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COMPARISON OF FRACTURE RESISTANCE BETWEEN IMPLANT-SUPPORTED BIS-ACRYL INTERIM 3-UNIT FDPS USING 5 DIFFERENT STRENGTHENING MECHANISMS: AN IN-VITRO STUDY

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ABSTRACT

Objective: A strong durable provisional restoration is needed when placing it for long term as in case of implant. **Materials and methods:** Six techniques of PFP reinforcement were investigated and were assigned to different groups (n=10): group (ZP) zirconia Powder, group (SK8) silk thread, group (RC8) size 00 retraction Cord, group (RF8) Resin impregnated glass fiber ribbon, group (KV8) Kevlar 29 cord, group(KV) Kevlar 29 strands incorporated in resin mix, (CL) unenforced Bis-acryl as control group. Seventy Metal Dies were 3D printed having Soft Tissue Gingiva Mask. Using a custom-made silicon Index, 70 PFP were fabricated and were cemented to their corresponding metal dies using zinc polycarboxylate cement. All specimens were thermal cycled for 1000 cycles using order of 20 sec at 55˚C and 20 sec at 5˚C with 10 sec transport. Fracture resistance test was done using universal testing machine with a load cell of 5 kN. at crosshead speed of 0.5 mm/min. All specimens were loaded to failure. Data were collected, Tabulated and statistically analyzed. **Results:** Results showed higher mean values of CL group (780.8±164) followed by RF8 group (614.2±158.2), followed by RC8 group (550.2±339.2), followed by KV8 group (442.1±198.4), followed by KV group (403.9±306), followed by SK8 group (175.9±90.8), and finally ZP group (136.5±135.7). One-Way ANOVA revealed significant difference between tested groups (P= 0.036). **Conclusions:** Bis-acryl had better mean fracture resistance values than all other strengthening mechanisms. Bis-acryl did not gain more strength by any of the added materials. One-Way ANOVA revealed significant difference between all tested groups.

KEYWORDS: Fracture resistance, Bis-acryl, Interim, Kevlar.

INTRODUCTION

Meeting aesthetic, mechanical, and biological needs is crucial for Provisional Fixed Prostheses (PFP) [1]. Their key functions are to ensure positional stability, comfort, and protection of the pulp. Additionally, it is imperative that they are easy to clean, to maintain periodontal health, and have adequate durability and strength to withstand the forces of mastication, providing occlusal stability[2,3]. Furthermore, they are required to function for extended periods during adjunctive treatment, necessitating materials that can withstand prolonged use.

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Premature failure can result in extended repair times, patient discomfort, abutment displacement, and functional or aesthetic issues. At present, the materials utilized for Provisional Fixed Prostheses (PFP) comprise of bis-acryl resins and poly (methyl methacrylate) (PMMA). Bis-acryl resins are the more commonly employed material, as they have minimal complications and are relatively easy to use [(4)].

The flexural strength of PFP is critical, particularly for long-span prostheses with small pontics/connector occluso-gingival height, where the patient exhibits parafunctional habits like bruxism or clenching [(5,6)] or when the provisional prostheses are worn for an extended period. A study that compared the flexural strengths of various provisional materials for fixed prostheses discovered that bis-acryl resins had the highest flexural strength[(7)], This is due to their difunctionality, which allows them to cross-link with other monomers, imparting toughness and strength to the material. These properties make bis-acryl resins an ideal material for use in PFP that require longevity and durability to withstand masticatory forces and the rigors of parafunctional habits [(6)].

According to some researchers, fracture toughness is considered to be more crucial than flexural strength in assessing the strength of a biomaterial, as it more accurately predicts long-term performance[(8,9)]. The failure of provisional restorations is frequently caused by crack propagation that begins on the restoration surface[(8,10)]. In another study, it was observed that bis-acryl resins exhibited considerably higher fracture toughness than PMMA resins. This suggests that bis-acryl resins are more resistant to crack propagation, which is a critical characteristic for provisional restorations that must endure prolonged use and withstand masticatory forces[(11)]. There are several techniques available for strengthening and reinforcing Provisional Fixed Prostheses (PFP), including the use of various types of fibers such as glass, polyethylene, and carbon, as well as cast-metal strengthening, metal-wire, and acrylic resin processing.

