The usage of short fiber-reinforced composites to restore anterior and posterior teeth with direct restorative techniques

Based on the PhD thesis of the same title

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Publications providing the basis of the thesis:

I. **Sáry T**, Garoushi S, Braunitzer G, Alleman D, Volom A, Fráter M. Fracture behaviour of MOD restorations reinforced by various fiber-reinforced techniques - An in vitro study. J Mech Behav Biomed Mater. 2019 Oct;98:348-356. doi: 10.1016/j.jmbbm.2019.07.006.

II. **Sáry T**, Garoushi S, Braunitzer G, Alleman D, Volom A, Fráter M. Corrigendum to "Fracture behaviour of MOD restorations reinforced by various fiber reinforced techniques - An in vitro study" [J. Mech. Behav. Biomed. Mater. 98 (2019) 348-356]. J Mech Behav Biomed Mater. 2020 Feb;102:103505. doi:10.1016/j.jmbbm.2019.103505. Epub 2019 Nov 4. Erratum for: J Mech Behav Biomed Mater. 2019 Oct;98:348-356. PMID: 31694796.

III. Fráter M, **Sáry T**, Néma V, Braunitzer G, Vallittu P, Lassila L, Garoushi S: Fatigue failure load of immature anterior teeth: Influence of different fiber post-core systems. Odontology. 2020 May 2. doi: 10.1007/s10266-020-00522-y.

IV. Fráter M, **Sáry T**, Garoushi S. Bioblock technique to treat severe internal resorption with subsequent periapical pathology: a case report. Restor Dent Endod. 2020 Aug 18;45(4):e43. doi: 10.5395/rde.2020.45.e43.

Related publications:

I. Forster A, **Sáry T**, Braunitzer G, Fráter M. In vitro fracture resistance of endodontically treated premolar teeth restored with a direct layered fiber-reinforced composite post and core. J Adhes Sci Technol. 2016;31:1454–66. https ://doi.org/10.1080/01694243.2016.12597 58.

II. Balázs Szabó P., **Tekla Sáry**, Balázs Szabó. The key elements of conducting load to fracture mechanical testing on restoration-tooth units in restorative dentistry. Analecta Technica Szegedinensia. 2019. Vol. 13., No. 2. doi: 10.14232/analecta.2019.2.59-64

III. Fráter M, **Sáry T**, Jókai B, Braunitzer G, Säilynoja E, Vallittu PK, Lassila L, Garoushi S. Fatigue behavior of endodontically treated premolars restored with different fiber-reinforced designs. Dent Mater. 2021 Mar;37(3):391-402. doi: 10.1016/j.dental.2020.11.026.

IV. Fráter M, **Sáry T**, Braunitzer G, Balázs Szabó P, Lassila L, Vallittu PK, Garoushi S. Fatigue failure of anterior teeth without ferrule restored with individualized fiber-reinforced post-core foundations. J Mech Behav Biomed Mater. 2021 Mar 3;118:104440. doi: 10.1016/j.jmbbm.2021.104440.

V. Fráter M, **Sáry T,** Vincze-Bandi E, Volom A, Braunitzer G, Szabó P B., Garoushi S, Forster A. Fracture Behavior of Short Fiber-Reinforced Direct Restorations in Large MOD Cavities. Polymers 2021, 13, 2040. https://doi.org/10.3390/polym13132040

Introduction

Mimicry in the field of science involves reproducing or copying a model, a reference. If we, dentists, want to replace what has been lost, we need to agree on what is the correct reference. For the restorative dentist, this unquestionable reference is the intact natural tooth. Natural teeth, through the optimal combination of enamel and dentin, demonstrate the perfect and unmatched compromise between stiffness, strength and resilience. Restorative procedures and alterations in the structural integrity of teeth can easily violate this subtle balance.

Physiologic performance of intact teeth is the result of an intimate and balanced relationship between biological, mechanical, functional and esthetic parameters. In modern dental practice, the restoration and the tooth should form a structurally adhesive and optically cohesive medium, which has the ability to withstand repetitive multi-axial biomechanical force loads over a prolonged period of time. The definition of the term “biomimetic” in the field of restorative dentistry is the study of the structure and function of the tooth tissue as a model for the design and manufacturing of materials, and techniques to restore teeth. In fact, the primary aims of biomimetic dentistry are to be as minimally invasive as possible, and to substitute the missing hard dental tissues with restorative materials closely resembling the natural tissues regarding their mechanical features and properties. A typical biomimetic restorative approach is the combined use of artificial materials to replace different hard dental tissues, such as the use of porcelain to replace enamel and composite resins to replace dentin, combined with optimized bonding strategies. This construction is possible if we choose an indirect treatment for restorative purposes. As logical as it might seem, however, the use of this approach is limited in practice, due to both financial and technical limitations. Practically, the most challenging aspect is the ability to apply all these engineering concepts in the small biological structure of a tooth.

