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Fracture Strength of Various Types of Large Direct Composite and Indirect Glass Ceramic Restorations

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Clinical Relevance

The use of a glass fiber reinforced composite may result in more repairable failures when severely compromised endodontically treated molars are restored.

SUMMARY

Introduction: The objective of this study was to investigate the mechanical behavior of severely compromised endodontically treated molars restored by means of various types of composite buildups, full-contour lithium disilicate crowns (with or without post) or a lithium disilicate endocrown.

Methods and Materials: One hundred five sound molars were endodontically treated and randomly assigned to 1 control group (endodontic access cavity only) and 6 experimental groups (n=15): glass fiber reinforced composite (GFRC group), direct microhybrid composite (C group), direct microhybrid composite restoration with glass fiber post (CP group), composite buildup and full-contour

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lithium disilicate crown (LDS group), additional glass fiber post (P-LDS group), and endocrown (EC group). Molar crowns in the treatment groups were removed 1 mm above the cementoenamel junction and restored. All specimens were thermomechanically aged (1.2×10^6 cycles at 1.7 Hz/50N, 8000 cycles 5°C to 55°C) and axially loaded until failure. Data were analyzed using analysis of variance and Tukey post hoc test (α=0.05).

Results: Fracture strength was significantly affected by the type of restoration (*p*=0.000; statistically similar groups identified with superscript letters): LDS^{B} (3217±1052 N), P-LDS^{AB} (2697±665 N), EC^{AB} (2425±993 N), C^{A} (2192±752), control^{A} (1890±774 N), CP^{A} (1830±590 N), and GFRC^{A} (1823±911 N). Group GFRC obtained significantly more repairable fractures than the other groups.

Conclusions: Significant differences in fracture strength were obtained between LDS, the composite restorations, and control group. Direct composite restorations showed similar fracture strength as P-LDS and EC. Incorporating a glass fiber reinforced composite resulted in significantly more repairable failures.

INTRODUCTION

Fracture is a frequent cause for extraction of an endodontically treated tooth. Two studies evaluating the reasons for the extraction of endodontically treated teeth demonstrated unrestorable cusp or vertical root fractures in 11.2 % to 28.5 % of cases.[1,2] Hence, it is of clinical importance that the restoration of an endodontically treated tooth results in a tooth-restoration complex that is resistant to fracture.[3] The durability of the post-endodontic restoration largely depends on the amount of remaining tooth tissue.[4–6] Data from a retrospective study showed that endodontically treated molars with a large amount of remaining tooth structure had a better 5-year cumulative survival rate than molars with two remaining walls or less (78% vs 18%).[5]

Post-endodontic restoration can be achieved by an indirect or a direct operative procedure. A conventional indirect procedure of restoring severely mechanically compromised teeth is by creating a ferrule of at least 2 mm in height and cementation of a full contour crown in cases where there is ample remaining vertical height to provide retention and resistance to the indirect restoration.[7] If the former is not the case, post-and-core buildup is commonly provided prior to fabrication of the crown.[8] Endocrowns could be a viable adhesive alternative to these post-and-core buildups in structurally compromised molar teeth.[9,10] An endocrown is a monolithic restoration that extends into the pulp chamber. This type of restoration functions particularly well in molar teeth, since the pulp chamber of such teeth provides a large area for adhesion of the restoration. When fabricated from a glass ceramic or indirect composite, adhesive cementation results in the preservation of tooth structure and enamel because retention does not merely rely on macrogeometry. However, when enamel is lost, adhesion to dentin remains a clinical challenge.[11] For ceramic inlays and onlays with a cervical outline in dentin there is a 78% higher risk of failure compared with restorations with an outline in enamel.[12] Immediate dentin sealing (IDS) improves adhesion to dentin.[13]