While the use of steel-wire has been shown to improve the fracture toughness of PFP, the results of fiber strengthening have been higher, likely due to better adhesion of the resin to the fibers [(3)]. Furthermore, the fatigue resistance of fiber-strengthened polymers was found to be higher than that of polymers strengthened using metal-wires. This suggests that the use of fiber-strengthened materials may be more effective in improving the durability and longevity of PFP, which is crucial for long-term functioning and patient satisfaction [(12)].

The use of fibers in the manufacturing of Provisional Fixed Prostheses (PFP) has demonstrated a high success rate in increasing both fracture toughness and flexural strength. This improvement may be attributed to the transfer of stress from the weak polymer-matrix to the glass fibers, which possess higher tensile strength [(13)]. Silane-impregnated glass fibers can enhance flexural strength by forming a chemical bond with the organic resin matrix, resulting in a stronger and more homogeneous bis-acryl resin. Using this technique in manufacturing PFP can lead to more durable restorations that better withstand masticatory forces and provide long-term stability[(14)]. In addition, the reinforcing impact of glass fibers is more noticeable with longer spans of PFP.

By incorporating fiber reinforcement in the manufacturing process, it is possible to prevent premature and catastrophic failures by halting the progression of fractures, thereby avoiding complete separation[(15)]. Positioning the strengthening fibers apically can increase fracture resistance by preventing the spread of the originating fracture throughout the PFP [(16)]. Despite being in a less-favorable location of the PFP, fibers placed on the occlusal surface still provide strengthening and contribute to high fracture resistance [(17)]. According to another study, silanized glass fibers seem to be the most suitable technique for strengthening PFP resins when both esthetics and function are important [(18)].

The strength of fiber reinforced PFP depends on various factors, including the amount of fibers in the polymer-matrix, fiber orientation, fiber impregnation, and the bond between the fibers and the polymer matrix (19-21). Stephanie Kwolek created DuPont Kevlar in the 1930s, which is a para-aramid heat-resistant synthetic fiber with strong inter-chain bonds in its molecular structure. It is best known for its use in ballistic body-armor due to its incredible strength (22). Kevlar has also been used in medical applications as a reinforcement for bone cements (23,24). Improved mechanical properties of Kevlar fiber have led to its use in strengthening provisional restorations, as shown in medical studies (25).

The authors of the current article were motivated by the various reinforcing techniques reported in the literature aimed at extending the service time of provisional restorations, particularly in cases such as provisional over implant or pulp capping. One such study by Panyayong et al.,(26) found improved mechanical properties of acrylic resin blocks through the addition of zirconia and titania powder to the acrylic mixture.

This study aimed to evaluate the effectiveness of five different configurations of reinforcing materials for a three-unit interim restoration compared to an unreinforced control group. The null hypothesis stated that there would be no significant difference between the tested groups.

MATERIALS AND METHODS

Sample grouping:

Six techniques of PFP reinforcement were investigated and were assigned to different groups (n=10): **group(ZP)** zirconia Powder, **group(SK8)** silk thread wrapped as a Figure of 8 pattern around middle third of abutment, **group(RC8)** size 00 retraction Cord wrapped as a Figure of 8 pattern around middle third of abutment, **group(RF8)** Resin impregnated glass fiber ribbon wrapped as a Figure of 8 pattern around abutment, **group(KV8)** Kevlar 29 cord wrapped as a Figure of 8 pattern around middle third of abutment, **group(KV)** Kevlar 29 strands incorporated in resin mix. Compared against unenforced Bis-acryl as control **group (CL)**. (Table 1)

TABLE (1) Reinforcing materials grouping and product details.

