A Comparative Study of Mechanical Properties of Different Types of Fiber Reinforced Composites Used in Periodontal Therapy

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Fiber reinforced composites (FRC) are used in periodontal therapy for stabilization of mobile teeth with compromised bone support. The type of fiber and the type of composite have a great influence on mechanical properties of FRC. The specimens made of different FRC systems were subject to a three-point bending test. The results indicate that the specimens which exerted the best ratio between high deflection, low flexural modulus and medium flexural strength have the best indications to be used in periodontal therapy. Regarding the fracture pattern, the FRC recommended for splinting are those that separate in two discrete parts while maintaining an intact polyethylene fiber. This aspect allows intraoral repairs, increasing the life-span of the periodontal splints.

Keyword: fiber reinforced composite, periodontal splint, three-point bending test

Fiber reinforced composite (FRC) is a combination of fiber and resin matrix. The fiber is the reinforcing part, providing stability and stiffness, while the resin matrix is the protecting part, assuring the reinforcement and the possibility to work with the material [1, 2].

The mechanical characteristics and the effectiveness of the fiber reinforcement in FRC are based on fiber type (Glass, Polyethylene, Carbon, Aramid), quantity of fibers, fiber structure including unidirectional, bidirectional and randomly oriented fiber, fiber position, fiber-resin matrix adhesion, fiber and resin matrix properties, quality of fiber impregnation and water sorption of the matrix [3-5].

In dental applications, these materials are usually subject to flexure or bending. While clinical performance is the final criterion of success, flexure is still the most widely reported mechanical property, and test results are useful in developing and selecting new materials for clinical use [1, 6, 7].

Fiber reinforced composites are used for stabilization of mobile teeth with compromised periodontal support, allowing also the rehabilitation of masticatory function. In the scientific literature very few studies are mentioned regarding the combination of different types of fibers with different types of composite resins [1, 7-10].

This study was designed to investigate the influence of fiber type and design, resin impregnation and type of composite on mechanical properties of fiber reinforced composite. The aim was to assess and compare (1) the maximum load, (2) the maximum deflection, (3) the flexural strength, (4) the flexural modulus and (5) the fracture pattern for different systems of fiber reinforced composite.

Experimental part

In order to evaluate and compare different systems of fiber reinforced composites, the objective was to vary different parameters which can influence the characteristics of the samples: (1) different types of fibers- glass and polyethylene, (2) different designs- unidirectional and braided, (3) different treatments of the fiber- with or without impregnation, (4) different widths of the fiber- 2 and 3 mm, (5) different types of composites- packable and flowable, microhybrid and nanohybrid. Details of the materials used in this experimental study are given in table 1.

Product	*Manufacturer*	*Batch number*	*Type of material and chemical composition*
Construct	Kerr	5102784, 5116767	Ultra-high strength, cold gas plasma-treated silanated biaxial braided polyethylene fibers
Construct Resin	Kerr	5100456	Fumed silica, grounded barium alumina-borosilicate, dimethacrylate resins, silane
Interlig	Angelus	30643	Braided glass fiber impregnated with light cured composite resin
Splint-it	Pentron	182141	Unidirectional glassfiber impregnated with resin
Filtek Z250	3M Espe	N602076	Microhybrid composite
Premise Packable	Kerr	4957927	Trimodal nano-filled composite
Premise Flowable	Kerr	5123370	Trimodal nano-filled composite
Brilliant Flowable	Coltene	F52923	Nano-filled composite

Table 1
MATERIALS USED FOR SPECIMEN PREPARATION

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Specimens divided in groups (n=5)	*Type of fiber*	*Width of fiber*	*Composite resin*
A1	Construct	2 mm	Filtek Z250
A2	Interlig	2 mm	Filtek Z250
A3	Construct	3 mm	Filtek Z250
A4	Splint-it	3 mm	Filtek Z250
B1	Construct	2 mm	Premise Packable
B2	Interlig	2 mm	Premise Packable
B3	Construct	3 mm	Premise Packable
B4	Splint-it	3 mm	Premise Packable
C1	Construct	2 mm	Premise Flowable
C2	Interlig	2 mm	Premise Flowable
C3	Construct	3 mm	Premise Flowable
C4	Splint-it	3 mm	Premise Flowable
D1	Construct	2 mm	Brilliant Flowable
D2	Interlig	2 mm	Brilliant Flowable
D3	Construct	3 mm	Brilliant Flowable
D4	Splint-it	3 mm	Brilliant Flowable

Table 2
SPECIMENS DIVIDED IN 16 GROUPS VARYING THE TYPE AND THE WIDTH OF THE FIBER AND THE COMPOSITE RESIN USED

Specimen preparation

A total of 80 specimens were divided in 16 groups (n=5) (table 2) and prepared according to ISO Standard 4049/2000 [11].

