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Composite Resin Core Buildups With and Without Post for the Restoration of Endodontically Treated Molars Without Ferrule

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Clinical Relevance

When restoring endodontically treated molars without ferrule, the use of a post must be questioned and may be substituted by the selection of improved buildup materials.

SUMMARY

Objective: The aim of this study was to investigate the restoration of highly damaged, broken-down endodontically treated molars without the ferrule effect using glass ceramic crowns on different dual-cure composite resin core buildups.

Methods and Materials: Thirty (N=30, n=15) decoronated, endodontically treated teeth (no ferrule) were restored without a ferrule with a direct buildup using the dual-curing composite Multicore HB (group MHB) or the dual-curing composite core buildup Multicore Flow in combination with glass-fiber–reinforced composite post (FRC post; group MFP). All teeth were prepared to receive bonded glass ceramic crowns (Empress CAD luted with Variolink II) and were subjected to accelerated fatigue testing. Cyclic isometric loading was applied to the palatal cusp at an angle of 30 degrees and a frequency of 5 Hz, beginning with a load of 200 N (×5000 cycles), followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until failure or to a maximum of 185,000 cycles. Groups were compared using the life table survival analysis (log rank test at *p*=0.05). Average fracture loads and number of survived cycles were compared with one-way analysis of variance (Scheffé post hoc at *p*=0.05). Previously published data from the same authors about core buildups made of

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high-performance polymers (group HPP, n=15) and light-curing composite resin without FRC posts (group TEC, n=15) and with FRC posts (group TECP, n=15) using the same experimental setup were included for comparison.

Results: None of the tested specimen withstood all 185,000 load cycles. There was no significant difference in mean fracture load (p=0.376), survived cycles (p=0.422), and survival (p=0.613) between MHB (facture load 859.4 N±194.92) and MFP (796.13 N±156.34). Group HPP from a previous study appeared to have significantly higher performance than all other groups except MHB. All groups with posts were affected by an initial failure phenomenon (wide gap at the margin between the buildup/crown assembly and the root).

Conclusions: HPP and MHB enhanced the performance of all-ceramic leucite-reinforced glass ceramic crowns, and insertion of a fiber-reinforced composite post was not influential when using other materials.

INTRODUCTION

Severely damaged and endodontically treated teeth (ETT) offering only a minimal "ferrule" represent such a challenge in clinical practice that clinicians are tempted to not restore them and rather to rely on implant-supported restorations instead.[1-3] A number of clinicians and patients, however, still have preferences and convictions geared toward preserving the original root and periodontal ligament in order to avoid or postpone more invasive surgical procedures.

Improving the prognosis of restored ETTs requires understanding their biomechanical properties and behavior. Clinically relevant physical properties of dentin do not seem to be affected by root canal treatments.[4,5] However, structural defects of a tooth's hard tissue caused by decay or tooth preparation lead to an increased risk of fracture of ETTs.[6,7] In this context, it could be shown that an endodontic access cavity (removal of the pulp roof), combined with the loss of the marginal ridges (MOD preparation) as important static parameters, result in maximum tooth fragility.[8] According to former traditional prosthodontic techniques, it was generally necessary to retain nonadhesive indirect core buildups by the placement of an indirect cast endodontic post.[9] Unfortunately, this often resulted in further loss of healthy tooth structure.

Today, advanced adhesive procedures are allowing practitioners to save and stabilize valuable tooth structure through bonded composite resin buildups.[10] Posts are still being advocated in combination with adhesive buildups,[11] among which fiber-reinforced posts seem to be the most popular.[12] Although there are attempts to classify the indications for posts, considering important factors, such as crown height, wall thickness, circumferential integrity, and diameter and shape of the canal,[13] there is still no general consensus about the indications for post placement. On the contrary, it has to be questioned whether the technique-sensitive procedure of post placement is worth the risks. For example, for endodontically treated molars with two- and one-wall defects restored with indirect composite resin onlays, the insertion of a fiber post did not increase fracture resistance.[14] Moreover, the removal of natural dentin during the preparation of the root canal for the post seems to reduce the fracture strength of the tooth.[15] Therefore, the main goal for any treatment—and even more so for severely broken-down teeth—must be to preserve as much dental hard tissue as possible. Of special importance is the conservation of cervical tissue to create a ferrule effect, which seems to be crucial to optimize the biomechanical behavior of the restored tooth.[12] As the ferrule effect has proven to generally increase fracture resistance, currently a minimum ferrule of 1 mm is considered necessary to stabilize the restored tooth.[16]

Severely broken-down teeth, however, do not always offer enough tooth structure to create a ferrule effect. It is therefore fitting to investigate other elements (eg, the use of a post and the buildup material itself) that could compensate for the absence of a ferrule. Composite resins, either light-cured or dual-cured, are commonly used with or without posts. The group of dual-cured materials can be further categorized into more viscous (paste-like) or more flowable ones with very distinct material properties. It was demonstrated that the performance of all-ceramic crowns is influenced by the elastic modulus of the core buildup.[17] Previous data by the present authors (same operator in strictly identical conditions) also showed that computer-aided design and computer-aided manufacturing (CAD/CAM) buildups without posts and made from high-performance polymers (HPP) can enhance the load-bearing capacity and survival of all-ceramic crowns. The question remains whether a highly filled dual-cure buildup material used