Group	Strengthening technique	Diameter / width	tensile strength MPa	Manufacturer
SK8	Silk Thread	0.85mm	330	YLI Threads, japan
KV8	Kevlar 29 cord	0.85mm	2920	DuPont de Nemours, Inc., USA
KV	Kevlar 29 strands	0.1mm		DuPont de Nemours, Inc., USA
RC8	Retraction cord (100% cotton)	0.85mm	49	CFPM - Tremblay-en-France, France
RF8	Glass fiber ribbon	Width 4 mm	11	(Fiber-Splint One-Layer, Polydentia SA, Mezzovico-Vira, Switzerland)
ZP	Partially Stabilized Zirconia（PSZ）	50 µm	500	Henan Rongsheng Technology Group, Zhengzhou city Henan province, China
CL	Bis-acrylic	-	77	Tempofit premium, DETAX GmbH, Ettlingen, Germany

Metal Dies Fabrication:

Two Diameter 4.8 mm One-piece implant/abutment analogue (RN analogs, Straumann AG, Basel, Switzerland) were vertically placed using parallelometer (af350, Amann Girrbach AG, Koblach, Austria) in an acrylic resin block (Orthodontic acryl, Vertex Orthoplast, 3D systems, Soesterberg, Netherlands). Distance between them was 15.5 mm measured from the center of each abutment[27]. After setting the assembly was scanned using Extra Oral scanner (rainbow scanner Plus, Dentium, Gangnam-gu, Seoul, Korea). STL file was exported to 3D selective laser fusion printer machine (MYSINT100, SISMA S.p.A. Via dell'Industria, Vicenza, Italia) and 70 metal dies were printed. Dies were collected, support was removed and dies were finished and polished (Fig (1 a&b).

Soft Tissue for Gingiva Mask Fabrication:

Seventy gingival replicas were 3D printed and glued (Super glue, Alteco group of companies, Japan) on the metal framework to accurately fabricate connectors of same thickness and ginigival shape. It was done Using Flexible Resin material (80A, FormLabs, Boston, MA, USA) and 3D printer (Form 3B+, FormLabs, Boston, MA, USA), Washed (Form Wash, FormLabs, Boston, MA, USA) then cured (Form Cure, FormLabs, Boston, MA, USA). (Fig: 2)

Silicon Index Fabrication:

Three-units PFP (maxillary first premolar, second premolar and first molar) were designed and 3D printed (Temporary CB Resin, FormLabs, Boston, MA, USA), Washed (Form Wash, FormLabs, Boston, MA, USA) then cured (Form Cure, FormLabs, Boston, MA, USA).

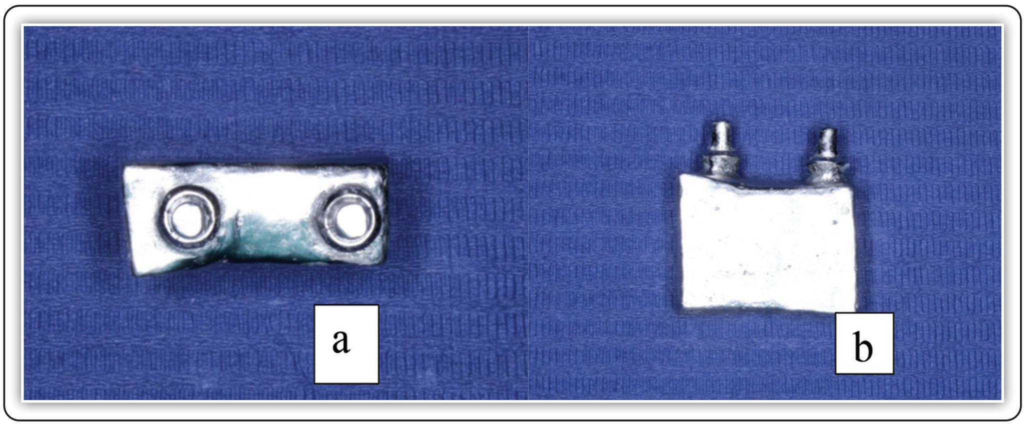

FIG (1) Metal die a) occlusal view, b) lateral view.