The first step was to fabricate a stainless steel bar-shape specimen with the following measurements: 2x2x25mm. After recording the impression of the bar with polysiloxane condensation silicon (Zetaplus, Zhermack) we obtain a mold with the established dimensions (fig.1, 2). A first increment of 0.9mm thickness of resin composite was layered in each mold and then a 25mm long segment of fiber was placed on top of the composite. In the groups where Construct fiber was used, the fiber was previously hand impregnated with the manufacturer specified resin (Construct Resin, Kerr) (fig. 3, 4).

The light-curing of the specimens was performed in three phases, 20 s of light-exposure for each of the three thirds. The LED curing light unit had 1100 mW/cm^2 power, 430-480nm wavelength and it was positioned at 5mm distance between the tip and the specimen (fig. 4).

A second layer of composite resin was applied to fill up the mold and it underwent the same curing procedure (fig. 5). After taking the specimens out of the mold, the thickness and the width were measured using a digital micrometer with an accuracy of 0.01mm. The specimens were finished with a silicon carbide grinding paper, until the dimensions of 2±0.05mm in height and in width were obtained. All the procedures were performed by the same person in order to calibrate the protocol. The specimens were stored at room temperature in distilled water for 24 h before mechanical testing (fig. 6).

Mechanical testing

A three-point bending test was carried out to assess the flexural strength and the flexural modulus from the measured deflection of the specimens. The specimens have been tested with static short duration loads on a universal testing machine type WDW-5CE and with a distance of 20 mm between the two supports. The load was applied at the middle of the test specimens perpendicular to the long axis, with a rounded-ended striker at a cross-head speed of 0.05mm/min. The static testing has been performed at room temperature and normal

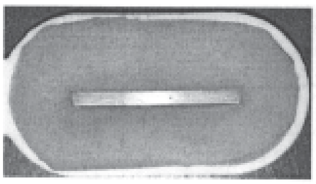

Fig.1. The impression of the stainless steel bar

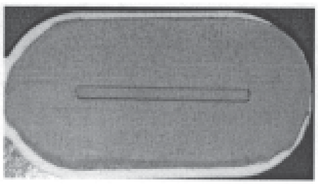

Fig. 2. The silicone mold

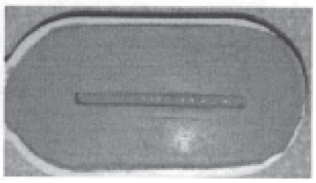

Fig. 3. First layer of composite with 0.9 mm thickness

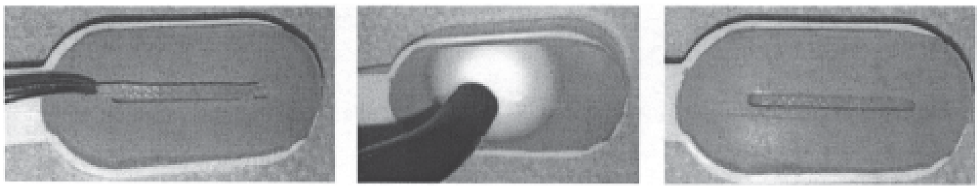

Fig.4. Placing of the fiber on the first layer of composite and light curing for 60 s