Table 1: *Overview Over Properties of Materials for Core Buildups*

Parameter	Experimental HPP	Tetric EvoCeram	Multicore HB	Multicore Flow
Matrix	Dimethacrylates	Bis-GMA, UDMA, ethoxylated Bis-EMA	Dimethylacrylates	Dimethylacrylates
Matrix (wt%)	22.0	16.8	13.5	28.1
Filler	Barium glass fillers (15%), Ytterbium trifluoride (9%), Mixed oxides (44%), Siliciumoxide (3%), Copolymer (7%)	Barium glass fillers, ytterbium trifluoride, Mixed oxides	Barium glass fillers, Ba-Al-fluorosilicate glass, highly dispersed silicon dioxide, ytterbium trifluoride	Barium glass fillers, Ba-Al-fluorosilicate glass, highly dispersed silicon dioxide, ytterbium trifluoride
Filler content (wt%)	78	48.5	86.1	71
Prepolymers		34.0		
Flexural strength (MPa)	167	120	140 (dual curing)	135 (dual curing)
			125 (self-curing)	120 (self-curing)
Flexural modulus	11,400	10,000	18,000 (dual curing)	9000 (dual curing)
			14,000 (self-curing)	7500 (dual curing)
Compressive strength (MPa)	n.n.	250	250	250
Vickers hardness (MPa)	915	580	1000 (dual curing)	510 (dual curing)
Water absorption, 7 days (μg/mm^3)	28	21.2	14.5 (dual curing)	25 (dual curing)

without a post can compete with a flowable material in combination with a glass-fiber–reinforced composite (FRC) post.

The aim of the present study was to investigate the restoration of broken-down endodontically treated molars without the ferrule effect using glass ceramic crowns onto two different core buildups: a core buildup using no post from a high-viscosity and elastic modulus dual-cure material (Multicore HB [MHB]) and a core buildup from a flowable dual-curing composite with the use of a fiber-reinforced post (Multicore Flow+FRC post [MFP]). The null hypotheses were 1) that MHB core buildup would not lead to different fatigue strength of all-ceramic crowns compared to the MFP core buildup and 2) that dual-cure MHB and MFP buildups would not yield different results compared to CAD/CAM HPPs and light-cured composite resin buildups (with or without posts). Previously published data by the same authors using an identical experimental setup were used to test this second hypothesis.[18]

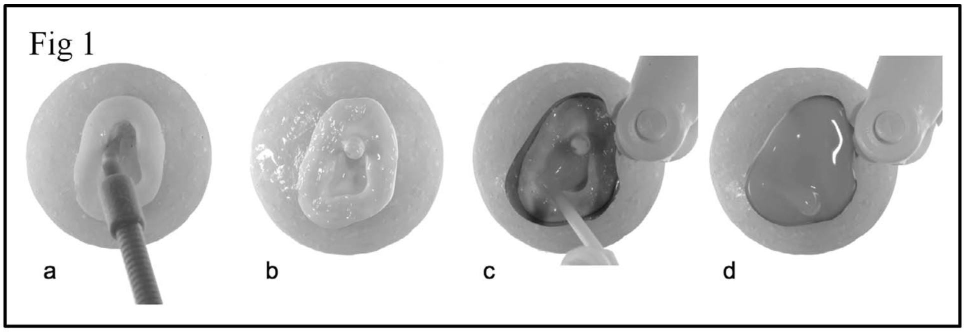
METHODS AND MATERIALS

On approval from the Ethical Review Committee of the University of Southern California, (Los Angeles, CA, USA) and the Ludwig-Maximilians University (Munich, Germany), 30 maxillary third molars were collected. In order to evenly distribute the teeth according to their size and shape, all specimens were organized by the randomly reassigned multiplets (RRM) principle in two groups of 15 teeth, as described elsewhere.[18] All teeth were mounted up to 2.0 mm below the cemento-enamel junction (CEJ) into acrylic resin, and standardized defects were generated by removing the clinical crown horizontally down to 1 mm above the CEJ. The pulp chamber was opened, and root canals were cleaned and shaped using the stepback technique (maximum file 35) and then partially filled and covered by glass-ionomer cement (Ketac Molar, 3M ESPE, Seefeld Germany) up to 1.5 mm below the level of the occlusal reduction.

Teeth from group MHB were restored with a direct buildup using the dual-curing composite Multicore HB (Ivoclar Vivadent, Schaan, Liechtenstein) In group MFP, an FRC post system was applied before the core buildup was carried out using the dual-curing composite Multicore Flow (Ivoclar Vivadent). The properties of the two resin materials are presented in Table 1. The detailed procedures to create the different core buildups are described below.