In molars with no or only a single coronal wall remaining, the clinician and patient have to consider treatment alternatives in relation to costs and durability. Indirect restorations are relatively costly and frequently overstretch the patients' financial budget, especially after recent pre-restorative endodontic treatment. A possible alternative could be a directly made full composite buildup. Fabricating a full composite buildup, however, is a clinical challenge, since it is rather difficult to adequately restore the original morphology of the tooth. Polymerization shrinkage and the degree of conversion also affect the final result and the survival of the restoration.[14] Incorporating glass fibers into the bulk of composite may result in less polymerization shrinkage, higher fracture resistance, and deflection of fractures to a more restorable failure.[15]

In a systematic review of the Cochrane collaboration,[16] it was concluded that further clinical trials are needed to compare direct and indirect restorations in the rehabilitation of endodontically treated teeth. For a better understanding of the mechanical behavior, various types of restorations may be proposed, as well, which forms the rationale for the present study. The fracture strength of severely compromised endodontically treated molars restored by various direct and indirect means, using composite or glass ceramic materials, either with or without a post, were compared under the null hypotheses that there would be no difference in mean fracture strength and mode of failure among the various groups.

METHODS AND MATERIALS

A total of 105 sound extracted third molars, similar in size (mesiodistal length 9–11 mm; root length 10–13 mm as measured from the cementoenamel junction [CEJ] to the apex), were included (n=15 per group). Exclusion criteria were: presence of caries or cracks, abnormal morphology, roots <10 mm, presence of restorations, or root canal treatment. All molars were embedded 1 mm below the CEJ in polyvinylchloride tubes (height: 10 mm; diameter: 12 mm) using autopolymerizing acrylic resin (Autoplast, Condular, Wager, Switzerland). Teeth were stored for a maximum of four months in distilled water before preparation. All materials used are listed in Table 1.

Endodontic Treatment

Conventional endodontic access cavities were prepared and all root canals were shaped up to working length using a rotary file system (WaveOne Primary/ISO 25, taper 8%; Dentsply Sirona, Milford, CT, USA). Gutta-percha cones were placed using a root canal sealer (AH Plus; Dentsply Sirona), seared off 1 mm below the canal entrance, and covered with a resin-modified glass ionomer cement (Vitrebond, 3M ESPE, St Paul, MN, USA). Root canal sealer was removed using a microbrush drenched in an 80% alcohol solution. The access cavity was restored using a three-step etch-and-rinse adhesive (Optibond FL, Kerr, Orange, CA, USA) and a microhybrid composite (Clearfil AP-X Posterior A3, Kuraray, Okayama, Japan). The composite was layered and each increment light-cured for 20 seconds using a high-power curing unit (Bluephase 20i; Ivoclar Vivadent, Schaan, Liechtenstein). The output of the curing unit was >1100 mW/cm^2 throughout the experiment (Bluephasemeter, Ivoclar Vivadent). After endontic treatment, specimens were stored in distilled water for a maximum of four months.

Randomization and Specimen Preparation

After endodontic treatment all teeth were randomly assigned via sealed envelopes to a control group (control; no further preparation) or one of six treatment groups (n=15; see Figure 1). A three-dimensional scan was obtained for all teeth in the BioGeneric Copy mode of an intraoral scanning device (Cerec Omnicam, Sirona Dental Systems GmbH, Bensheim, Germany). A putty impression (Provil Novo fast set, Heraeus Kulzer GmbH, Hanau, Germany) of the intact molars was made. The crowns of teeth in all treatment groups were removed using a coarse diamond wheel bur (5909 FG, Komet Dental, Lemgo, Germany) 1 mm above the CEJ (preserving a ring of enamel around the outline) and immediately restored.

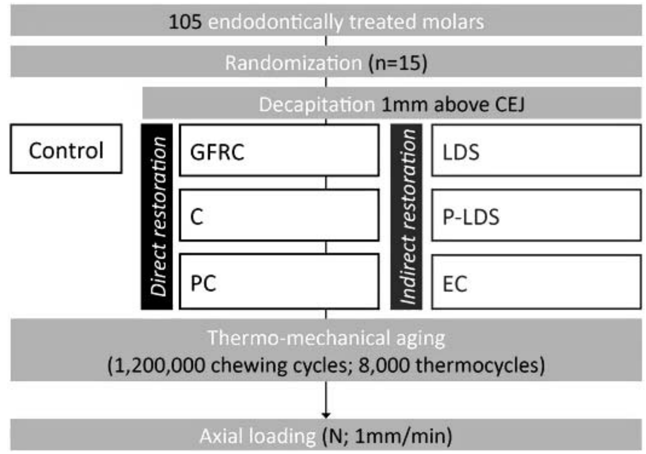

Figure 1. *Overview of the different study groups and flow chart showing the experimental sequence. GFRC, glass fiber reinforced composite; C, composite; PC, composite + post; LDS, lithium disilicate crown; P-LDS, lithium disilicate crown + post; EC, endocrown.*