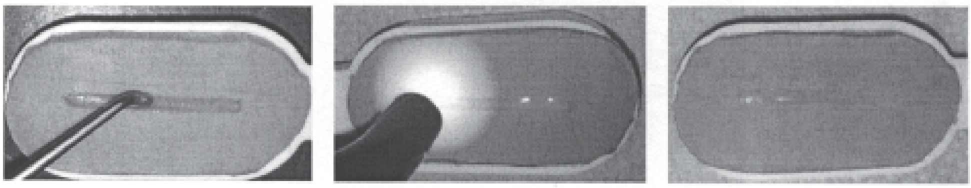

Fig. 5. Placing the second layer of composite and light curing for 60 s

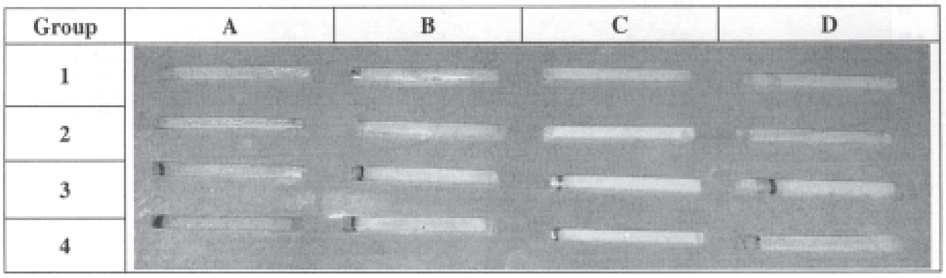

Fig. 6.Specimens categorization in one of the 16 groups with colorimetric marks

humidity conditions. During testing, the load-deflection curves were recorded with computer software.

Bending testing of a unidirectional composite is generally limited to specimens with the fibers aligned parallel to the beam axis. An adequate support span-to-specimen thickness ratio justifies the failure of specimens only due to the bending moment. For three-point bending test, the maximum bending moment in the beam, and hence the location of the maximum tensile and compressive flexural stresses, is at midlength of the beam and is equal to $M_{max} = Fl / 4$. The maximum stress at the surfaces of the beam is [12]:

$$\sigma_{\max} = \frac{M_{\max} \cdot h/2}{I_z} \qquad (1)$$

where:

M_{max} - maximum bending moment; I_z – moment of inertia, for a beam of rectangular cross section- $I_z = b \cdot h^3 / 12$; b - the width of the test specimen; h - the thickness of the test specimen

Substitution of M_{max} and I_z into equation (1) gives:

$$\sigma_{\max} = \frac{\frac{F \cdot l}{4} \cdot \frac{h}{2}}{\frac{b \cdot h^3}{12}} = \frac{3}{2} \cdot \frac{F \cdot l}{b \cdot h^2} \qquad (2)$$

The flexural modulus (E) was calculated with the following formulae:

$$E = \frac{F \cdot l^3}{4 \cdot f_{\max} \cdot bh^3} \qquad (3)$$

where:

l - the span length- the distance between the supports; f_{max}- the deflection of beam.

SEM observations

The structure of each tested specimen was examined using a scanning electron microscope (SEM QUANTA 200 3D,FEI Netherlands). The surface was scanned and observed on the screen at 50x, 100x, and 200x magnifications.

Statistical methods

The collected data were subject to a one-way analysis of variance (ANOVA). All tests were performed at a significance level of $\alpha = 0.05$. Statistical software STATISTICA (data analysis software system, version 8.0., StatSoft, Inc.) was used for statistical data analysis.

Results and discussions

The specimens were tested until fracture failure or until they were displaced from the support. It was noticed that the first fracture line appeared along the axis of the force, on the bottom surface of the specimen where the normal stress of tension is. The crack evolved until the junction layer between the fiber and the composite veneer and then the fracture was spreading along the fiber. In the last stage, cracks appeared at the compression side- the top surface of the composite (fig 7). The fracture failure describes two patterns: the complete transversal separation of the specimens in two parts and the delamination of the composite, while maintaining the fiber integrity. The maximum loads, equivalent to the fracture force and the maximum deflection of the specimens, are presented in tables 3 and 4.

The flexural strength and flexural modulus values were calculated (table 5) based on the table 3 values and the equations (2) and (3) where F represent the load values at the highest point of load-deflection curve.

The maximum force supported by the specimens was founded in the A3 group (52.2±1.41N) and the lowest was in the D1 group (13.61±0.73N).

Regarding the groups with 2 mm width fiber, the following observations were made: the glass fibers reinforced specimens (A2, B2, C2, D2) allow a higher load and consequently a higher fracture force, with no influence from the composite type, when compared with polyethylene fibers reinforced specimens. *Anagnostou* reported higher values of the fracture force for both fiber types: 57.4±7.7N for polyethylene reinforced specimens (Ribbond- THM) and 55.84±2.9N for glass fiber reinforced specimens (Splint-It), but with no statistical differences