Group MHB: Conventional Core Buildup With Dual-Cure Composite Resin

Following 10-15 seconds of dentin and 30 seconds of enamel etching with 37% phosphoric acid (Total Etch, Ivoclar Vivadent), the Syntac adhesive system was applied according to the manufacturer's recommen-



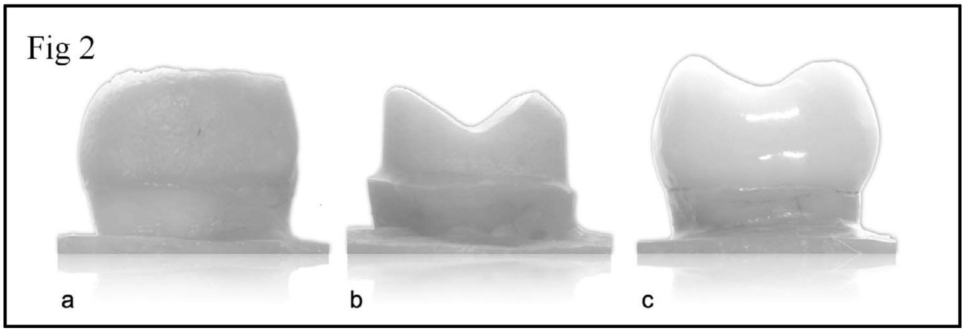


Figure 1. *Group MFP. (a and b): Placement of post (FRC post with Multilink Automix) and application of Multicore Flow (c and d) using a Tofflemire matrix.*

Figure 2. *(a): Core buildup with Multicore HB. (b): Standardized preparation for full ceramic crown. (c): Standardized glass ceramic crown adhesively luted on tooth.*

dations. The base and the catalyst paste of MHB were mixed with a spatula on a mixing pad at a ratio of 1:1. The material was cautiously kneaded to avoid air inclusions before the material was applied in bulk to the tooth and shaped slightly larger than the desired core dimension. Each surface was light cured for 60 seconds (20 seconds per surface, three times; 1000 mW/cm^2; Allegro, Den-Mat, Santa Maria, CA, USA).

Group MFP: Core-Buildup With Dual-Cure Composite Resin (Multicore Flow) and FRC-Post (FRC Postec Plus)

A glass-fiber–reinforced post (FRC Postec Plus System, Ivoclar Vivadent) was placed in the palatal root according to the manufacturer's recommendations. The post space was prepared (~10 mm deep measured from the defect surface) with the FRC Postec Plus Reamers at 1000-5000 rpm for a post size of 1 (white; 0.7mm). The post was tried in and checked for proper fit and then cut 3 mm above the defect surface and cleaned with phosphoric acid etching gel for 60 seconds, rinsed with water, and dried before applying silane-containing coupling agent (Monobond Plus, Ivoclar Vivadent) for 60 seconds (Figure 1).

The manufacturer of the post system recommends the application of Multilink-Automix in combination with the FRC-Postec as a system. Primers A and B were mixed at a 1:1 ratio and applied for 15 seconds into the root canal and on the prepared tooth surface by scrubbing with light pressure. The excess was removed with a strong stream of air and paper points. Multilink Automix was applied to the post, and the post was rotated to its final position. The excess of Multilink Automix was strategically dispensed over the prepared and primed surface of the tooth and light cured for 20 seconds. A Tofflemire matrix was placed, and the dual-cure core buildup material Multicore Flow was injected to fill the matrix space and light cured for 40 seconds. After 5 minutes, the matrix was removed, and further light polymerization was applied to each surface for 60 seconds (20 seconds per surface, three times).

Preparation for Glass Ceramic Crowns

All teeth were prepared to receive a standardized full anatomic glass ceramic crown: occlusal clearance of 2.0 mm, circumferential reduction of 1.0 mm with an axial convergence taper of 12 degrees (no ferrule), and preparation height of 7.0 mm from the level of the embedding resin to the cusp tips and 5.0 mm at the central groove (Figure 2).

Manufacturing of Glass Ceramic Crowns

A standardized full anatomic crown in the form of a simplified maxillary molar with three cusps was designed using the Cerec system. The CEREC database was used, and adjustments were made for each individual tooth in order to obtain specific dimensions of the crowns: 1.5 mm at the central groove, 2.0 mm at cusp tips, and 1.0 mm of circumferential thickness. Restorations were milled from leucite-reinforced glass ceramic blocks (Em-

Figure 3. *Specimen in load chamber, filled with distilled water to submerge specimen during testing.*

press CAD, Ivoclar Vivadent), and all measurements were verified manually using a caliper and confirmed visually by uniform translucency across specimens. The surface of the crowns was finished by mechanical polishing (OptraFine, Ivoclar Vivadent).

Adhesive Luting of the Glass Ceramic Crowns

The fitting surface of the milled glass ceramic crown was etched with hydrofluoric acid (<5%; IPS Ceramic Etching Gel, Ivoclar Vivadent) for 60 seconds and cleaned with phosphoric acid for 10 seconds (Total Etch) and in an ultrasonic bath for 2 minutes. Silane-containing coupling agent was applied (Monobond Plus) and heat dried for 60 seconds. Immediately before cementation, the adhesive resin (Heliobond, Ivoclar Vivadent) was applied to the crown, air thinned, but not light cured. The tooth was conditioned by air abrasion of the core buildup (27 μm aluminum oxide; 0.5 bar, 10 seconds, 1-cm distance), followed by 30 seconds of phosphoric acid etching to clean the surface and etch the enamel areas. Adhesive resin (Heliobond) was applied to all surfaces, air thinned, but not light cured. All crowns were cemented using a dual-cure composite cementation system (Variolink II, Ivoclar Vivadent). Following careful elimination of excess of unpolymerized composite resin, the vestibular, occlusal, and palatal surfaces of the crown were polymerized for 60 seconds (20 seconds per surface, three times). All margins were covered with an air-blocking barrier (Liquid Strip, Ivocalr Vivadent) for the last polymerization cycle. Each specimen was stored in distilled water at ambient temperature for at least 24 hours before testing.

