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A comparative evaluation of flexibility and bond strength of stainless steel wire, glass fiber reinforced composite and polyethylene fiber reinforced composite used in splinting of traumatized permanent teeth: An *in-vitro* study

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Abstract

Aim: The aim of this in-vitro study was to evaluate and compare the flexibility and bond strength of stainless steel wire, glass fiber reinforced composite and polyethylene fiber reinforced composite used in splinting of traumatized permanent teeth.

Materials and methods: In this study, a total of 60 samples were prepared of which 30 samples were tested for flexibility and 30 samples were tested for bond strength. For both parameters, based on the splinting material used, the samples were divided into 3 groups with 10 samples in each group: Group 1- stainless steel wire (8 braid flat dead soft wire by Ortho-Direct®), Group 2- glass fiber reinforced composite (Interlig by Angelus®) and Group 3- polyethylene fiber reinforced composite (Ribbond by Ribbond®). For flexibility testing, three-point bending test was carried out and for testing bond strength, pull out stress test was carried out. The statistical analysis was done using ANOVA F test, followed by Dunnett's multiple comparison test.

Results: For flexibility, no statistically significant difference ($p>0.05$) was found amongst the three groups at 1 mm deflection. Statistically significant difference ($p<0.05$) was found between Group 1 and Group 3 at 2 mm deflection. The difference between Group 1 vs Group 2, and Group 2 vs Group 3 was highly significant ($p<0.001$) at both 2 mm and 3 mm deflection. For bond strength, the difference between the mean load values for all three groups was found to be highly significant ($p<0.001$).

Conclusion: The highest flexibility was observed with polyethylene fiber reinforced composite, followed by stainless steel wire while glass fiber reinforced composite demonstrated the lowest flexibility. Polyethylene fiber reinforced composite showed the highest bond strength, followed by glass fiber reinforced composite, while stainless steel wire exhibited the least bond strength.

Keywords: Splint, wire-composite, fiber reinforced composite, flexibility, bond strength

1. Introduction

Traumatic dental injuries have become a frequent emergency in children and adults alike [1]. Literature suggests that dental splinting holds a pivotal role as it stabilizes the subluxated, luxated, avulsed and root fractured tooth and thereby optimizes healing outcomes for the involved pulp and/or the periodontal ligament [2]. There are several means of splinting traumatized teeth. This includes suture splints, arch bars, orthodontic appliances, direct composite splints, wire-composite splints, resin splints, metal (Titanium Trauma Splint) splints [3]. Studies have shown that optimal lateral support and vertical flexibility for the splinted teeth is offered by the conventional wire-composite splints [4]. This method is cost effective and requires less chair time. However, with extracoronal wire ligation, the splints have poor esthetics, show gradual discoloration, have a bulky contour and show higher incidence of splint fracture [5].

Over the years, other materials like fiber reinforced composite (FRC) have been used for splinting of traumatized teeth. The FRC materials are designed by reinforcing dental resins with kevlar, carbon, glass, silane treated glass and ultra-high-molecular-weight polyethylene (UHMWPE) [6]. Glass fiber reinforced composite materials are known to have good esthetics, good fatigue life and good chemical resistance to acids and solvents [7].

Polyethylene fiber reinforced composite materials have enhanced mechanical and esthetic properties, improved modulus of elasticity, flexural properties, and resistance to fracture [8].

Irrespective of the material used, one of the prime requirements of an ideal splinting material is its high flexibility as it reduces the likelihood of root resorption and shows better reorganization of periodontal ligament fibers of the injured teeth [9]. Also, a good bond strength of the splint material to the tooth increases the clinical success rate of the splint [3].

As per our review of literature, not many studies have been done to compare the flexibility and bond strength of glass fiber reinforced composite, polyethylene fiber reinforced composite and conventional wire-composite splint. Therefore, the aim of this in-vitro study was to evaluate and compare the flexibility and bond strength of stainless steel wire, glass fiber reinforced composite and polyethylene fiber reinforced composite used in splinting of traumatized permanent teeth.

2. Materials and Methods

The study was conducted in the department of Pedodontics and Preventive dentistry. The study was approved by the Institutional Review Board.

The study consisted of 60 samples of which 30 samples were prepared for testing flexibility and 30 samples were prepared to test the bond strength. For both parameters, based on the splinting material used, the samples were divided into 3 groups with 10 samples in each group: Group 1- stainless steel wire (8 braid flat dead soft wire by Ortho-Direct®), Group 2- glass fiber reinforced composite (Interlig by Angelus®) and Group 3- polyethylene fiber reinforced composite (Ribbond by Ribbond®).