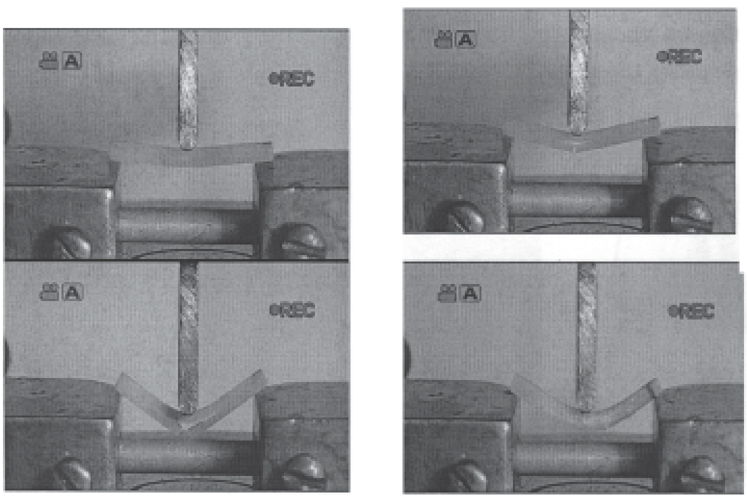

Fig. 7. Stages of the three-point bending test

Groups (n=5)	Maximum load (N)				Maximum deflection (mm)			
	Sum	Average	Std. Dev.	Variance	Sum	Average	Std. Dev.	Variance
A1	74.01	14.80	0.66	0.44	28.29	5.66	0.85	0.73
A2	85.14	17.03	1.31	1.71	11.69	2.34	0.60	0.36
A3	261.00	52.20	1.41	1.99	28.20	5.64	0.68	0.47
A4	105.21	21.04	1.48	2.20	7.45	1.49	0.61	0.38
B1	72.08	14.42	0.99	0.98	15.46	3.09	0.67	0.44
B2	85.06	17.01	0.85	0.72	14.79	2.96	0.50	0.25
B3	196.02	39.20	1.63	2.67	35.81	7.16	0.70	0.49
B4	115.19	23.04	1.03	1.06	9.26	1.85	0.39	0.15
C1	111.98	22.40	1.26	1.58	36.55	7.31	0.69	0.48
C2	143.01	28.60	0.93	0.87	11.83	2.37	0.52	0.27
C3	200.14	40.03	1.27	1.62	28.92	5.78	0.52	0.27
C4	182.99	36.60	1.72	2.95	13.55	2.71	0.61	0.37
D1	68.04	13.61	0.73	0.53	35.45	7.09	0.67	0.46
D2	93.80	18.76	0.96	0.91	19.59	3.92	0.54	0.29
D3	153.90	30.78	1.23	1.51	31.25	6.25	0.63	0.39
D4	153.10	30.62	1.43	2.06	20.09	4.02	0.52	0.27

Table 3
MAXIMUM LOAD AND MAXIMUM DEFLECTION VALUES

	Source of Variation	SS	Df	MS	F	P-value
Maximum load (N)	*Between Groups*	9464.86	15	630.99	424.17	<0.001
	Within Groups	95.21	64	1.49		
	Total	9560.06	79			
Maximum deflection (mm)	*Between Groups*	310.64	15	20.71	54.80	<0.001
	Within Groups	24.19	64	0.38		
	Total	334.83	79			

Table 4
ONE-WAY ANOVA RESULTS FOR MAXIMUM LOAD AND MAXIMUM DEFLECTION

Groups (n=5)	Flexural strength (MPa)				Flexural modulus (GPa)			
	Sum	Average	Std. Dev.	Variance	Sum	Average	Std. Dev.	Variance
A1	913.85	182.77	7.22	52.12	10.01	2.00	0.31	0.10
A2	1051.66	210.33	16.82	282.98	28.93	5.79	1.59	2.53
A3	3222.98	644.60	14.28	203.90	35.14	7.03	0.79	0.63
A4	1299.22	259.84	18.01	324.28	59.67	11.93	4.41	19.49
B1	890.22	178.04	12.46	155.22	18.02	3.60	0.64	0.41
B2	1050.51	210.10	10.68	113.99	22.26	4.45	0.99	0.99
B3	2420.48	484.10	18.16	329.70	20.69	4.14	0.38	0.14
B4	1422.50	284.50	12.34	152.38	48.74	9.75	2.42	5.84
C1	1383.20	276.64	16.73	279.76	11.62	2.32	0.30	0.09
C2	1766.07	353.21	11.01	121.20	46.95	9.39	1.76	3.09
C3	2471.53	494.31	14.53	211.18	26.13	5.23	0.41	0.17
C4	2259.54	451.91	19.28	371.83	52.68	10.54	2.27	5.13
D1	840.27	168.05	9.04	81.68	7.28	1.46	0.20	0.04
D2	1158.26	231.65	11.08	122.83	18.18	3.64	0.35	0.12
D3	1900.64	380.13	15.31	234.39	18.60	3.72	0.27	0.07
D4	1891.01	378.20	19.07	363.67	29.15	5.83	1.03	1.06