Loading Procedure and Configuration

Masticatory forces were simulated using closed-loop servohydraulics (Mini Bionix II, MTS Systems, Eden Prairie, MN, USA). The masticatory cycle was simulated by an isometric contraction (load control) applied through an artificial composite resin cusp (Z100, 3M ESPE) in the shape of a semicylinder (2.5-mm radius). The low stiffness and tooth-like wear of the composite resin cylinder allows realistic simulation of tooth contacts through wear facets distributing the load without reaching the compressive limit of the tissues or restorative materials. All specimens were placed in the load chamber at 30-degree angulation and situated with a positioning device (sliding table) to create a single contact between the semicylinder and the palatal cusp. The loading point was equidistant to the cusp tip and central groove (Figure 3). The load chamber was filled with distilled water to submerge the specimens during testing. Cyclic load was applied at a frequency of 5 Hz, starting with a warm-up load of 200 N for 5000 cycles (preconditioning stage), followed by stages of 400, 600, 800, 1000, 1200 and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until fracture or to a maximum of 185,000 cycles.

Analysis

The mean fracture load and average number of endured cycles was calculated, and the fracture mode was evaluated for both group MHB and group

MFP following a three-examiner agreement. A distinction was made between three fracture modes, considering the repairability of the tooth to be, respectively, "catastrophic" (tooth/root fracture that would require tooth extraction), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage, [chip or crack] of underlying tooth structure), or "reparable" fracture (cohesive or adhesive failure of restoration only).

The fatigue resistance of the two groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted. This allowed the calculation of survival probability (%) at each load step. The influence of the core buildup on the fracture strength was analyzed using the log-rank test at a significance level of 0.05. The fracture load and number of cycles at which the specimen failed were compared using an unpaired *t*-test at a significance level of 0.05.

Supplementary data from a previous study about same design buildups and crowns by the same authors under strictly identical experimental conditions were combined with the present data for additional computation and comparison (life table survival analysis followed by Bonferroni-corrected pairwise comparisons using the log-rank test and fracture/cycles with one-way ANOVA followed by Scheffé post hoc tests).

The previous study included a CAD/CAM-fabricated indirect core buildup milled from an experimental HPP material (Ivoclar Vivadent), a conventional direct buildup using the light-curing composite Tetric EvoCeram (TEC; Ivoclar Vivadent), and an FRC post–supported core buildup using also the light-curing composite Tetric EvoCeram (TECP; Ivoclar Vivadent). The properties of the resin materials are presented in Table 1. The detailed procedures are described elsewhere.[18]

RESULTS

In groups MHB and MFP, none of the tested specimens withstood all 185,000 load cycles; therefore, the mean fracture load could be calculated. The mean fracture load for group MHB with 859.4 N $\pm$ 194.92 was not significantly different from group MFP (796.13N$\pm$156.34; p=0.376). Identical results were found when the number of survived cycles (MHB: 76,515.87$\pm$27,264.25; MFP: 68,339.47$\pm$27,706.96) was statistically compared (p=0.422). Mean fracture loads and average number of survived cycles are displayed in Figure 4.

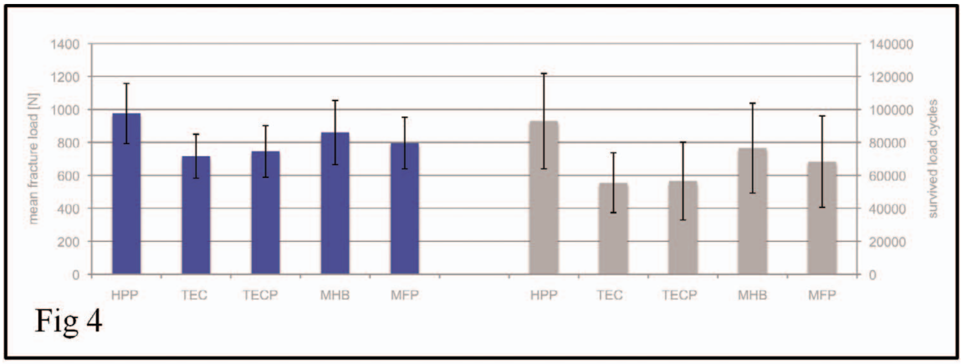
During cyclic loading, initial failures (MFPi) were detected in 20% (3/15) of specimens of group MFP. Failure of the specimen was preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root. The gap was always located at the opposing side of the post. Such occurrence was never found in the other groups. In group MHB, no initial failures could be detected. The life table survival graphs for groups MHB, MFP, and MFPi are displayed in Figure 5. Log-rank test showed no statistically significant differences in the survival of group MHB compared to group MFP (p=0.613) or group MFPi (p=0.221).