2.1 For testing flexibility

A total of 30 samples were prepared using the three different splinting materials by cutting them into a length of 30mm each. Wetting of the Group 3 material was done using the proprietary resin as per the manufacturer's instructions. Group 2 and Group 3 samples were cured using composite light curing unit as per the manufacturer's instructions. Each sample (from all 3 groups) was subjected to a three-point bending test using load at a crosshead speed of 1mm/min delivered through universal testing machine. The bending load values at different deflections (1mm, 2mm, 3mm) were recorded in Newtons (N).

2.2 For testing bond strength

A total of 30 acrylic blocks were prepared. Each block consisted of two sound human maxillary incisors with their roots embedded in acrylic and exposed crowns contacting each other proximally. The enamel surfaces of the teeth were polished using pumice slurry for 2 minutes. To have a uniform area of bonding, a square with 3 mm side was marked on the middle third of the labial surface of each tooth using a template. The marked area was initially acid etched (3M ESPE Scotchbond multipurpose etchant), rinsed with water and air dried, followed by application and curing of a fifth generation bonding agent (3M ESPE Adper Single bond 2). 10 splinting materials from each group were cut to equal lengths of 15mm with centre point marked at 7.5mm. Wetting of the Group 3 material was done using the proprietary resin as per manufacturer's instructions. Each splinting material (from all 3 groups) was placed on the labial surfaces of teeth and a photopolymerizable flowable composite resin (nanohybrid- 3M ESPE Filtek Z350 XT) was applied to the marked area and cured using a composite light curing unit as per the manufacturer's instructions. After splinting, the acrylic moulds were subjected to pull out stress test using universal testing machine. A hook fixed onto the upper jig was attached to the previously marked centre point of the splinting material and the testing was carried out at a crosshead speed of 3mm/min until the complete debonding of the splint from the teeth occurred. The maximum load required during the testing to debond the splint was reported in Newtons (N) and the bond strength (MPa) was calculated by dividing the maximum load value (N) with the area of bonded surface (mm^2). $1MPa=1N/mm^2$.

2.3 Statistical analysis

SPSS for Windows, Version 16.0. Chicago, SPSS Inc. Released 2007 software was used to analyse the data. Data for flexibility and bond strength was expressed as means with standard deviation (SD). Probability $p<0.05$ was considered as significant, alpha error was set at 5% with confidence interval of 95% set for the study. Power of the study was set at 80% with beta error set at 20%. The data obtained for the three groups was statistically analysed using ANOVA F test. Post hoc data analysis which follows ANOVA was done using Dunnett's multiple comparison test. Post hoc test analysed multiple pair–wise comparison among individual group in relation to following variables i.e. load values in newton (N) and bond strength in MPa.

3. Results & Discussion

3.1 Results

3.1.1 For flexibility testing

Table 1 shows mean load values (N) at various deflections (1mm, 2mm, 3mm). The mean load values under 1 mm deflection for Group 1 (stainless steel wire), Group 2 (glass FRC) and Group 3 (polyethylene FRC) were found to be 0.2 ± 0.07, 0.22 ± 0.06 and 0.14 ± 0.03 N respectively.

Table 2 shows the comparison of mean load values between all Groups under various deflections. At 2 mm deflection, mean load values for Group 1, Group 2 and Group 3 were found to be 0.26 ± 0.06, 0.51 ± 0.51 and 0.17 ± 0.03 N respectively. Mean load values under 3 mm deflection for Group 1, Group 2 and Group 3 were found to be 0.33 ± 0.06, 0.74 ± 0.09 and 0.26 ± 0.07 N respectively. At 1 mm deflection, the difference found amongst these groups was not statistically significant ($p>0.05$). The difference between the values recorded for Group 1 and Group 3 was statistically significant ($p<0.05$) at 2 mm deflection, but was not found to be statistically significant ($p>0.05$) at 3 mm deflection. The difference between Group 1 vs Group 2, and Group 2 vs Group 3 was highly significant ($p<0.001$) at both 2 mm as well as 3 mm deflection.