Direct Composite Buildups

After crown removal, the pulp chamber composite was removed up to a depth of 4 mm using a red ring diamond shoulder bur (899KR.314.018, Komet Dental). Putty impressions were cut in half to serve as a mold for the composite buildups to restore the previous anatomy. In group GFRC, a 1-mm thick wall was constructed with a microhybrid composite (GC Essentia Universal, GC, Leuven, Belgium) using the putty impression. The central part and the pulp chamber were restored using a glass fiber-reinforced composite (GC EverX Posterior, GC) in 2-mm increments and photopolymerized for 20 seconds. The glass fiber-reinforced composite was totally covered using a microhybrid composite photopolymerized for 20 seconds, and glycerin gel was applied over the buildup and light-cured for 40 seconds.

In group C, the same process was followed, but this time using a microhybrid composite resin only (Clearfil AP-X Posterior A3; Kuraray).

In group CP, a preparation was made in the largest canal to fit a glass fiber post (RelyX Fiber post red, 3M ESPE), ensuring a 4-mm apical gutta-percha seal. Conditioning of the post consisted of silica-coated

Table 1: *Brands, Types, Chemical Compositions, Manufacturers, and Batch Numbers of the Materials Used for the Experiments*

Brand	Type	Chemical Composition	Manufacturer	Batch Number
Ultra-etch	Etching agent	35% phosphoric acid	Ultradent, St Louis, MO, USA	D080, L090, K021, F080, T031
Optibond FL	Bonding agent	Primer: 2-hydroxyethyl methacrylate, glycero-phosphate dimethacrylate, phthalic acid monomethacrylate, ethanol, water, photo-initiator	Kerr, Orange, CA, USA	6286025
		Adhesive: triethyleneglycol dimethacrylate, urethane dimethacrylate, glycero-phosphate dimethacrylate, 2-hydroxyethyl methacrylate, bisphenol-A glycidyldimethacrylate, filler, photo initiator		6113545
Clearfill AP-X Plt	Microhybrid composite	Bisphenol-A glycidyldimethacrylate, triethyleneglycol dimethacrylate, silanated barium glass filler, silanated silica filler, silanated colloidal silica, dl-camphorquinone	Kuraray, Okayama, Japan	2E0706
RelyX Fiber Post	Glass fiber post	Glass fibers (80% to 90%), resin matrix (10% to 20%)	3M ESPE, St Paul, MN, USA	56860
EverX Posterior	Glass fiber reinforced composite	E-glass fibers, barium borosilicate glass filler, bisphenol-A glycidyldimethacrylate, triethyleneglycol dimethacrylate, PMMA, mix camphorquinone	GC EUROPE, Leuven, Belgium	1609082
Essentia Universal	Microhybrid composite	Strontium glass fillers, ianthanoid fluoride, FALSi glass, fumed silica, ethoxylated bisphenol-A dimethacrylate	GC EUROPE, Leuven, Belgium	160727A
Tetric EvoFlow A3	Flowable composite	Dimethacrylates, barium glass fillers, ytterbium trifluoride, silicon dioxide, mixed oxide and copolymer, additives, catalysts, stabilizers, pigments	Ivoclar Vivadent, Schaan, Liechtenstein	W05639
Cojet sand	Blasting particles	Aluminum trioxide particles coated with silica, particle size: 30 μm	3M ESPE, St Paul, MN, USA	442859
IPS Ceramic Etching Gel	Ceramic etching gel	<5% hydrofluoric acid	Ivoclar Vivadent, Schaan, Liechtenstein	V23918
Monobond Plus	Silane coupling agent	Ethanol, 3-trimethoxysilsylpropylmethacrylate, methacrylated phosphoric acid ester	Ivoclar Vivadent, Schaan, Liechtenstein	T45804
Clearfill DC core plus Dentin	Dual-curing composite	A Paste: bisphenol-A glycidyldimethacrylate, hydrophobic aliphatic dimethacrylate, hydrophilic aliphatic dimethacrylate, hydrophobic aromatic dimethacrylate, silanated barium glass filler, silanated colloidal silica, colloidal silica, dl-camphorquinone, initiators, pigments	Kuraray, Okayama, Japan	000029
		B Paste: triethyleneglycol dimethacrylate, hydrophilic aliphatic dimethacrylate, hydrophobic aromatic dimethacrylate, silanated barium glass filler, silanated colloidal silica, aluminum oxide filler, accelerators		
IPS e.max CAD HT A3	Lithium disilicate glass ceramic	97% silicon dioxide, aluminium oxide, phosphorus pentoxide, potassium oxide, sodium oxide, calcium oxide, fluoride, 3% titanium dioxide, and pigments, water, alcohol, chloride	Ivoclar Vivadent, Schaan, Liechtenstein	V31667, U51707, S04180