When considering previous data (five groups), ANOVA showed significant differences between the groups for fracture load and for survived cycles. HPP was significantly different from group TEC (fracture load: p=0.004; cycles: p=0.005) and TECP (fracture load: p=0.016; cycles: p=0.007) but not from MHB (fracture load: p=0.507; cycles: p=0.541) and MFP (fracture load: p=0.104; cycles: p=0.148). Between groups TEC, TECP, MFP, and MHB, no significant differences were found (Figure 4).

During cyclic loading, initial failures were detected in 26.7% of specimens of group TECP (TECPi) and 20% of specimens of group MFP (MFPi) (Figure 6). Because clinical detection of such failures appears to be questionable, the analysis of survival was conducted for the "total failure" (TECP, MFP) and for the "initial failure" (TECPi, MFPi). For total failure, HPP showed, even after Bonferroni correction, significantly higher survival than TEC (p=0.001) and TECP (p=0.001). Differences between all other groups were not significant. When considering initial failure, however, HPP proved also to survive significantly better than TECPi and MFPi. The life table survival graphs for groups HPP, TEC, TECP, and TECPi are displayed in Figure 7. Table 2 gives the p-values for groupwise comparisons.

Analysis of Failure Mode

Following the three-examiner agreement, groups HPP and TECP showed the highest rate of catastrophic failures (each 80%), followed by MFP (73.3%). Groups without a post, except for HPP, showed the lowest number of catastrophic failure (TEC: 53.3%; MHB: 60%). Figure 8 shows examples of different failure modes, and Figure 9 gives the percentage of specimens of each specific fracture mode for each group.



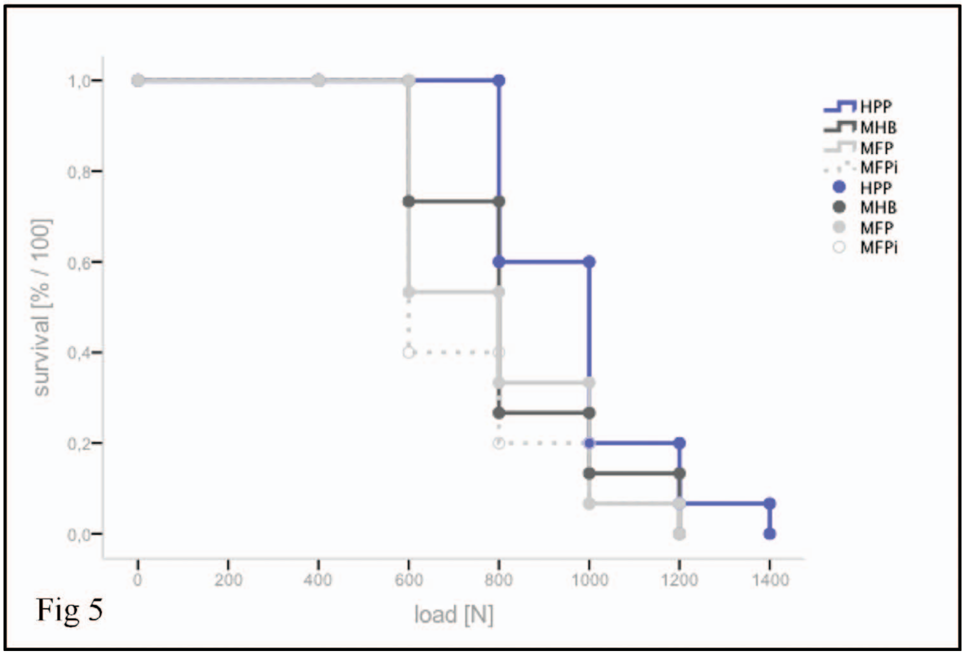


Figure 4. *Mean fracture loads (blue) and average number of survived load cycles (grey) and their standard deviations, respectively (previous data included[18]).*

Figure 5. *Life table survival graphs for groups MHB, MFP, and MFPi. For better comparison, the survival graph of group HPP from a previous study was added.*

DISCUSSION

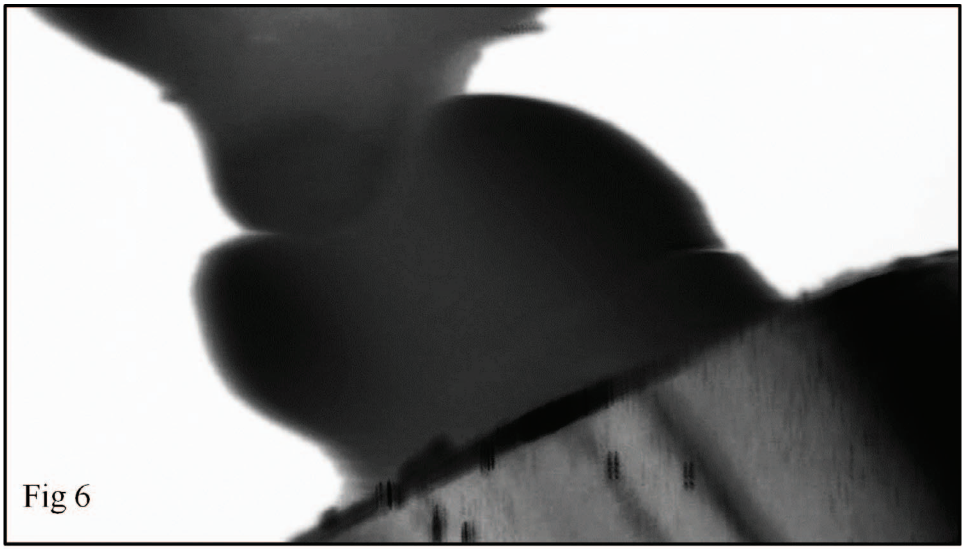
In this study, the performance of leucite-reinforced glass ceramic crowns over two different buildups for the rehabilitation of highly damaged, endodontically treated molars with no ferrule effect was evaluated. A core buildup without post using a high-viscosity dual-cure material (MHB) with a high elastic modulus and a core buildup made of flowable dual-curing composite in combination with MFP were tested. Results were compared with previously published data by the same authors using a strictly identical experimental setup. The first null hypothesis, stating that MHB core buildup would not lead to different fatigue strength of all-ceramic crowns compared to the MFP core buildup, was accepted, as no statistically significant differences could be found between the groups. Because HPP showed higher survival rates and fracture resistance compared to TEC, TECP, TECPi, and MFPi, the second null hypothesis was rejected.