Table 5
FLEXURAL STRENGTH AND FLEXURAL MODULUS VALUES

	Source of Variation	SS	df	MS	F	P-value
Flexural strength (MPa)	*Between Groups*	1443128	15	96208.51	452.60	<0.001
	Within Groups	13604.45	64	212.57		
	Total	1456732	79			
Flexural modulus (GPa)	*Between Groups*	769.53	15	51.30	20.58	<0.001
	Within Groups	159.56	64	2.49		
	Total	929.10	79			

Table 6
ONE-WAY ANOVA RESULTS FOR FLEXURAL STRENGTH AND FLEXURAL MODULUS

between the two systems. In our study we used one type of composite for each specimen (flowable or packable), while in Anagnostou study there where used two types of composite for the same specimen: a flowable composite on the bottom of the specimen (Flow-It, Pentron) and a medium viscosity composite above the fiber (Simile, Pentron) [13].

This study showed that different fiber types when combined with given composites have a major impact on the system flexural strengths. The results regarding the higher flexural strength of glass reinforced specimens are in concordance to those reported by Sharafeddin [6]. For the specimens reinforced with unidirectional glass fiber and Filtek Z250, Sharafeddin reports a flexural strength of 500±31.24MPa, which is higher than the flexural strength found in our A2 study group (210.33±16.82MPa). The differences can be explained by the position of the reinforcing fiber at the bottom of the specimen, which concur to an increased maximum flexural strength as Garoushi demonstrated in previous studies. In our study, the fiber was placed at the middle of the specimen [14-15]. For Construct- Premise Flow specimens, Juloski reported a flexural strength of 287.62±85.91MPa, similar to that obtained in this study in C1 group - 276.64 ±16.73MPa [16].

The maximum deflection, which allows a partial elastic recovery, varies between 1.49±0.61mm and 7.31 ±0.69mm. There have been noticed high deflection values

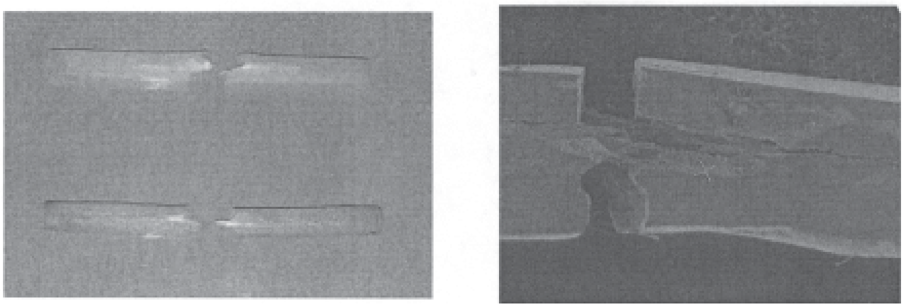

Fig. 8. The fracture pattern of FRC with braided glass (group 2) – macroscopic aspect of the tested specimens and 50x SEM magnification

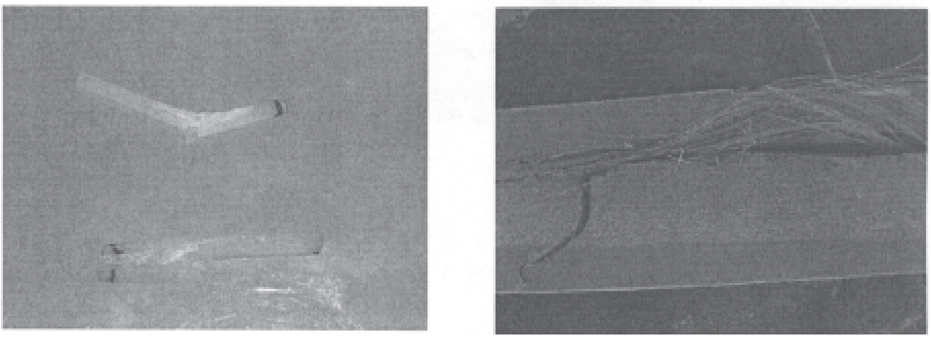

Fig. 9. The fracture pattern of FRC with unidirectional glass (group 4)– macroscopic aspect of the tested specimens and 50x SEM magnification