particle abrasion (CoJet Sand, 3M ESPE) and subsequent silanization (Monobond Plus, Ivoclar Vivadent) for 60 seconds. A dual-polymerizing core buildup material (Clearfil DC Core Plus Dentin, Kuraray) was used to lute the post in the root canal and fill the pulp chamber. The post was cut 1 mm below the occlusal table. Molars were subsequently restored using the same material as in group C.

Indirect Restorations

Molar crowns were removed and the pulp chamber prepared as described in the Direct Composite Buildups section. Teeth in group LDS received a composite buildup as described in group C. For group P-LDS, a post was inserted and the buildup prepared as described in group CP.

After the buildup, teeth in groups LDS and P-LDS were prepared for a lithium disilicate full-contour crown (IPS e.max CAD HT A3, Ivoclar Vivadent) with a 1-mm chamfer margin and 2-mm ferrule in sound tooth structure, resulting in an outline only in dentin. Occlusal reduction was 1.5 mm. Preparations were scanned using an intraoral scanning device (Cerec Omnicam, Sirona Dental Systems GmbH, Bensheim, Germany). The crown was designed using the previously stored Biogeneric Copy and subsequently milled (InLab MC XL, Sirona Dental Systems GmbH, Bensheim, Germany). A provisional restoration (ProTemp 4, 3M ESPE, Seefeld, Germany) was cemented (Durelon, 3M ESPE). After two weeks, the provisionals were removed and the preparation cleaned using a pumice slurry. The composite buildup was treated using silica-coated particle abrasion until the surface appeared matte, followed by etching the total preparation using phosphoric acid for 15 seconds. Primer (Optibond FL Primer, Kerr) was applied to the dentin for 30 seconds and the buildup silanized for 60 seconds (Monobond Plus, Ivoclar Vivadent). The preparation was covered with a filled adhesive (Optibond FL Adhesive, Kerr), but not light-polymerized. The intaglio surface of the crown was etched using 4.9% hydrofluoric acid (IPS Ceramic Etching gel, Ivoclar Vivadent) for 20 seconds, followed by thorough rinsing and ultrasonic cleaning for 5 minutes in distilled water. After ultrasonic cleansing, the etched surface was silanized for 60 seconds. The same filled adhesive was applied on the surface of the crown. The preparation was covered with a heated microhybrid composite (Enamel Plus HFO, Micerium, Avegno, Italy), and the crown was seated under constant pressure. Light polymerization was performed through glycerin gel for 90 seconds per side (occlusal, buccal, and lingual) and the restoration was polished using fine rubbers (brownie/greenie, Shofu Dental, Ratingen, Germany).