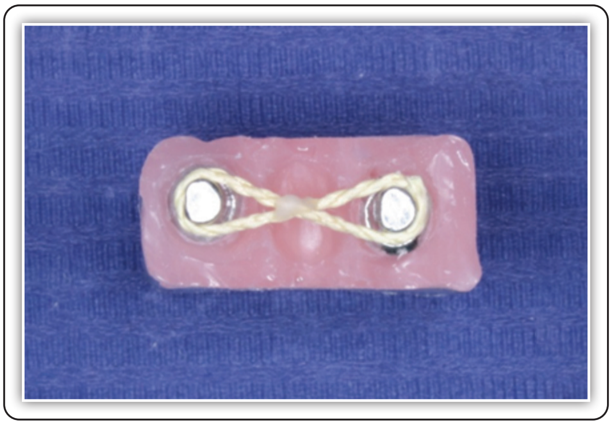

FIG (2) Kevlar figure of 8 over gingival mask.

A silicon index was fabricated from the printed 3-units PFP using duplication silicon (Elite double 8, Zhermack SpA, Badia Polesine (RO), Italy). The index was used to fabricate PFPs.

All metal dies were painted with a thin layer of petroleum gel (Vaseline, Unilever, USA) using micro-brush, to avoid adherence of provisional material to it.

Figure-of-8 groups PFP Fabrication:

For groups; SK8, KV8, RC8, and RF8, strengthening material was tied as an "8-figure" passing around and in between implant abutment. For groups SK8, KV8 and RC8 a double knot was tied and excess cord was cut using a scissor. (Fig: 2) For group RF8, Ribbon surrounded the abutments as an "8-figure" and two ends were light cured.

Part of provisional material (Tempofit premium, DETAX GmbH, Ettlingen, Germany) was injected around on the metal die covering the strengthening cords completely. A second part was injected in the silicon index and inverted on the metal dies under light finger pressure. Rubbery excess of material was removed using a scaler. After complete set of PFP (4 min) silicon index was removed and a new PFP was fabricated using same routine until all PFPs within afro mentioned groups were fabricated. (Fig: 3)

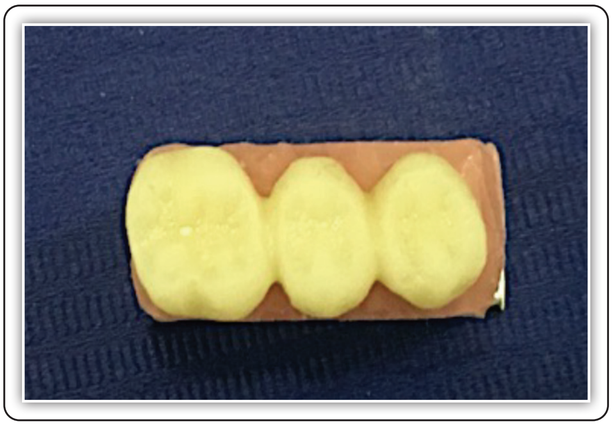

FIG (3) Finished PFP.

KV group PFP Fabrication:

Ten mm of Kevlar 29 cord was unbraided and cut into a 2mm small strands. Provisional material was injected onto a glass slab and the strand abound was thoroughly mixed with it. The mixed material was applied into the silicon mold and inverted on the metal dies. Next steps were followed exactly as previous groups.

ZP group PFP Fabrication:

Half a gram of PSZ powder was thoroughly mixed with provisional material on a glass slab. The mixed material was applied into the silicon mold and inverted on the metal dies. Next steps were followed exactly as previous groups.