Table 2: p-*Values of Pairwise Comparisons*

TEC	0.0001*					
TECP	0.0001*	0.688				
TECPi	0.0001*	0.453	0.285			
MHB	0.066	0.054	0.12	0.025		
MFP	0.032	0.157	0.303	0.066	0.613	
MFPi	0.005*	0.592	0.77	0.213	0.221	0.512
	HPP	**TEC**	**TECP**	**TECPi**	**MHB**	**MFP**

** Significant difference at the 0.005 level of significance after Bonferonni correction. Statistical analyses were carried out considering either groups TECP and MFP (total failure) or TECPi and MFPi (initial failure).*

The applied stepped load protocol, using a closed-loop servohydraulic system, represents a compromise between the conventional load-to-failure protocol and the time-consuming low-load fatigue test, allowing a physiological representation of mastication.[19] As shown by Fennis and others,[20] this test strategy seems to provide a better simulation of the



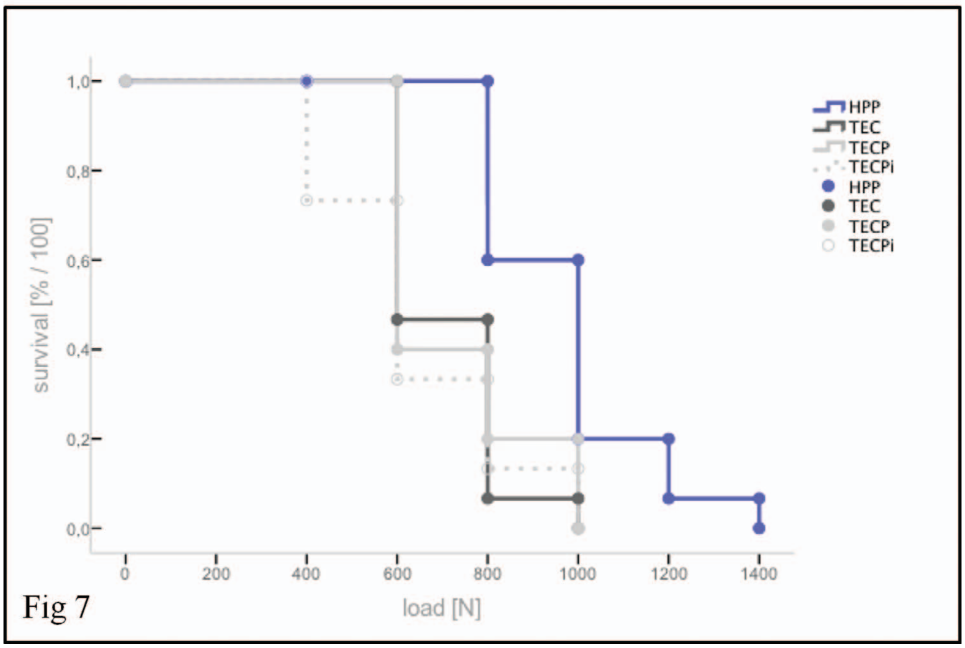


Figure 6. *Initial failure of the specimen was preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root. The gap was always located at the opposing side of the post. Such occurrence was never found in the groups without post. Because clinical detection of such failures appears to be questionable, the analysis of survival was conducted for the "total failure." Image motion blur is due to loading dynamics and water immersion.*

Figure 7. *Life table survival graphs for groups HPP, TEC, TECP, and TECPi.*

clinical conditions than static load tests. Therefore, the presented protocol appears to be the best compromise between available *in vitro* fatigue testing methods and clinical reality. To further challenge the restoration, the previously described load protocol with increasing loads from 200 up to 1400 N and a frequency of 5 Hz[21] was combined with an angle of force of 30 degrees concentrated on the working cusp. This method represents an extreme load configuration (worst-case scenario) and was selected because no specimens failed during pilot tests in which the load was applied axially and distributed on a tripodic contact. The extreme character of the applied method becomes even clearer when the loads are compared with a study by Sakaguchi and others[22] using a similar testing machine. They correlated 250,000 cycles at only 13.6 N with 1 year of clinical service. Therefore, it can be expected that an accelerated life cycle of the restored tooth may have been simulated.