Increased use of composite materials in both anterior and posterior regions has made technological advances in this field necessary. In spite of the fact that both amalgam and composite resin are considered to be suitable materials for restoring Class I and Class II cavities in both premolar and molar teeth, in many countries resin composites have almost totally replaced amalgam as a restorative material in posterior teeth. Magne et al. showed that amalgam fillings in Class I and Class II cavities could not ideally reinforce the tooth and could not substitute the missing dental tooth structure in terms of biomechanical features. Resin composite restorations in the posterior region have shown good overall clinical performance in small and medium sized fillings, with annual failure rates mostly between 1-3 %. However, large restorations showed a tendency to fail due to mechanical, fracture-related problems, resulting in decreased longevity. It seems from the literature that resin composite fillings show limitations due to their insufficient mechanical properties when utilized to restore large cavities.

Many studies have aimed to improve the mechanical properties of composite resins. Fracture within the body and at the margins of restorations, polymerization shrinkage and secondary caries have been cited as major problems regarding the mechanical failure of posterior composites. The fracture-related material properties, such as fracture resistance, deformation under occlusal load, and the marginal degradation of materials have usually been evaluated by the determination of the basic material parameters: flexural strength and fracture toughness. From a biomimetic point of view, we aspire to replace dentin with materials that have similar biomechanical properties. Fracture toughness of microhybrid and nanohybrid composite resin materials are significantly lower than that of dentin [8]. Regarding the microstructure, composite resins consist of filler particles (generally not fibers) embedded in a resin matrix, whereas dentin consists of collagen fibers embedded in a hydroxyapatite matrix. Consequently, observing the microanatomy of the tissue itself, dentin should rather be seen as a fiber-reinforced composite instead of a particulate filler one. Composite resins which are reinforced with millimeter scale short fibers show a quite interesting similarity to natural dentin, considering their microstructure and their biomechanical properties. Studies have shown that short fiber-reinforced composite (SFRC) differed significantly and has superior fracture toughness, flexural strength, and flexural modulus compared to other tested bulk-fill or conventional composite resin materials. Also, the studies have shown a strong correlation between fatigue performance and the material's fracture toughness, and the SFRC was able to withstand both compressive static and fatigue loads. The mentioned toughening capability of SFRC over their competition materials is due to two main factors: the millimeter-scale short fibers, which fulfill the critical fiber length measures, and the semi-interpenetrating polymer network (semi-IPN) structure.

The studies described in this thesis sought to examine how fiber-reinforced composite (FRC) materials can be used in the most efficient way to reinforce the dental structure in both endodontically non-treated and root canal treated cases.

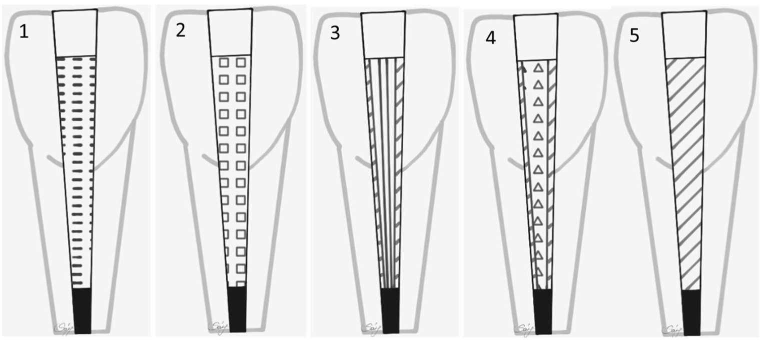
Material and Method

For the **anterior** study, four hundred upper bovine incisors were collected and stored in 0.5% chloramine-T. The largest oro-vestibular and mesio-distal dimension and the hight of the coronal portion from the cemento-enamel junction (CEJ) were measured. The oro-vestibular and mesio-distal dimensions of the root part were also measured. According to the measurements, only the teeth with a maximum deviation of 10% from the determined mean were included in this study (a sum of one hundred-eighty teeth).