For group EC, the pulp chamber was prepared as described in the Direct Composite Buildups section to receive a lithium disilicate endocrown. IDS was performed. Dentin was etched with 35% phosphoric acid (Ultra-etch, Ultradent, St Louis, MO, USA) for 15 seconds, rinsed and dried. A primer (Optibond FL Primer, Kerr) was applied and scrubbed in for 20 seconds, followed by suction drying. A filled adhesive (Optibond FL Adhesive, Kerr) covering only the dentin was light-cured for 20 seconds and covered with a layer of flowable composite resin (Tetric Evoflow A3, Ivoclar Vivadent). Final light-curing was performed through glycerin gel for 40 seconds. After the application of IDS, the enamel was cleaned using a red ring bur at low speed. A provisional restoration was cemented for two weeks. The endocrowns were milled and cemented according to the protocol described for groups LDS and P-LDS.

Aging, Fracture Test, and Fracture Analysis

All specimens were thermomechanically aged (SD Mechatronik CS-4.8 Chewing Simulator, Feldkirchen-Westerham, Germany) to simulate five years of clinical service. Per specimen, an axial 50 N load was applied using a ceramic antagonist sphere for a total of 1.2×10^6 cycles at a frequency of 1.7 Hz. Thermal cycling (8000 cycles) was carried out simultaneously with temperatures changing from 5°C to 55°C (dwelling time 30 seconds). After aging, the specimens were checked for wear and fractures under an optical microscope (10×, OPMI pico, Zeiss, Jena, Germany). Thereafter they were loaded using an 8-mm ball-shaped load on the occlusal plane until fracture (1 mm/min). All fractures were visually analyzed at 40× magnification (Wild Heerbrugg, M3Z Schott, Switzerland) and divided into categories: 1) repairable failures and 2) nonrepairable failures. Repairable failures were defined as failures that would not result in tooth loss and further specified as follows: a) fracture within the restoration, b) fracture of the restoration and adhesive failure, and c) combined fracture of the restoration and tooth with a maximum of 1 mm below the original outline. Nonrepairable failures resulted in extraction of the tooth and were classified as 1) a fracture more than 1 mm below the original outline or 2) root fracture. Representative failures of each category were sputter-coated with a 3-nm thick layer of gold (80%)/palladium (20%) (90 s, 45 mA; Balzers SCD 030, Balzers, Liechtenstein) and fractures analyzed using cold field emission scanning electron microscope (LyraTC, Tescan, Brno, Czech Republic).

Statistical Analysis

Results were analyzed using IBM SPSS 24 (SPSS Inc., Chicago, USA) statistic software package. After checking assumptions of normality and homogeneity of variance, a one-way analysis of variance was conducted with the fracture strength as the depen-

Table 2: Fracture Strength Results (Newtons)[a]						
Group	**n**	**Mean±SD**	**Minimum**	**Maximum**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Control	15	1890±774[A]	599	3223	1461	2318
GFRC	15	1823±911[A]	808	4384	1318	2327
C	15	2192±752[A]	852	3715	1775	2609
CP	15	1830±590[A]	993	2896	1504	2157
LDS	15	3217±1052[B]	1644	4976	2635	3800
P-LDS	15	2697±665[AB]	867	3621	2323	3065
EC	15	2425±993[AB]	1092	4997	1875	2976

Abbreviations: GFRC, glass fiber reinforced composite; C, microhybrid composite; CP, microhybrid composite + post; LDS, lithium disilicate full contour crown; P-LDS, lithium disilicate full contour crown and glass fiber post; EC, endocrown.
[a] Same upper-case letters (A or B) indicate no significant difference between groups.

dent variable and the type of restoration as the independent variable. A *post hoc* analysis was performed using Tukey honestly significant difference. To compare the mode of failure between groups, a Fisher-Freeman-Halton Exact test was performed. A p-value <0.05 was considered significant in all aforementioned tests.

