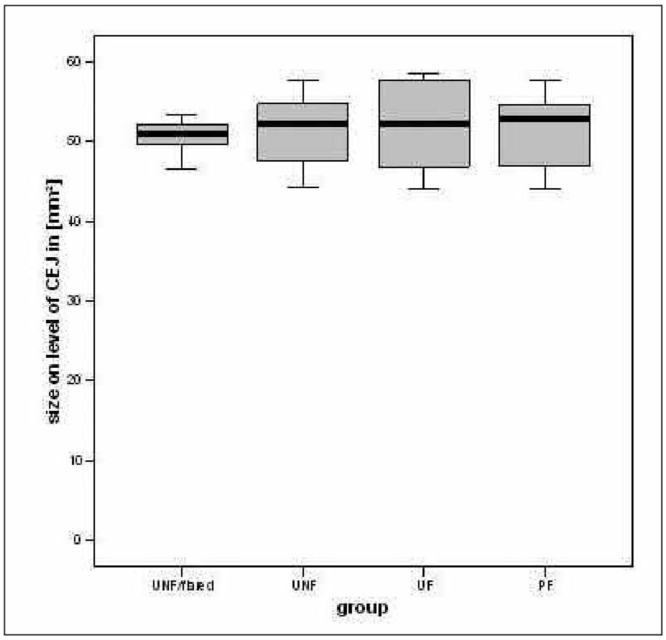

Figure 2: *Even distribution of tooth size among test groups, size was calculated from the product of mesio-distal and facial-lingual dimensions at the level of CEJ.*

Table 1: *Materials Used for Specimen Preparation (FRC=Fiber Reinforced Composite)*

Group	n	Post	Luting Material	Build-up [mm]	Ferrule	Crown Material
UNF/Flared	8	Glass FRC	Unicem	composite	0	All-ceramic
UNF	8	Glass FRC	Unicem	composite	0	All-ceramic
UF	8	Glass FRC	Unicem	composite	2	All-ceramic
PF	8	Glass FRC	Panavia	composite	2	All-ceramic

crowns of 2 groups were cut 2-mm coronal to the CEJ, and the remaining 2 groups were cut at the incisal border of the proximal CEJ.

The canal spaces of UNF/flared specimens were enlarged by removing the internal dentin to a depth of 5 mm. Residual dentin wall thicknesses of 0.5 to 0.75 mm[1] were ensured. In all groups, gutta-percha was removed (Gates-Glidden-burs), leaving at least 4 mm apically. The root canal was prepared with a tapered drill 1.4 mm maximum in diameter (Fiberpoints Root Pins post kit, Schuetz-Dental, Rosbach, Germany) to achieve an intraradicular post length of 8 mm. The root canals and tooth surfaces were cleaned with an airborne particle abrasion system (DentoPrep, Aluminium Oxide Microblaster, Rønvig, Danmark and Cojet, 3M ESPE, Seefeld, Germany). With the exception of Group PF, all specimens received glass fiber reinforced posts (Fiberpoints Root Pins Glass, diameter 1.4 mm, length 13 mm, Schuetz-Dental) luted with a self-adhesive resin cement (RelyX Unicem, 3M ESPE). Light curing was performed for 2 seconds (Optilux light curing unit, Demetron Research Corp, Danbury, CT, USA). The remaining space between the post and canal wall of the group UNF/flared was filled with self-adhesive cement. Excess material was removed, and final light curing was performed for 1 minute.

Coronal specimen surfaces were etched for 15 seconds with 35% phosphoric acid (Panavia etching agent; Kuraray Europe, Duesseldorf, Germany) and rinsed. Composite cores (NewBond, Kuraray Europe; Clearfil Core, Kuraray Europe) were built up. In the PF group, the canals were preconditioned with a self-etching primer (ED-Primer, Kuraray, Osaka, Japan). The posts were cemented as per the manufacturer's instructions with dual curing resin cement (Panavia F, Kuraray Europe). Excess bonding material was removed, and the composite cores were built up as described above.

Specimens were prepared with a circumferential 1.2 mm shoulder to meet all-ceramic crown requirements. Preparation of the UNF/flared and UNF group ended at the finishing line directly on the level of the composite build-up. Specimens from groups UF and PF received a finishing line that ended 2 mm below the composite build-up in dentin to ensure an appropriate dentin ferrule.

With the help of a silicone mold, 32 similar crowns were fabricated from an all-ceramic material (Empress II, Ivoclar-Vivadent, Schaan, Principality of Liechtenstein). The crowns were adhesively luted with self-adhesive universal cement that was partly used for the post cementation described above (RelyX Unicem) according to the manufacturer's instructions. Table 1 gives an overview of the materials used.

All specimens were blocked out with wax 2 mm below the finish line to imitate biologic width. To simulate human periodontium, the roots of the teeth were covered with a 0.1 mm thick layer of autopolymerizing silicone (Anti-Rutsch-Lack; Wenko, Wensselaer, Germany).[12-13] The teeth were embedded in autopolymerizing acrylic resin (Technovit 4000, Kulzer, Wehrheim, Germany), orienting their long axes facially 135° from the horizontal (Figure 1). To prevent overheating, the teeth were submerged in water for 5 minutes during resin polymerization.