CL group PFP Fabrication:

Part of provisional material was injected around on the metal die. A second part was injected in the silicon index and inverted on the metal dies under light finger pressure. Next steps were followed exactly as previous groups.

Cementation of PFPs:

All PFPs were cemented to their corresponding metal dies using zinc polycarboxylate cement (HY-Bond Polycarboxylate cement, SHOFU INC. 11 Kamitakamatsu-cho, Kyoto, Japan) mixed according to manufacturers' instructions. Excess was removed using microbrush.

Thermal cycling of all specimens:

All specimens were thermal cycled (THE-1200, SD MECHATRONIK GMBH, Feldkirchen-Westerham, GERMANY) for 1000 cycles using order of 20 sec at 55˚C and 20 sec at 5˚C with 10sec transport [28].

Fracture Resistance Testing:

To conduct the testing, each specimen was secured to the lower fixed part of an Instron 8875 universal testing machine with a 5 kN load cell. A folded tin-foil measuring 1 mm in thickness was placed between the occlusal surface and the 5.8 mm diameter metallic indenter attached to the upper movable part of the machine to prevent stress concentration. The specimens were subjected to a uniaxial static load applied to the inclined cuspal planes of the PFP pontic at a crosshead speed of 0.5 mm/min. The load was increased until failure, which was indicated by an audible cracking sound and confirmed by a sudden drop in the load/deflection curve. The failure loads were recorded in Newton using Nexygen-MT-4.6 computer software (Nexygen-MT-4.6; Lloyd Instruments, Largo, FL)[29].

Statistical Analysis

The data collected in the study were analyzed using the SPSS 18.0 computer software (SPSS, Inc, Chicago, USA). The normality of the data distributions was evaluated using the Kolmogorov-Smirnov normality tests. One-way analysis of variance (ANOVA) and Bonferroni post-hoc test were conducted at a significance level of α=0.05. The sample size of n=10 per group was determined to have acceptable power to detect clinically relevant differences [30].

RESULTS

1. Kolmogorov-Smirnov normality tests

The test was conducted on 7 groups to decide the distribution-normality of the results in each group. This selects the statistical analysis applied. Results of test showed no significant difference between data in each group. So, data are normally distributed in each group.

2. Descriptive Statistics

Analysis showed higher mean values of CL group (780.8±164) followed by RF8 group (614.2±158.2), followed by RC8 group (550.2±339.2), followed by KV8 group (442.1±198.4), followed by KV group (403.9±306), followed by SK8 group (175.9±90.8), and finally ZP group (136.5±135.7) (Table 2) (Fig 4).

TABLE (2) Descriptive statistics and One-way ANOVA

Groups (n=10)	Mean±Std. Dev. (Newton)	Min.	Max.	One-way ANOVA
CL	780.8±164	559	1029	
KV8	442.1±198.4	166	745	
KV	403.9±306	84	963	
ZP	136.5±135.7	40	397	P= 0.036
RC8	550.2±339.2	135	1081	
SK8	175.9±90.8	109	326	
RF8	614.2±158.2	303	898	

Analysis of Variance (ANOVA) - One-Way ANOVA test revealed significant difference between tested groups (P= 0.036) (Table 2).