The major advantage of *in vitro* studies over *in vivo* ones is their opportunity to create a high level of standardization with well-defined parameters, such as the biomechanical status of specimens.[23] To achieve a high level of standardization, even when using natural tooth with different age, size, and shape, only maxillary molars were used and distrib-

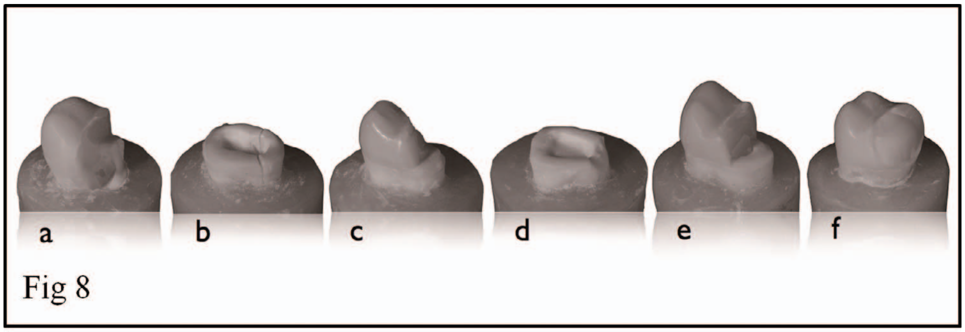


Figure 8. *Failure mode. All specimens were analyzed and classified into one of the three failure modes: "catastrophic" (tooth/root fracture that would require tooth extraction) (a and b), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage [chip or crack] of underlying tooth structure) (c and d), or "reparable" fracture (cohesive or cohesive/adhesive fracture of restoration only) (e and f). The analysis was carried out in accordance with a previous study.[18]*

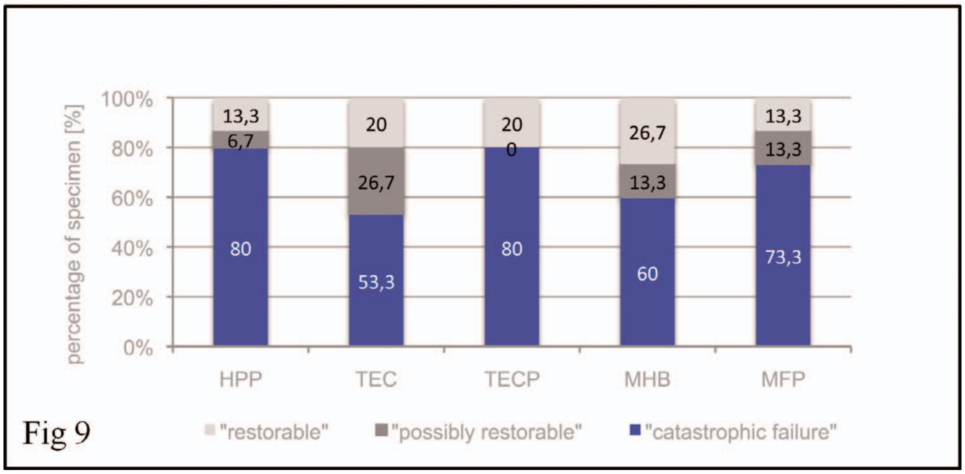


Figure 9. *Percentage of specimens per group for each fracture mode.*

uted into test groups by the RMM method. Further, CAD/CAM technology helped to achieve similar crown design with highly reproducible anatomy, cuspal inclines, grooves, and a strictly similar thickness parameter for each specimen. Using manual techniques to fabricate the crowns, such a level of standardization seems to be hard to achieve. This high level of standardization enabled the loading of the specimen in a strictly identical configuration and, further, comparing the results of this study with previously published data from the authors using the same methodology. In order to avoid masking the effect of the core buildup, high-strength ceramics were omitted as coverage material. Instead, leucite-reinforced glass ceramic was used for the fabrication of the crowns. By the same principle, teeth were prepared without a ferrule in order to avoid making the underlying core hypofunctional.[24]

In view of the present results, the use and effect of FRC posts can be questioned. No significant difference could be observed between groups MHB and MFP/MFPi. These findings are in accordance with a previous study by Scotti and others[14] stating that a fiber-post insertion did not increase the fracture resistance of severely broken-down endodontically treated mandibular molars restored with indirect composite resin overlays. The use of a highly viscous material with a high elasticity modulus (MHB) may have played a significant role in avoiding the technical and sensitive procedure of post placement. Even though there were no statistically significant differences, group MHB showed higher mean fracture load and failure resistance combined with more favorable failure modes when compared to MFP. Additionally, no initial failures could be observed in group MHB, whereas 20% of specimens showed initial failures (MFPi) in group MFP. The initial failure phenomenon, that is, a wide gap at the margin between the buildup/crown assembly, intensifying and preceding total failure, was essentially associated with the presence of a post (including group TECP in the previous study)[18] and never happened in no-post groups (HPP, TEC, MHP). This gap occurred and could be detected only under high oblique loads (>400 N). Due to the flexibility of the FRC post, the gap closes again in the absence of force. As a result, the detection of such initial failures is extremely difficult in the clinical situation, as only low to medium loads are usually applied during clinical examination. However, high loads are very likely to occur during mastication[25] and may lead to a pumping effect, facilitating bacterial infiltration and possibly causing secondary decay. A possible explanation for this phenomenon is that the post acts as a lever (rotation center) and causes the opening of a gap opposite to the load side during oblique loading (30 degrees). In addition, post systems are usually supplied with their own self-etching and/or self-adhesive dentin bonding system. Because initial failures did not occur when the total etch-and-rinse three-step dentin adhesive was used (HPP, TEC, MHB), the efficiency of the simplified adhesives may be questioned. Further studies are needed to evaluate whether initial failures would also occur when limiting the application of the post adhesive system to the root canal itself and using a classic adhesive on the remaining dentin surface to which the core material is bonded. This would further complicate the already time-consuming, material-intensive, and technique-sensitive procedure of post insertion and buildup.