Teeth were randomly distributed among 6 study groups (n=30). One group was left intact to later serve as control (Group 6). The rest of the teeth (Group 1.-5.) were cut to obtain a length of 12 mm below the CEJ using a slow-speed, water-cooled diamond disc. Furthermore, after sectioning of the apical part, all teeth were examined under magnification for root fractures. Coronal access was made by using a round-end parallel diamond (881.31.014 FG – Brasseler USA Dental, Savannah, GA, USA) and an Endo Z bur (Dentsply Maillefer, Tulsa, OK, USA) in a high-speed handpiece. Next, the root canal was enlarged by Gates Glidden burs No. 1-6 with copious water cooling until an ISO size #140 could be passively extended through the apex. Each canal was then prepared with a GC Fiber Post drill size 1.6 (GC Europe, Leuven, Belgium) in order to simulate an immature tooth with thin walls. A 4-mm apical plug of grey Pro-Root MTA (mineral trioxid aggregate) (Dentsply Tulsa Dental, Tulsa, OK, USA) was placed in each tooth with a MAP System (Dentsply Maillefer, Tulsa, OK, USA). After complete setting of the MTA was confirmed with an endodontic explorer the teeth were further restored. The radicular dentin was refreshened with a No. 4 Gates Glidden bur and flushed with chlorhexidine and saline. The enamel borders of the coronal cavity were acid-etched selectively with 37% phosphoric acid and rinsed with water. After drying the cavity completely, a dual-cure one-step self-etch adhesive system (G-Premio Bond and DCA, GC Europe, Leuven, Belgium) was used for bonding according to the manufacturer's instructions. The adhesive was light cured for 60 s using an Optilux 501 quartztungsten-halogen light-curing unit (Kerr Corp., Orange, CA, USA).

The teeth in all groups were then treated as follows (Figure 1):

1. Figure: Schematic figure representing the anterior test groups (Group 1–5).



Group 1: The teeth were reconstructed with the Bioblock technique described by Fráter et al. building a direct layered FRC post and core from SFRC (everX Posterior, GC Europe).

Group 2: The teeth were reconstructed with SFRC flow (GC Europe) as described in Group 1.

Group 4: the teeth received a 1.6 mm diameter conventional FRC post (GC Fiber Post, GC Europe).

Group 5: The teeth were reconstructed with a dual-cure resin composite core material (Gradia Core, GC Europe) without any FRC material.

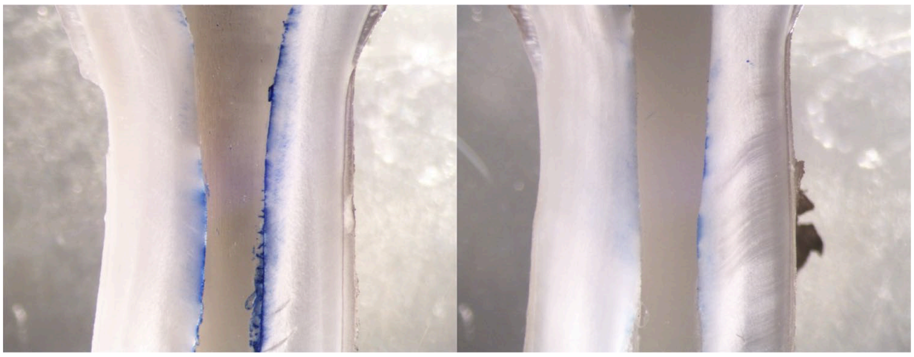
To simulate the periodontal ligaments, the root surface of each tooth was coated with a layer of liquid latex separating material prior to embedding. All specimens were embedded in methacrylate resin at 2 mm from the CEJ to simulate the bone level.

After the restorative procedures, mechanical testing was carried out on 25 anterior teeth from each group (n= 150) and 5 anterior teeth from each restored group (n=25) underwent sectioning, microleakage and microhardness testing.

For mechanical testing, the restored specimens were submitted to a modified accelerated fatigue-testing protocol by a hydraulic testing machine at an angle of 135 degrees to the long axis of each tooth. Cyclic isometric loading was applied on the palatal surface of the coronal part of the tooth using a round-shaped metallic tip. A cyclic load was applied at a frequency of 5 Hz, starting with gradually increasing static loading till 100 N in 5 seconds, followed by cyclic loading in stages of 100 N, 200 N, 300 N, 400 N, 500 N and 600 N at 5,000 cycles each. Specimens were loaded until fracture occurred or until the total of 30 000 cycles were carried out, which was the whole testing procedure. For the survival analyses, the number of cycles at which the specimen failed were recorded.

For the microleakage test, teeth were sectioned sagitally in the mid-mesio-distal plane and were dyed with a permanent marker. The dye penetration along the post/core margins of each section was evaluated independently using a stereo-microscope (Heerbrugg M3Z, Heerbrugg, Switzerland) at a magnification of 6.5x. The extent of dye penetration was recorded in mms and was later calculated as a percentage of the total margin length (Figure 2).