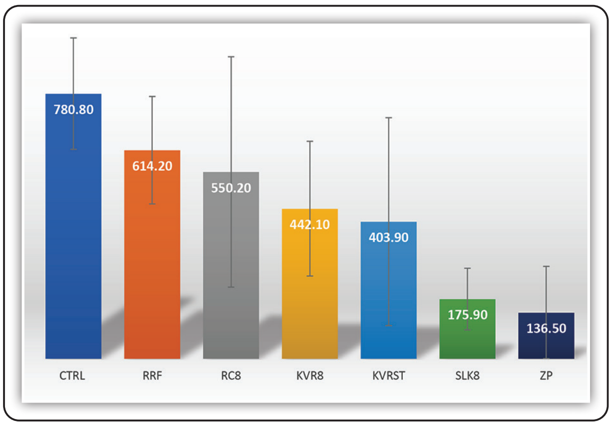

FIG (4) Mean, standard deviation of fracture resistance values in Newton

4. Post-Hoc Tukey LSD

There were significant differences when comparing CL group, which scored the highest fracture resistance mean values, with all remaining groups except RF8 group (P=0.90). On the other hand, SK8 and ZP which scored the lowest fracture resistance mean values showed significant differences when compared with all remaining groups. There were no significant differences between CL and RF8 (P=0.90), and between SK8 and ZP (P=0.685). KV group also show significant differences when compared with all studied group except with KV8 (P=0.694), and RC8 (P=0.135). KV8 also showed no significant differences when compared with RC8 (P=0.267), and with RF8 (P=0.080).

TABLE (3) Post-Hoc Tukey LSD results

Group	Provisional Material Type	Mean Difference	P-Value
CL	KV8	338.70	0.001
	KV	376.90	0.0002
	ZP	644.30	0.00000001
	RC8	230.60	0.020
	SK8	604.90	0.00000004
	RF8	166.60	0.090
KV8	KV	38.20	0.694
	ZP	305.60	0.002
	RC8	-108.10	0.267
	SK8	266.20	0.008
	RF8	-172.10	0.080
KV	ZP	267.40	0.007
	RC8	-146.30	0.135
	SK8	228.00	0.021
	RF8	-210.30	0.033
ZP	RC8	-413.70	0.0001
	SK8	-39.40	0.685
	RF8	-477.70	0.0001
RC8	SK8	374.30	0.005
	RF8	-64.00	0.510
SL8	RF8	-438.30	0.001

DISCUSSION

Current study was conducted to assess fracture resistance of multiple strengthening mechanisms for Bis-acrylic provisional PFP. In order to serve in situations that need the provisional to serve for long duration of time. In this study certain procedural steps were implemented to ensure standardization and to secure to fulfill the aim of the study.

Metal Dies were custom-fabricated having implant abutments; to withstand compressive strength testing without failing themselves and for simulating metal implant abutment real clinical situation. It was 3D printed and not casted to be perfectly similar in shape for standardization purposes. Soft Tissue for Gingiva Mask was 3D printed to simulate real ridge-lap area of the PFP.

All PFP were exactly fabricated similar to each other thanks to the silicon Index mold. It is fabricated form extra tear resistant silicon that can withstand multiple poring without tear or change in dimensions

Kevlar was selected for this article as it's known for its extraordinary strength and used in bullet-proof vests. Silk is also well known by its strength. Retraction cord-Made of cotton- and Glass fiber resin both are dental products that easily found in any clinic. Zirconia powder was also added to the groups as zirconia particles are well known strengthening material to composites resin and glass ceramics. Figure-of-8 technique in cords application was chosen as it is by far the simplest technique to be implemented by general dentists.

3-Unit bridges were fabricated and not discs to simulate the true clinical condition. As each one could render whole different result. Zinc polycarboxylate cement was chosen as it is used routinely to cement long term provisionals in implant dentistry. Samples were thermocycled for 1000 times which represents one year in service [31]. A 1 mm thick folded tin-foil was positioned between the occlusal surface and the loading tip of the PFP to prevent stress concentration and premature fracture of specimens due to unnatural concentration of force by the application rod, which does not simulate real clinical situation.

Results of current study indicated that all specimens in test groups failed at a lower force than the control group. This may be explained by the assumption that the incorporated materials acted as points of weakness in PFP and disturbed the homogeneity of Bis-Acryl.