The use of a post in combination with the high-viscosity MHB and the milled HPP material seems to be impractical from the clinical perspective. Therefore, these combinations were not included in this study. Generally, in view of the results, the use of a post should be questioned even in the absence of a ferrule effect. The groups with posts show the least fracture loads and failure resistance, combined with higher rates of unfavorable catastrophic fracture modes (TECP: 80%; MFP: 73.3%). The least catastrophic failures were found with direct no-post buildups (TEC, MHB). This aligns well with the description by Zicari and others[24] stating that shortening the post and the ensuing preservation of tooth structure offers the potential for re-restorability through a failsafe mechanism and thus may reduce the occurrence of catastrophic failures. In addition, clinical data seem to confirm that the absence of a post is associated with increased survival of ETT.[2]

Among groups without posts, HPP showed the highest fracture load and fatigue resistance but also a high percentage of catastrophic failures (80%). The reasons for this behavior have been discussed previously.[18] HPP is an industrially polymerized composite resin, and due to the semidirect fabrication, polymerization shrinkage occurs only within the luting material. Generally, a trend could be recognized that lower load-bearing groups tended to show fewer catastrophic failures. Further research is needed to establish the optimal balance between strength and favorable failure mode. In the present study, the most surprising and favorable combination of strength and failure mode could be observed in group MHB. The monomer matrix of MHB consists of dimethacrylate (13.5 wt%). The inorganic fillers are barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, and highly dispersed silicon dioxide for a total of 86 wt%, which exceeds all other buildup materials. Additional contents are catalysts, stabilizers, and pigments (0.5 wt%). The total content of inorganic fillers is 70 vol%. Particle sizes range from 0.04 to 25 μm. Group MHB, together with HPP, showed the highest survival and fracture loads; however, MHB showed only 60% catastrophic failures against 80% in group HPP. The more adhesive failure modes in group MHB, leading to fewer catastrophic failures, might be explained by the different mode of application of the adhesive system. The strong performance of MHB might also come from its high elastic modulus (18,000 MPa) and hardness (Vickers hardness: 1000 MPa), as it was demonstrated that a higher elastic modulus of the core buildup increased the fracture resistance of all-ceramic crowns.[17] Because MHB was hand mixed, its maximum potential may have been diminished by the inclusion of air bubbles and porosities. On the other hand, the lesser mechanical properties of HPP seem to have been offset by the polymerization under industrial conditions. Therefore, a CAD/CAM block of MHB might represent the best performance (combination of mechanical properties and industrial processing). The only shortcoming of MHB, besides its handling, is its high opacity combined with an ocher shade. Some practitioners may view this as an advantage when removing excesses and repreparing. In the present study, MHB was applied directly to the bonded dentin surface. Further research should explore whether the use of MHB should be preceded by the placement of a flowable liner in more complex geometries. A complete evaluation of the previously mentioned materials and techniques should include microleakage/nanoleakage studies, although this was not the scope and was not investigated in the present study.

There are several clinically relevant elements that can be drawn from this *in vitro* study. Omitting placement of a post significantly facilitates clinical procedures without interfering with longevity as long as the right materials are selected. The use of HPP offers several innovative treatment options. For example, a fully anatomically shaped HPP crown can be used as a long-term provisional immediately after root canal treatment (eg, chairside using an intraoral scanner and milling unit) to achieve a reliable bacteria-proof sealing.[26,27] Subsequently, after recovery of the surrounding tissues and confirmation of endodontic status and prognosis, the polymer restoration can serve either as the definitive restoration or as a core buildup under an all-ceramic crown.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following can be concluded when restoring endodontically treated molars without a ferrule:

1. An indirect CAD/CAM-fabricated core buildup from an HPP and a direct core-buildup made from MHB might enhance the load-bearing capacity and fatigue resistance of all-ceramic leucite-reinforced glass ceramic crowns.
2. Insertion of a fiber-reinforced post does not enhance the load-bearing capacity and survival of all-ceramic leucite-reinforced glass ceramic crowns on direct core buildups from dual-cure or light-curing composite.
3. In the presence of FRC posts, failure of the specimen was often preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root (initial failure). This significantly affected the survival rate.
4. The most favorable combination of strength and failure mode could be observed in group MHB using MHB as buildup material.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of Ludwig-Maximilians University, Germany, and the Ethical Review Committee of the University of Southern California, Los Angeles.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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