2. Figure: Pictures of sectioned specimens (Groups 4 and 5) showing microgaps at resin composite-root canal interface.



The microhardness of the luting composite and the SFRC inside the canal was measured using a Struers Duramin hardness microscope (Struers, Copenhagen, Denmark) with a 40 objective lens and a load of 1.96 N applied for 10 s.

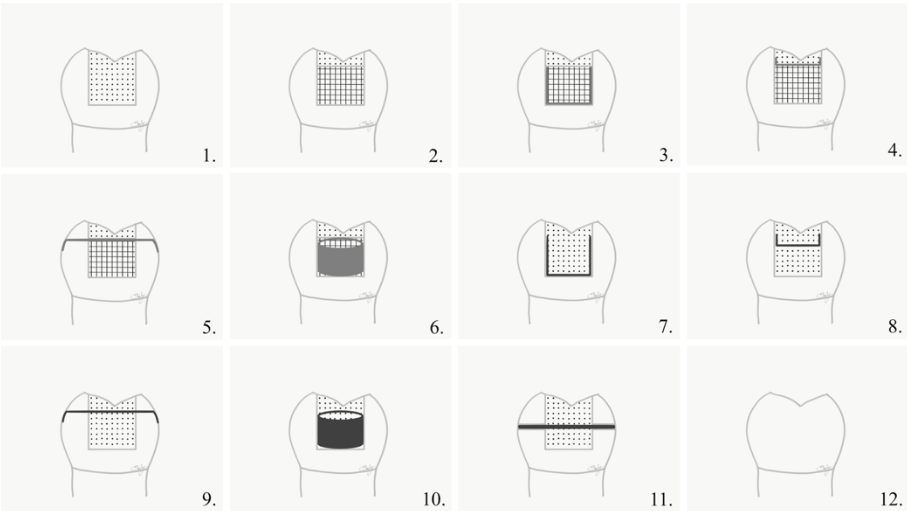
For the **posterior** study, 240 mandibular third molars were selected that were extracted for periodontal or orthodontic reasons. The freshly extracted teeth were immediately placed in 5.25% NaOCl for 5 minutes and then stored in 0.9% saline solution at room temperature until use, all within 2 months of extraction. The inclusion criteria were the same as in the anterior study.

The teeth were randomly distributed over 12 study groups (n=20). One group was left intact to later serve as control (Group 12). The rest of the teeth received a standardized MOD cavity preparation with the remaining walls being 2.5 mms thick and the depth of the cavity being 5 mms deep, prepared by the same trained operator as described by Forster et al. The cavities were restored as follows (Figure 3):

Group 1: The cavities were restored with a microhybrid composite restorative material (G-aenial Posterior PJ-E, GC Europe), applied with an oblique incremental technique, placed in consecutive 2 mm thick increments.

Group 2: The cavities were restored with an SFRC material (everX Posterior) applied in a bulk-fill technique.

3. Figure: Schematic figure representing the molar test groups (Group 1-12).



Group 3: A piece of 3 mm wide pre-impregnated glass fiber net (everStickNET, GC Europe) with a size approx. the same as the remaining cavity was cut and placed on "the bottom" of the cavity in a bucco-lingual direction. The net was placed in a way that it would not reach the margins of the cavity, leaving 1.5-2 mm space for the future occlusal composite layer.
After curing for 40 s, the cavity was restored with SFRC and a final layer of occlusal composite as described in Group 2.

Group 4: First, the cavities were restored with SFRC as described in Group 2. When there was only approx. 1.5-2 mm space remaining occlusally in the cavity, a piece of 3 mm wide pre-impregnated glass fiber net (everStickNET) was placed on the cavity walls in a bucco-lingual direction. The net was placed so that it would not reach the margins of the cavity. After curing for 40 s, the cavity was restored with a final layer of occlusal composite as in Group 2.

Group 5: The cavities were restored with SFRC and a final layer of occlusal composite as in Group 2. After finishing the restoration, a 4 mm wide and 1.5 mm deep groove was prepared on the occlusal surface of the restoration between the cusp tips, from a buccal to lingual direction, with a high-speed bur under water cooling. Both end of each groove was on the coronal one-third of the buccal and lingual walls of the teeth. After selective enamel etching in the mentioned area, the groove was rinsed, dried and adhesively treated. A piece of pre-impregnated glass fiber net, matching the size of the prepared groove, was cut and placed into the groove. After curing for 40 s, the cavity was restored with a final layer of occlusal composite as in Group 2.