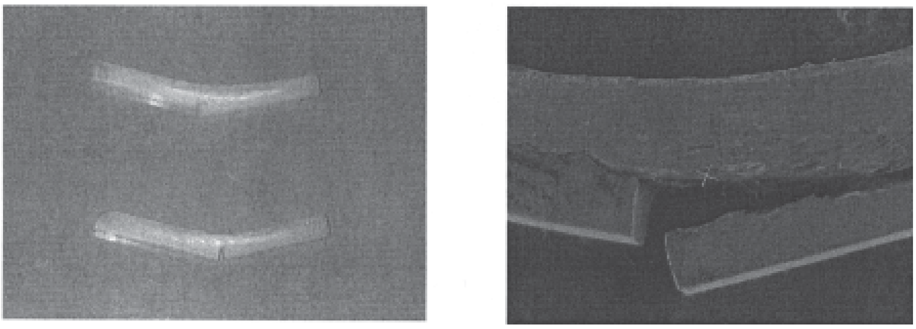

Fig. 10. The fracture pattern of FRC with polyethylene (group 1)– macroscopic aspect of the tested specimens and 50x SEM magnification

for groups A1, B1, C1 and D1, the polyethylene fiber reinforced specimens. These high deflections can be correlated with a low flexural modulus. It is important to high light that the relatively low flexural strength is sometimes desirable in order to allow a minimum of micro movements of splinted teeth, which contributes to the periodontal repair process [16].

When comparing the 2 mm polyethylene fibers with the four types of resins, one can point out that flowable resins allow a higher deflection and a low flexural modulus. Specimens reinforced with glass fiber accept a low deflection and a high flexural modulus which means a high toughness.

For specimens reinforced with 3 mm fibers, the groups with polyethylene registered higher fractures forces compared with glass fibers. The maximum flexural strength was registered in group A3 (Construct+ Filtek Z250) - 644.60±14.28MPa.

Celeste C.M. van Heumen performed meta-regression analyses and observed a lower flexural modulus of polyethylene reinforced specimens regardless the dimension, impregnation, manufacturer or type of composite. This finding is in accordance with the results achieved in the present study [8].

Al-Darwish stated that the fiberglass provided an excellent adhesion between the fiber and the resin matrix and that the reinforcing effects of fiberglass increased the mechanical qualities of the matrix [3]. Improved adhesion of composites and glass fibers could be due to the silica contents of the fiber and consequent stronger bonds which in turn lead to an increased flexural strength [6, 17].

Analysing the fracture pattern, the strong adhesion between fiber glass and composites layers must be mentioned. In group 2 (braided glass fiber) the specimens were separated in two distinguished parts with the same structure: composite, fiber, composite (fig. 8). For specimens in group 4, destruction by delamination in the mass of the fiber was noticed (fig. 9). The fracture pattern in the groups 1 and 3 (braided polyethylene fibers) is in accordance with results of Sharafeddin and Pereira studies [6, 18]. The specimens showed the fracture in two discrete parts of the inferior composite layer while it was still attached to the intact polyethylene fiber, proving the stability and firmness of the polyethylene structure (fig.10). This means that the periodontal splint is kept in place even after the initiation of the crack which allows intraoral repair, enabling the functionality of the restoration after the initial failure. Ellakwa indicates that the physical and chemical properties of composite dominate the modulus of FRC specimens and not the incorporation of fibers. This aspect is partly in agreement with the results of this study and can be applied only for group D [19].

All these aspects must be correlated with information about clinical survival of periodontal splints, in order to obtain the best clinical outcome of fiber reinforced composites restorations [20].

Conclusions

Within the limitations of the experimental design, the following were concluded:

The type of the fiber has a great influence on the flexural strength of specimens.

The specimens which exerted the best ratio between high deflection, low flexural modulus and medium flexural strength have the best indications to be used in periodontal therapy.

Regarding fracture pattern, the specimens which have been separated in two discrete parts while maintaining the polyethylene fiber intact are indicated for splinting because they allow intraoral repairs, increasing the longevity of the periodontal splint.

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