Table 1: Mean load values (N) at various deflections (1mm, 2mm, 3mm)

	1 mm	2 mm	3 mm
Group 1 (Stainless steel wire)	0.20	0.26	0.33
Group 2 (Glass FRC)	0.22	0.51	0.74
Group 3 (Polyethylene FRC)	0.14	0.17	0.26

Table 2: Comparison of mean load values between all Groups under various deflections

Deflection	Group	Comparison group	Mean Difference	p value, Significance
1 mm	Group 1	Group 2	0.02	p = 1.0, ns
		Group 3	0.06	p = 0.486,ns
	Group 2	Group 3	0.08	p = 0.196, ns
2 mm	Group 1	Group 2	0.25	$p<0.001$**
		Group 3	0.09	p = 0.01*
	Group 2	Group 3	0.34	$p<0.001$**
3 mm	Group 1	Group 2	0.41	$p<0.001$**
		Group 3	0.07	p = 0.142
	Group 2	Group 3	0.48	$p<0.001$**

$p>0.05$ – not significant, *$p<0.05$ – significant, ** $p<0.001$ – highly significant

3.1.2 For bond strength testing

Table 3 shows the mean bond strength (MPa) values recorded for the three groups and the comparison between them. The mean values obtained for Group 1, Group 2 and Group 3 were 0.73 MPa, 1.17 MPa and 1.57 MPa, respectively. The difference between the three groups was found to be highly significant ($p<0.001$).

Table 3: Comparison of mean bond strength (MPa) between all Groups

Bond strength	Mean (S.D) (in MPa)	Anova F Test	P value, Significance
Group 1 (Stainless steel wire)	0.73 (0.15)	F = 97.84	$p<0.001$, highly significant difference
Group 2 (Glass FRC)	1.17 (0.12)		
Group 3 (Polyethylene FRC)	1.57 (0.12)		
Dunnett's Post-hoc test to find pair–wise comparison among groups:			
Group	**Comparison group**	**Mean Difference**	**p value, Significance**
Group 1	Group 2	0.43	$p<0.001$**
	Group 3	0.83	$p<0.001$**
Group 2	Group 3	0.40	$p<0.001$**

$p>0.05$ – not significant, *$p<0.05$ – significant, ** $p<0.001$ – highly significant

3.2 Discussion

Flexibility of a material is inversely proportional to the load required to deflect it. In this study, polyethylene FRC was found to be the most flexible material, followed by stainless steel wire, with glass FRC having the least flexibility. The studies conducted by Ellakwa AE et al in 2002 [10], A. Gaspar Junior in 2009 [11], R. Yapp and J.M. Powers in 2011 [12], and Jelena Juloski et al in 2012 [13], showed polyethylene FRC to be more flexible than glass FRC, which is in accordance with the findings obtained in this study. A study conducted by Shiva Alavi and Tayebe Mamavi in 2014 [14], concluded that glass FRC group had significantly higher load compared to stainless steel wires under 0.5, 1 and 1.5 mm deflections, and Sergio Mazzoleni et al in 2010 [15] found that polyethylene FRC was more flexible than wire-composite splint, which is in accordance with the results obtained in this current study.

The high flexibility of polyethylene FRC could be attributed to its patented lock stich pattern and leno weave which prevents stresses to transfer back into the resin by distributing forces throughout the weave [16]. The less flexibility of glass FRC could possibly be due to the resin pre-impregnation as the pre-impregnated reinforcement fibers are known to create a substructure that has been shown to have a flexural modulus that is 10 times higher than that of the hand impregnated designs [17].

In this study, polyethylene FRC was found to have the maximum bond strength, followed by glass FRC, followed by stainless steel wire which is in accordance with the results found in a study conducted by Dave Foek et al in 2013 [18]. Tina Puthen et al in 2015 [19] found that wire-composite group demonstrated significantly lower bond strength compared to polyethylene FRC group, while a study done by Jelena Juloski et al in 2013 [13] demonstrated that polyethylene FRC had greater bond strength as compared to glass FRC, which similar to the results obtained in the present study.

The lower bond strength of stainless steel wire could be due to the fact that wire does not chemically bond to the dental resin and is only embedded in it [20]. On the other hand, the higher bond strength of both the FRC materials could be attributed to their composition which allows them to chemically bond to dental resin. Amongst the two FRC materials, polyethylene FRC demonstrated a higher bond strength probably due to its unique fiber design which helps it bond better [6].

As the flexibility and bond strength in this study were evaluated under in-vitro conditions, the results cannot be completely extrapolated to the more dynamic oral situations [15], which is one of the limitations of this study. Also, in three-point bend test, stress was applied in only one direction, therefore simulating just one of the many clinically possible loading conditions [13]. No qualitative analysis was done to check for the interface at which the debonding occurred denoting the need for future studies to examine these failure types.

4. Conclusion

The results within the limitations of this study suggest that the highest flexibility was observed with polyethylene fiber reinforced composite i.e. Ribbond (Ribbond®), followed by stainless steel wire i.e. 8 braid flat-dead soft wire (Ortho-Direct®) while glass fiber reinforced composite i.e. Interlig (Angelus®) demonstrated the lowest flexibility. Polyethylene fiber reinforced composite showed the highest bond strength, followed by glass fiber reinforced composite, while stainless steel wire exhibited the least bond strength.

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