Group 6: 1 piece of 3 mm wide pre-impregnated glass fiber net was placed in the cavity, applied circumferentially to the walls. The net was placed so that it would cover the axial walls but not reach the margins of the cavity. After curing for 40 s, the cavity was restored with SFRC and a final layer of occlusal composite as in Group 2.

Group 7: 1 piece of 3 mm wide LWUHMW polyethylene ribbon fiber (Ribbond-Ultra THM; Ribbond Inc., Seattle WA, USA) was placed into the cavity covering the cavity walls in a bucco-lingual direction forming a fiber layer with Ribbond just as in Group 3, only there with the glass fiber net. In all groups where polyethylene fibers were used, the fibers were first saturated with adhesive resin (StickRESIN, GC Europe), the excess resin was removed with a hand instrument and then placed into the bed of un-cured flowable composite (G-aenial Universal Flo, GC Europe). The fiber was placed in so that it would not reach the margins of the cavity. After curing for 40 s, the cavity was restored with microhybrid composite as in Group 1.

Group 8: The cavities were restored with a microhybrid composite applied in an oblique incremental technique. The material was placed in consecutive 2 mm thick increments. When there was only approx. 1.5-2 mm space remaining of the cavity occlusally, 1 piece of 3 mm wide LWUHMW polyethylene ribbon fiber (Ribbond-Ultra THM) was cut and placed in the remaining cavity in a bucco-lingual direction, forming a fiber layer with Ribbond just as in Group 4 with the glass fiber net. After handling of the fibers and curing for 40s, the cavity was restored with a final layer of occlusal composite as in Group 1.

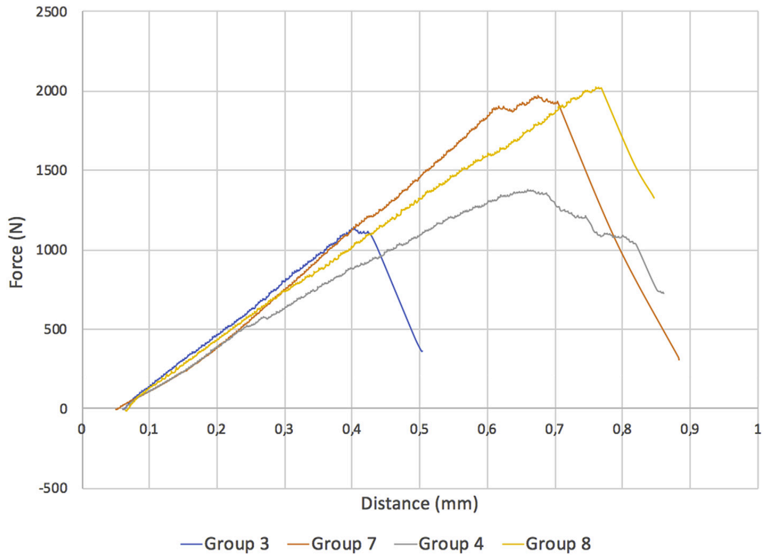
Group 9: the cavity was restored with microhybrid composite as in Group 1. After finishing the restoration, a 4 mm wide and 1 mm deep groove was prepared on the occlusal surface of the restoration between the cusp tips, from a buccal to lingual direction, with a high-speed bur under water cooling. The end of each groove was on the coronal one-third of the buccal and lingual walls of the teeth. After adequate adhesive treatment a piece of LWUHMW polyethylene ribbon fiber (Ribbond-Ultra THM) was placed into the groove. After handling of the fibers and curing for 40 s, the cavity was restored with a final layer of occlusal composite.

Group 10: A piece of LWUHMW polyethylene ribbon fiber was cut and placed on the cavity walls circumferentially. The fiber was handled and adapted into flowable composite as in Group 7. After curing for 40 s, the cavity was restored with microhybrid composite as in Group 1.

Group 11: 1 piece of 1 mm wide LWUHMW polyethylene ribbon ((Ribbond Ultra Orthodontic; Ribbond Inc., Seattle WA, USA) was placed through the previously performed holes on the buccal and lingual walls. This ribbon was placed into the prepared grooves on the external coronal surfaces, connecting the opposing walls like a tightrope. First the polyethylene fibers were fixed in one groove, light cured and covered with composite, and subsequently the rest of the fibers on the opposing side were tightly positioned with a tweezer and fixed to the opposing groove by light curing and composite coverage. This produced a “transcoronal splinting” inside the cavity. After curing for 40s, the cavity was restored with microhybrid composite as in Group 1.