RESULTS

All specimens survived the thermomechanical aging process. Wear facets were present on both the ceramic and composite restorations. An overview of the fracture strength results is presented in Table 2. Fracture strength was significantly affected by the type of restoration ($F[6, 98]=5.89$, $p=0.000$, $\omega=0.47$). *Post hoc* analysis revealed that there was a significant difference between group LDS (3217±1052 N) on the one hand and control (1890±774 N; $p=0.001$, $d=1.44$), GFRC (1823±911 N; $p=0.000$, $d=1.42$), C (2192±752 N; $p=0.018$, $d=1.12$), and CP (1830±590 N; $p=0.000$, $d=1.63$) on the other hand. No significant differences were found between groups LDS, P-LDS (2697±665 N), and EC (2425±993 N).

Table 3 shows the modes of failure per group. There was a significant association between the mode of failure and the type of restoration ($p=0.005$; two sided). The odds for a repairable fracture when GFRC was used were 4, 5.4, 8, and 28 times higher than for the full contour crowns, control group, EC, and other composite groups, respectively. Figures 2A through C and 3A through C show scanning electron microscope images of representative specimens. In group GRFC, a deflection of the fracture from the central part is visible (Figure 2A). Figure 3D shows that the adhesive failure occurred between the interface of the dentin and IDS layer, whereas the IDS layer, composite, and ceramic are still bonded.

DISCUSSION

The objectives of this study were to investigate the influence of the type of restoration on the fracture strength and mode of failure of severely compromised endodontically treated molars. According to the results, the hypothesis that the type of restoration had no influence on the fracture strength has to be rejected. Specimens from the LDS group ob-

Table 3: Failure Modes[a]					
	Repairable Failures			**Nonrepairable Failures**	
	Cohesive Crown	**Cohesive Crown + Adhesive**	**Cohesive Crown + Fracture Tooth**	**Fracture >1 mm Below CEJ**	**Root Fracture**
Control	4			1	10
GFRC*	3	3	4	4	1
C	1				14
CP	1			3	11
LDS	1	3	1	1	9
P-LDS	2	2	1		10
EC		1	2	1	11

Abbreviations: GFRC, glass fiber reinforced composite; C, microhybrid composite, CP, microhybrid composite + post; LDS, lithium disilicate full contour crown; P-LDS, lithium disilicate full contour crown and glass fiber post; EC, endocrown.
[a] Odds for a repairable failure were 4, 5.4, 8, and 28 times higher than for the full contour crowns, control group, EC, and other composite groups, respectively.

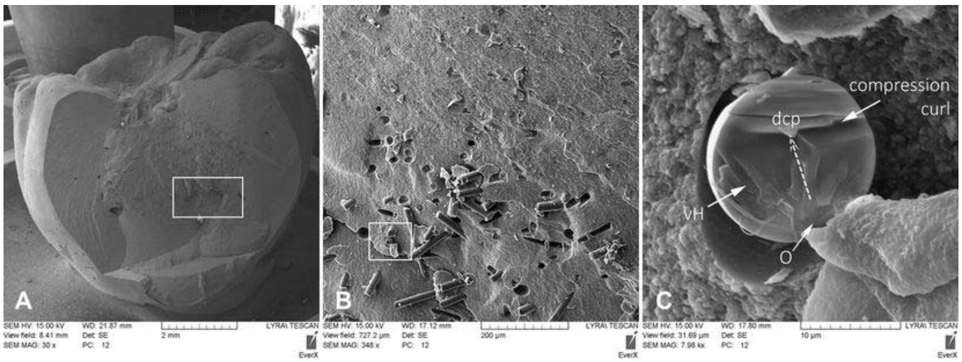

Figure 2. *Scanning electron microscope mages of a total specimen of GRFC (A), a close-up of the glass fiber reinforced microhybrid composite interface (B) and a fractured short glass fiber (C). Deflection of the fracture from the central part of the tooth is evident (A). Short glass fibers are oriented in different directions, thereby functioning as a stress breaker and deflector of the force (B). Detail of a fractured glass fiber (C) shows the point of origin (O), direction of crack propagation (dcp) and numerous velocity hackles (vH).*

tained a significantly higher mean fracture strength than the control and direct composite groups. To the authors' knowledge, no fracture strength studies are currently available that compare the direct composite and indirect restoration of endodontically treated molars. Even after thermomechanical aging, all types of restorations were able to withstand the mean masticatory force in humans, ranging from 600 N to 900 N.[17–19] This is in line with other studies.[20–22]