A 5-year period of service was simulated by TML (parameters: 6,000 thermal cycles [5°C/55°C, 2 minutes each cycle, H_20 dist] and 1.2 x 10^6 mastication cycles at an angle of 135° as described above).[14] A 50N force was applied 3 mm below the incisal edge on the palatal surface of the crown. After TML, the specimens were loaded in a universal testing machine (Zwick, Germany; crosshead speed of 1 mm/minute) until fracture occurred. Failure was defined as 10% loss of the maximum applied force. To reduce excessive stress concentrations, tin foil 0.3 mm thick was positioned between the steel piston and the crown. For all teeth, fracture load and fracture patterns were recorded.

Statistical Analysis

A non-parametric Kruskal-Wallis test was applied, followed by the Mann-Whitney test as post-hoc test, to study statistical differences in the maximum load capacity F_{max} between groups. To test differences in mode-to-fracture between groups, the Chi-square test was applied. All tests were 2-sided. The significance level was adjusted to α=0.05.

RESULTS

The results of the load test after TML and data describing the residual dentin thickness and root size responsible for group assessment of the specimens are displayed in Table 2. The even distribution of tooth size is also displayed in Figure 2. Six specimens of the UNF/flared group and 1 specimen of the UNF group did not survive TML. For further analysis, the maximum load capability F_{max} of these specimens was set as 0N. Excessively flared specimens without a ferrule showed the lowest values of F_{max}. Specimens without a ferrule preparation but unaffected residual dentin wall thickness achieved lower load capability with higher standard deviations than the ferrule-supported teeth of group UF. Specimens with posts having been inserted with conventional resin cement statistically reached the highest values (p<0.05), with almost twice the mean values of UF and values approximately 13 times higher than the UNF/flared group, with standard deviation being the highest observed for all groups. Statistical analysis using the Kruskal-Wallis test revealed significant differences between groups (p=0.001). Figure 2 shows the results of statistical analysis with the Mann-Whitney test as post-hoc analysis.

Table 2: *Root Size and Length; Load Values of Load Testing After TML and Failure Mode Observed*

Group	n	Residual Dentin* Minimum/Maximum [mm]		Root Size* (SD) [mm²]	TML Failure	Mean (SD) F_{max} [N]	Restorable Failure	Catastrophic Failure
		Palatal	Facial					
UNF/flared	8	0.5/0.75	0.5/0.75	50.7 (2.2)	6	68 (126)	8	0
UNF	8	2.4/2.9	2.5/3.5	51.4 (4.7)	1	315 (136)	4	4
UF	8	1.3/2.6	3.1/4.5	52.5 (6.2)	0	488 (72)	2	6
PF	8	2.3/3.1	2.5/3.6	51.4 (5.0)	0	860 (190)	3	5

*on CEJ-level

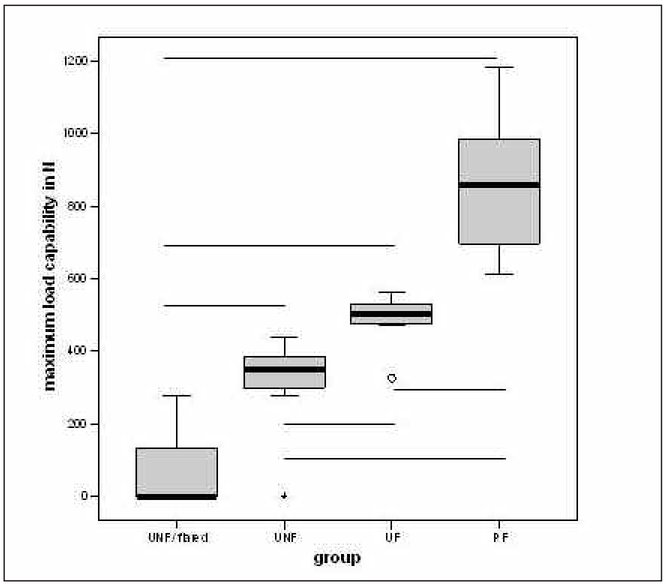

Figure 2: *Box plots of fracture load testing (median, 25th and 75th percentiles), continuous line mark statistical differences between the groups (p<0.05).*

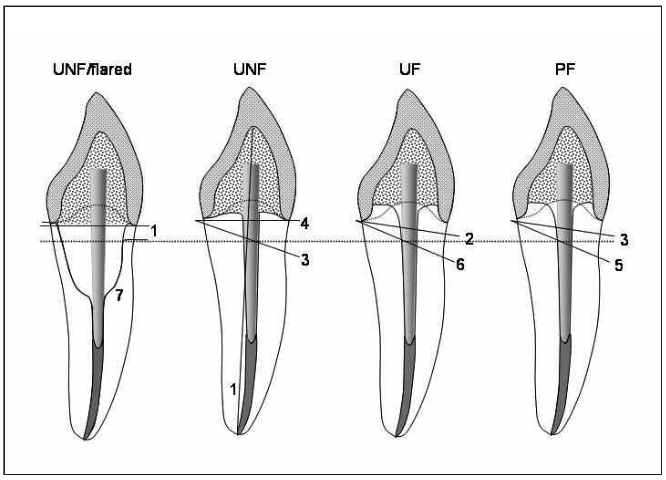

Figure 3: *Numbered lines display fracture patterns and frequencies after thermo-mechanical and linear loading, fracture lines below the dotted line were judged as catastrophic and thus non-restorable.*