The restored specimens were stored in physiological saline solution and subsequently embedded as described previously in the anterior study. Immediately after embedding, all specimens were subjected to a fracture resistance test. Teeth were quasi-statically loaded with a crosshead speed of 2 mm/minute, parallel to the long axis of the tooth in a universal testing machine, until they fractured. A force vs. distance curve was dynamically plotted for each tooth. In each case the specific failure load was determined when the force versus distance curve showed an abrupt change in load, indicating a sudden decrease in the specimen’s resistance to compressive loading (Figure 4)

4. Figure: Force versus distance curves of specimens representing each study groups. Peaks indicate the amount of maximal failure load.



After recording failure load, each specimen was visually examined for the type and location of failure (restorable or non-restorable fracture), as described above in the anterior study.

Statistical analysis was conducted in SPSS 23.0 (SPSS Inc., Chicago, IL).

In the **anterior** study the number of survived cycles was analyzed descriptively for each group and with the Kaplan-Meier method across the groups (with the Breslow test for the pairwise analyses). The frequency of restorable and non-restorable fractures was calculated for each group.

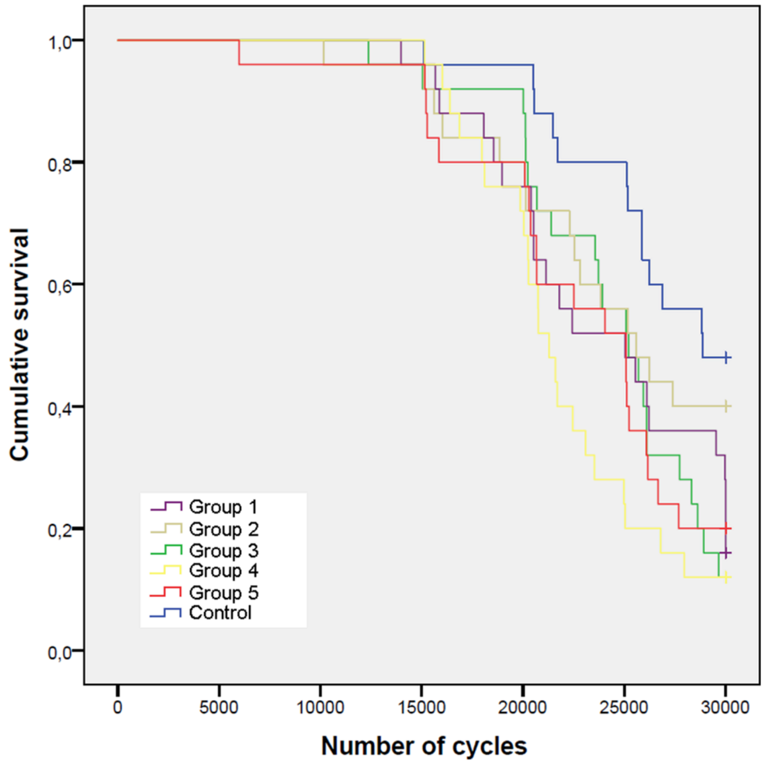
In the **molar** study for the comparisons between the groups, ANOVA with Tukey's HSD post-hoc test was used.

The general limit of significance was set at α=0.05 on both studies.

Results

The Kaplan–Meier survival curves of the **anterior** samples are displayed in Figure 5. Table 1 shows the p values for group-wise comparisons. In the anterior study the survival rate of Group 2 did not differ significantly from the intact teeth (control group). The rest of the anterior groups had significantly lower survival rates compared to the anterior control group. All restored anterior groups showed exclusively irreparable fractures, whereas the control group had some that were reparable, but most fractures were irreparable in this group as well (Table 2).

5. Figure: Fatigue resistance survival curves (Kaplan–Meier survival estimator) for all six groups.



1. Table: p values of pairwise log-rank post hoc comparisons (Kaplan–Meier survival estimator followed by log-rank test for cycles until failure or the end of the fatigue loading among all 6 groups)