Zirconia powder specimen's failure at the lowest mean value (136.5N) may suggest that authors should have used another way of incorporating the powder to the Bis-Acryl or used different concentrations. Zirconia particles may act as stress concentration areas or voids causing that catastrophic decrease in fracture resistance force. Silk scored slightly higher mean values (175.9N) than that of zirconia powder. Maybe because silk was placed in a figure-of-8 pattern that might had better effect than the powder particles. Kevlar strands specimens failed at a higher mean value (403.90 N). This may be due to the exceptional strength of than silk. Kevlar figure-of-8 specimens showed failure on forces of (442.10 N). This may be due to the figure of-8 cord application opposite to the dispersed stands. It could be suggested that Bis-Acryl failed to wet all materials used in the past 4 groups, causing the strengthening materials to isolated and acting as weakening points to the PFP. Figure-of-8 retraction cord specimens failed at a higher mean value (550.20 N), this could be due to the better wetting of Bis-Acryl to the cotton-made cord. Glass fiber ribbon group scored the highest mean values among the strengthening materials (614.20 N). This may be due to better bond between the Bis-Acryl and the silane layer on the resinous glass fiber ribbon.

The control group scored the highest mean values (780.8) suggesting that strengthening materials and mechanisms showed be perfectly incorporated within the Provisional material and carefully chosen not to be as weakening material. The strength of the resultant PFP may not depend on the sole strength of enforcing material but the harmony between the material and the enforcing mechanism.

Opposite to current results, a study tested the incorporation of zirconia and titania powder yielded better results than Bis-Acryl alone. This may be due to using block specimens not on a bridge shaped specimens as we did [26]. The block shaped specimens may have greater strength since connectors and pontics are not used. More studies are needed to support or reject our claim. The null hypothesis was rejected as there was statistically significant difference between tested groups.

CONCLUSIONS

Within the limitation of the current study, it could be concluded that:

1. Bis-acryl provisional had better mean fracture resistance values than all other strengthening mechanisms.
2. Bis-acryl provisionals did not gain more strength by any of the added materials.
3. One-Way ANOVA revealed significant difference between all tested groups.

REFERENCES

1. Rosenstiel SF, Land MF, Fujimoto J. Contemporary fixed prosthodontics, 5th ed., St. Louis: Mosby/Elsevier; 2016. p. 401-39.
2. Shillingburg HT, Sather DA, Wilson EL Jr, Cain JR, Mitchell DL, Blanco LJ, et al. Fundamentals of fixed prosthodontics. 4th ed. Chicago: Quintessence; 2012. p.241-68.
3. Hamza TA, Rosenstiel SF, El-Hosary MM, Ibraheem RM. Fracture resistance of fiber-reinforced PMMA interim fixed partial dentures. J Prosthodont 2006; 15:223-8.
4. Christensen GJ. The fastest and best provisional restorations. J Am Dent Assoc 2003; 134:637-9.
5. Rosenstiel SF, Land MF, Fujimoto J. Contemporary fixed prosthodontics. 5th ed. St. Louis: Mosby/Elsevier; 2006. p. 81-2, 401-2.
6. Haselton DR, Diaz-Arnold AM, Vargas MA. Flexural strength of provisional crown and fixed partial denture resins. J Prosthet Dent 2002; 87:225-8.
7. Nejatidanesh F, Momeni G, Savabi O. Flexural strength of interim resin materials for fixed prosthodontics. J Prosthodont 2009; 18:507-11.
8. Gegauff AG, Wilkerson JJ. Fracture toughness testing of visible light and chemical-initiated provisional restoration resins. Int J Prosthodont 1995;8: 62-86.