All specimens from the UNF/flared group and 4 specimens from group UNF fractured restorable, that is, they allowed for re-restoration. The combination of the ferrule and unaffected remaining dentin wall led to a majority of catastrophic failures. This failure judgement is recorded in Table 2. Nearly all (7) specimens from the UNF/flared group failed by loss of retention, as adhesive failure of the adhesively placed post and core unit. One specimen in the UNF group suffered vertical root fracture. Detailed information on fracture patterns is listed in Figure 3. Chi-square analysis of the type of failure, in terms of possibility of re-restoration, revealed statistical differences between groups (p=0.015).

DISCUSSION

This study investigated the potential of self-adhesive resin cement to stabilize a tooth with a thin-walled, excessively flared root canal access without ferrule support, compared to teeth with unaffected remaining dentin walls with and without ferrule preparation. Well-suited resin cement served as the positive control.

It could be shown that there is a significant impact on the remaining dentin wall thickness and the presence of a ferrule preparation on load capability. The load capability of conventional resin cement, which served as the control, was significantly higher than that of all other groups. The type of resin cement seems to have a substantial impact on load capability. However, only the combination of ferrule and adhesively luted posts, irrespective of the type of resin cement, revealed clinically acceptable mean values for the load capability of restored ETT.

Previous investigations describe a strengthening effect compared to a negative control; however, since there is no clinical parallel, these findings are not helpful to the clinician. Due to the fact that no previous investigation performed a 5-year simulation of clinical function by chewing simulation,[15] there is no comparison, since static compressive loading might imply different conclusions than chewing simulation.[16] Although a strengthening effect of adhesive post cementation is described,[17] and the potential of the self-adhesive cement to effectively bond to dentin and root dentin recently was proven,[18-19] maximum load values of flared specimens with remaining dentin walls <1 mm were far beyond values having been clinically observed.[20] This inferior result may be expected, since the space between the post and canal wall is large and might therefore overstress the luting system in terms of high polymerization stresses. The C-factor, defined as the ratio of bonded to unbonded adhesive surface,[21-22] is also unfavorable. The calculated value of the C-factor in a prepared root canal is 200.[23] It was previously speculated that a coronally well-fitting post is of paramount importance and may help minimize clinical failures.[24] The amount of surrounding hard tissue as a crucial aspect was already addressed.[25-30] The maximum load capability is affected by the strength of the surrounding hard tissue, which is directly correlated to its amount. A complete dislocation of the post-core-crown complex was frequently observed during chewing simulation. This observation indicates that teeth will not even withstand normal function under subcritical mastication forces. Although all failed teeth were restorable, a repeated restoration would not make sense. In excessively flared teeth, the ferrule concept is impossible, since ferrule preparation always causes even more loss of the remaining circumferential dentin. Nevertheless, the treatment approach under investigation is not clinically recommended; therefore, alternative techniques, such as incremental resin composite application with or without post, should be considered for further analyses.

To compare load values of thin-walled teeth, specimens with unaffected dentin wall thickness and without ferrule support were loaded. The restoration by FRC posts and self-adhesive cement without ferrule support increases the risk of early failure during function. However, in contrast to excessively flared teeth, maximum load capability of unferruled restorations might be clinically sufficient for patients without any history of heavy bruxism.

Comparing the load values of non-flared, unferruled with ferruled specimens repeatedly highlights the importance of the ferrule effect. However, ferrule might be only one of the key elements in the reconstruction of ETT.

The use of Panavia F resin cement for luting of FRC posts dramatically increased load capability. This observation is not explainable by the amount of remaining hard tissue alone. The remaining facial dentin thickness might be of special interest, since it is compressively loaded. Considering maximum and minimum values of the facial dentin thickness as extreme values, the resin group had even weaker roots than specimens in the self-adhesive universal resin test group. Thus, the impact of the type of resin cement is clearly obvious. However, in the ferruled groups, both cements showed a load capability above the clinically observed level of 370 N.[20]

This study indicates that further research is needed to develop an optimal luting material in conjunction with endodontic post cementation under unfavorable conditions of the root canal.

CONCLUSIONS

Flared unferruled teeth restored with FRC posts luted with self-adhesive cement and covered by all-ceramic crowns did not reveal a load capability that could be recommended for clinical use. Treatment alternatives should be taken into consideration.

The type of luting resin cement for endodontic posts seems to have a remarkable impact on the fracture capability of ETT.

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