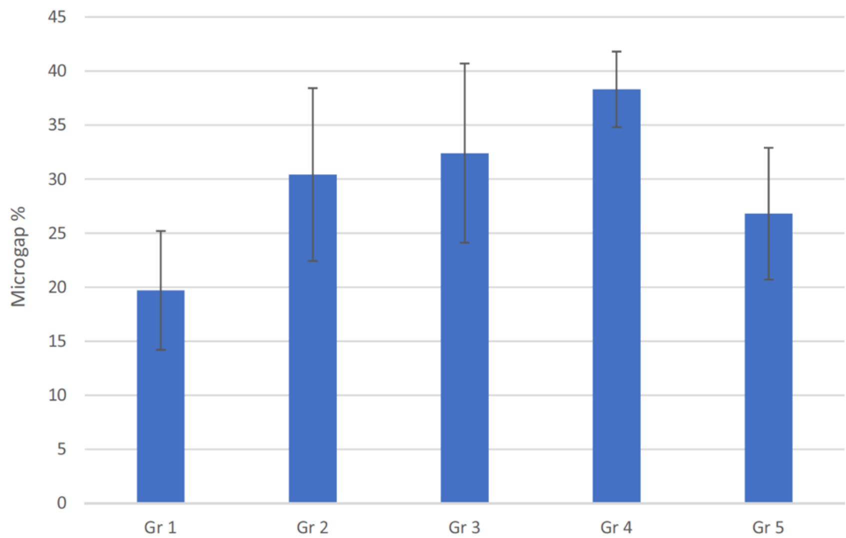
GROUPS	Control		Group 1		Group 2		Group 3		Group 4		Group 5	
	Chi square	Sig.	Chi square	Sig.	Chi square	Sig.	Chi square	Sig.	Chi square	Sig.	Chi square	Sig.
Control (intact teeth)	-	-	5.551	0.018	1.722	0.189	6.208	0.013	13.801	0.000	7.083	0.008
Group 1	5.551	0.018	-	-	0.793	0.373	0.000	1.000	1.434	0.231	0.143	0.705
Group 2	1.722	0.189	0.793	0.373	-	-	0.355	0.551	3.401	0.065	1.003	0.316
Group 3	6.208	0.013	0.000	1.000	0.355	0.551	-	-	3.467	0.063	0.254	0.614
Group 4	13.801	0.000	1.434	0.231	3.401	0.065	3.467	0.065	-	-	1.027	0.311
Group 5	7.083	0.008	0.143	0.705	1.003	0.316	0.254	0.614	1.027	0.311	-	-

2. Table: The distribution of fracture pattern among the study groups (n = 25)

FRACTURE PATTER	Group 1	Group 2	Group 3	Group 4	Group 5	Intact teeth
Restorable	0	0	0	0	0	2
Non-restorable	18	15	22	22	20	11
Fractured teeth	18	15	22	22	20	13
Non-fractured teeth	7	10	3	3	5	12

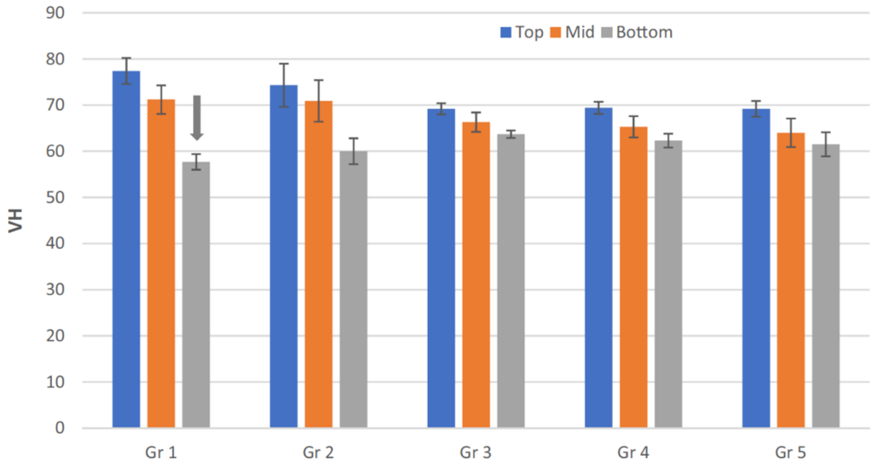
The mean values and standard deviations of microgap percentages at the post/core-root canal interface of the five restored anterior groups are presented in Figure 6. According to our findings, the Bioblock technique (Group 1) had low percentage of microgaps (19.7%) compared to the other groups, whereas Group 4 exhibited a remarkably high number of microgaps (38.3%) at the examined interphase in the root canal.

6. Figure: Mean percentage of microgaps observed in the anterior restored groups



The surface microhardness (Vickers hardness) of the luting composite and SFRCs decreased gradually within a limited range with increasing depth (Figure 7). The data showed no difference in Vickers hardness values between the tested dual-core luting composite and SFRCs at the top and middle parts of the canal. However, at the apical part, packable SFRC (Group 1) presented the most drastic decrease along with Vickers hardness values.