9. Goldman M. Fracture properties of composite and glass ionomer dental restorative materials. J Biomed Mater Res 1985; 19:771-83.
10. Gegauff AG, Pryor HG. Fracture toughness of provisional resins for fixed prosthodontics. J Prosthet Dent 1987; 58:23-9.
11. Geerts GA, Overturf JH, Oberholzer TG. The effect of different reinforcements on the fracture toughness of materials for interim restorations. J Prosthet Dent 2008; 99:461-7.
12. Vallitu PK. Comparison of the in vitro fatigue resistance of an acrylic resin removable partial denture reinforced with continuous glass fibers or metal wires. J Prosthodont 1996; 5:115-21.
13. Nohrstrom TJ, Vallittu PK, Yli-Urpo A. The effect of placement and quantity of glass fibers on the fracture resistance of interim fixed partial denture. Int J Prosthodont 2000; 13:72-8.
14. Solnit GS. The effect of methyl methacrylate reinforcement with silanetreated and untreated glass fibers. J Prosthet Dent 1991; 66:310-4.
15. Hamza TA, Rosenstiel SF, Elhosary MM, Ibraheem RM. The effect of fiber reinforcement on the fracture toughness and flexural strength of provisional restorative resins. J Prosthet Dent 2004; 91:258-64.
16. Vallittu PK. Glass fiber reinforcement in repaired acrylic resin removable dentures: preliminary results of a clinical study. Quintessence Int 1997; 28:39-44.
17. Vallittu PK. The effect of glass fiber reinforcement on the fracture resistance of a provisional fixed partial denture. J Prosthet Dent 1998; 79:125-30.
18. Kamble VD, Parkhedkar RD, Mowade TK. The effect of different fiber reinforcements on flexural strength of provisional restorative resins: an in-vitro study. J Adv Prosthodont 2012; 4:1-6.
19. Pfeiffer P, Grube L. In vitro resistance of reinforced interim fixed partial dentures. J Prosthet Dent 2003; 89:170-4.
20. Kim SH, Watts DC. Effect of glass-fiber reinforcement and water storage on fracture toughness (KIC) of polymer-based provisional crown and FPD materials. Int J Prosthodont 2004; 17:318-22.
21. Barry D. Hammond, And Jeffrey A. Hodd. Fiber-Reinforced Interim Fixed Dental Prostheses: A Clinical Protocol. J Prosthet Dent. 2016 October;116(4):496-500.
22. https://www.dupont.com/what-is-kevlar.html
23. Saha S, Kraay M. Bending properties of wire-reinforced bone cement for applications in spinal fixation. J Biomed Mater Res 1979; 13:443-457.
24. Saha S, Kraay MJ. Improvement of mechanical properties of acrylic bone cement by fiber reinforcement. J Biomech 19B4; 17:467-477.
25. Hess D, Belser U. Ponts provisoires en extension renforces au Kevlar. Rev Mens Suisse O don to-stomatol 1987;97: 457-462.
26. Panyayong W, Oshida Y, Andres CJ, Barco TM, Brown DT, Hovijitra S. Reinforcement of acrylic resins for provisional fixed restorations. Part III: effects of addition of titania and zirconia mixtures on some mechanical and physical properties. Biomed Mater Eng. 2002;12(4):353-66.
27. Gi-Beom Park, Soo-Yeon Shin. Study of the fracture resistance of zirconia on posterior fixed partial dentures based on inter-abutment distance. Journal of Dental Rehabilitation and Applied Science 36, no. 2 (2020): 61-69.
28. Mohammad M Rayyan, Ahmed Naguib Hussien, Hanan Naguib and Hiba Makarem. Fracture Resistance of Computer Aided Endocrowns Versus Conventional Core-Supported Computer Aided Full Crowns. Iajd. 2020; 10 (2): 55-59.
29. Rayyan MM, Abdallah J, Segaan LG, Bonfante EA, Osman E. Static and Fatigue Loading of Veneered Implant-Supported Fixed Dental Prostheses. J Prosthodont. 2020 Oct;29(8):679-685.
30. Sherine Badr Youness Badr, Mohammad Rayyan and Manal Ahmed Elshiekh. Evaluation of Fracture Resistance and Color Stability of Innovative Esthetic Crowns for Primary Posterior Molars. EDJ. 2021, July; 67:1879:1886.
31. Botega DM, Sanchez JL, Mesquita MF, Henriques GE, Consani RL. Effects of thermocycling on the tensile bond strength of three permanent soft denture liners. J Prosthodont. 2008 Oct;17(7):550-4.