Only a few studies investigated the fracture strength of endodontically treated molars restored with cusp-replacing direct composite restorations; however, the specimens were not subjected to any form of aging.[20,23] Salameh and others reported fracture strengths of 677±21 N and 833±180 N for direct composite restorations with and without a glass fiber post, respectively.[23] In another study, the fracture strength of extensive direct composite restorations without posts was 1421±320 N.[20] The fracture strengths found in the present study are comparable or higher, although the specimens were thermomechanically aged to simulate five years of clinical service.[24] A possible explanation could be the use of a highly filled microhybrid composite resin (70% volume, 86% weight filler load).[25] Only one study described the fracture strength of endodontically treated molars restored with fiber-reinforced composite (2251±586 N).[15]

The mean fracture strength of endocrowns in this study is comparable to that of endocrowns as reported by Gresnigt and others under axial loading (2428±566 N).[21] Carvalho and others reported values of 3181 N and 3265 N for full contour lithium disilicate crowns with a 4-mm composite buildup and endocrowns.[22] This higher value compared with those in the present study may be explained by the use of an antagonist resin sphere, which deforms under compressive load. No significant difference was found among the three ceramic groups. This is in line with another *in vitro* study, where no significant difference in mean fracture strength was found for the full coverage and endocrown lithium disilicate restorations on endodontically treated molars (1076±132 and 989±109 N respectively).[26]

Both for the direct composite and lithium disilicate group, the use of a post did not contribute to a higher fracture strength. This is in accordance with several other studies.[23,27–29] Lithium disilicate endocrowns performed significantly better than a composite post and core buildup and full contour crown (675±159 N vs 470±130 N).[27] In endodontically treated molars without ferrule, a post had no added benefit to the failure load of ceramic crowns covering a composite buildup.[30] This was also the case for large composite restorations with or without the use of a glass fiber post.[23,28]

As for the hypothesis that the type of restoration had no effect on the failure mode, the results show that group GFRC resulted in significantly more repairable failures; thus, the hypothesis can be rejected. A reason for this could be the deflection of the fracture during crack propagation by the glass fibers because of their different orientation (see Figure 2B).[15] Furthermore, glass fibers seem to absorb a lot of stress, as is apparent from the velocity hackles in Figure 2C.[31] In contrast, the representative specimens of groups C, P-LDS, and EC showed fractures within the pulpal chamber, resulting in nonrepairable failures (Figure 3A through C). Strain in the direct composite transfers stress to the root dentin, which is confirmed by strain measurements and finite element analysis.[32] Even when compared with the control, which only had a small class I filling, the odds for repairable failure of group GRFC were 5.4 times higher. The glass fiber reinforced composite therefore might be an interesting method to increase the chance of tooth survival after fracture. More research about the