7. Figure: Microhardness (Vickers hardness) mean values for resin composites at the top (coronal), middle and bottom (apical) part of the root canal. The arrow above Group 1's third/bottom column indicates that the Vickers hardness of this group dropped below 80% of the coronal part's value. Vertical lines represent standard deviation (SD)



Regarding the **molar** study, Table 3. summarizes the fracture thresholds for the different study groups. Teeth with transcoronal splinting (Group 11) yielded the highest fracture resistance among the restored molar groups, and interestingly, this was slightly even higher than that of the molar control group (intact teeth). Groups 1, 3 and 4 showed significantly lower fracture resistance values compared to intact molar teeth. The results of the post-hoc pairwise comparisons (Tukey's HSD) are given in Table 4. In terms of fracture pattern (Table 5.), the type and position of fibers within the restoration influenced the ratio of favorable and unfavorable fractures. Only SFRC (Group 2) was characterized by the highest percentage of favorable (i.e. reparable) fractures, while composite alone (Group 1) and transcoronal splinting (Group 11) yielded the lowest ratio.

3. Table: Descriptive statistics of the results by group. Group 1: composite; Group 2: SFRC; Group 3: B-L net at the bottom; Group 4: B-L net at the top; Group 5: net occlusal splinting; Group 6: net circumferential; Group 7: Ribbond B-L at the bottom; Group 8 Ribbond B-L at the top; Group 9: Ribbond occlusal splinting; Group 10: Ribbond circumferential; Group 11: Ribbond transcoronal splinting; Group 12: control

GROUPS	n	Mean (Newton)	SD
Group 1	20	1629.45	503.11
Group 2	20	1746.25	467.50
Group 3	20	1122.20	440.04
Group 4	20	1408.65	314.59
Group 5	20	1925.60	792.69
Group 6	20	2067.30	535.80
Group 7	20	1834.40	578.56
Group 8	20	2022.05	771.41
Group 9	20	2129.25	629.75

Group 10	20	1906.95	538.09
Group 11	20	2484.80	682.90
Group1 12	20	2266.30	601.14

4. Table: Significance matrix from the post-hoc pairwise comparisons (Tukey's HSD). The conventions are the same as in Table 1. Empty cells indicate lack of significance.

GROUPS	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12
Group 1	-										0.000	0.033
Group 2		-	0.041								0.005	
Group 3		0.041	-		0.001	0.000	0.009	0.000	0.000	0.002	0.000	0.000
Group 4				-		0.002		0.049	0.007		0.000	0.000
Group 5			0.001		-							
Group 6			0.000	0.023		-						
Group 7			0.009				-				0.026	
Group 8			0.000	0.049				-				
Group 9			0.000	0.007					-			
Group 10			0.002							-		
Group 11	0.000	0.005	0.000	0.000			0.026				-	
Group1 12	0.033		0.000	0.000								-

5. Table: Fracture pattern by groups. Number of observation and group percentages. The conventions are the same as in Table 1.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12
Reparable	4 (20%)	16 (80%)	8 (40%)	14 (70%)	13 (65%)	14 (70%)	8 (40%)	10 (50%)	10 (50%)	12 (60%)	4 (20%)	18 (90%)
Irreparable	16 (80%)	4 (20%)	12 (60%)	6 (30%)	7 (30%)	6 (30%)	12 (60%)	10 (50%)	10 (50%)	8 (40%)	16 (80%)	2 (10%)

Discussion and Conclusions

- The restoration of immature anterior teeth with the use of flowable SFRC as post-core material displayed promising performance in terms of fatigue resistance and survival.
- Microgap formation within the root canal does not seem to show direct correlation with fatigue survival values in case of immature anterior teeth.
- Surface microhardness values of the tested restorative materials decreased as the depth increased in the root canal.
- The surface microhardness values of SFRC materials utilized in the Bioblock technique were comparable to dual dual-cure materials within the root canal.
- Deep MOD cavities in non-root canal treated molars can be reinforced with fibers utilized in direct restorative techniques.
- Regarding fracture resistance, the use of polyethylene fibers seems to always be beneficial in the direct composite restoration of deep MOD non-root canal treated molars, regardless of position within the cavity or the restoration itself.
- Regarding fracture resistance, the efficacy of glass fiber net used together with SFRC for restoring non-root canal treated molars with large MOD cavities is highly dependent on the position of the net within the cavity or the restoration,
- Bulk-applied SFRC (to substitute dentin and the DEJ) covered with composite can reinforce deep MOD cavities in non-root canal treated molars.
- If fracture occurs within direct composite restorations used for the restoration of deep MOD cavities in non-root canal treated molars, it is predominantly an unfavorable (irreparable) fracture.

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