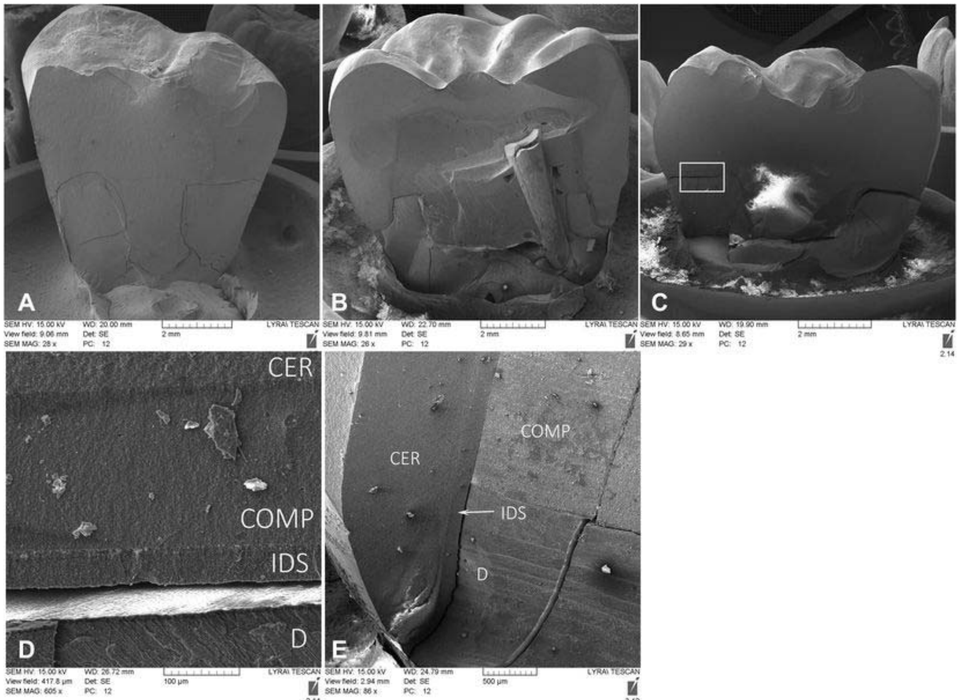

Figure 3. *Scanning electron microscope images of group C (A), P-LDS (B), EC (C), magnification of the IDS-dentin interface of group EC (D) and close-up of group LDS (E). Cracks are forming within the pulp chamber (A, B, and C). Fatigue crack propagation with their progression marks is clearly seen on both of the initiation points of the load-cell in group EC (C). Adhesive failure occurred between IDS and dentin, while the IDS-composite resin bonding remained intact (C and E). (E) The ceramic is still bonded to the direct composite build-up and IDS layer but is debonded between the dentin-IDS interface.*

possibilities of this material is needed. The use of a post did not result in more favorable fractures for CP (only one repairable failure), as opposed to Salameh and others, who found 100% restorable fractures when a glass fiber post was present.[23] This can be explained because the specimens in this study failed under a much higher load. As for the full contour crowns, the use of a post did not result in more repairable failures (five repairable failures for LDS and P-LDS). This is confirmed by another study.[29]

As is apparent from Figure 3D,E, when the adhesive interface is challenged by tensile forces due to fracture, the dentin-adhesive bond still remains the weakest link.

Several factors influence fracture resistance, such as direction of the force, crosshead speed and tooth embedment.[20,33] Some authors advise simulating the periodontal ligament.[33] Due to the risk of changes in the periodontal ligament material as a result of the extensive aging, no simulation of the periodontal ligament was incorporated.

In this study, the load was directed along the axis of the tooth, which resembles the direction of intraoral forces. However, a continuous load is not typically encountered in the mouth. During function, restorations are subjected to more fatigue loading. This was simulated by means of a chewing simulator. It is estimated that during normal function, the maximum whole tooth load varies between 70.6 N and 146 N.[34,35] In the present study, a load of 50 N was used during aging, which may have been too low. In contrast, Rosentritt and others stated that 1.2×10^6 times 50N may be sufficient to estimate the survival rate *in vivo*.[36] In future studies, cyclic loading might be a better simulation of the clinical environment.

From a clinical point of view, it is important to consider the consequences of creating a ferrule on severely compromised teeth: enamel is lost and surgical crown lengthening is often necessary. Moreover, adhesive cementation in these cases might not be possible any more, thereby reducing the fracture strength of the glass ceramic.[37] The results of this study contribute to the evidence of adhesive rehabilitation of such biomechanically compromised endodontically treated molar teeth, whether by means of direct composite or glass ceramic endocrowns, although more clinical research is needed.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following could be concluded:

- Under axial loading, direct composite restorations showed similar fracture strength values as lithium disilicate crowns with a composite post-and-core buildup and endocrowns;

- Endocrowns performed similar in terms of fracture strength compared with full contour lithium disilicate crowns;
- The use of a glass fiber post did not influence fracture strength;
- The use of a glass fiber reinforced composite core was associated with more repairable failures.

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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 the Medical Ethical Commission, University Medical Center Groningen.

Conflict of Interest

The authors of this article declare that they have no conflict of interest with any product, service, or company that is presented in this article.

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