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Effect of Two Methods of Reinforcement on the Fracture Strength of Interim Fixed Partial Dentures

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Keywords
Reinforcement; fracture strength; interim prostheses; provisionals; resins; fibers; metal mesh; fixed partial dentures.

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Abstract

Purpose: This study assessed the efficiency of reinforcing provisional restorations by adding a fine gauze metallic mesh or polyethylene fibers between the abutments spanning the pontic length.
Materials and Methods: Forty-five resin fixed partial dentures (FPDs) were constructed using three provisional resins. The three resin groups were further divided into three subgroups depending on their reinforcement. Specimens were loaded compressively, and the load required to fracture the specimens was recorded in Newtons. Data were presented as means and standard deviation values. A regression model with two-way ANOVA was used in testing significance. Duncan's post hoc test was used for pairwise comparison ($p \leq 0.05$).
Results: Duralay resin and Duralay fiber-reinforced restorations showed the highest fracture-resistance values, followed by Protemp and Snap, which showed statistically similar values. The three mesh-reinforced resin restoration materials showed no statistically significant difference between their fracture resistance values. Reinforcement did not alter the fracture resistance of Duralay and Protemp resin subgroups, but significantly increased that of Snap, equalizing it with the other resins. The three resin materials had similar moduli. Significant alterations occurred after fiber reinforcement. Results showed that fiber-reinforced Duralay resin showed the highest modulus values, while no statistical difference was found between the moduli of fiber-reinforced Protemp and Snap. Regarding the mesh-reinforced groups, Duralay had the highest modulus followed by Protemp and Snap. Reinforcements altered the modulus values of Duralay resin only. Mesh-reinforced Duralay resin showed the highest mean modulus, but no statistically significant difference was apparent between fiber-reinforced and control groups. As for Protemp and Snap resin subgroups, their moduli remained unchanged by reinforcements.
Conclusion: Initially, Duralay resin had higher fracture resistance values than Protemp II and Snap. Fiber and mesh reinforcements increased the fracture resistance of Snap. No statistically significant difference was evident among the fracture resistances of the three mesh-reinforced resin FPD restorations. The three resins had similar moduli. Fiber and mesh reinforcement increased the modulus of Duralay resin but did not change that of Protemp and Snap. Fiber and metal mesh reinforcements may alter the fracture strength and modulus of some, but not all, provisional resins.

Interim prostheses are those placed between the time of tooth preparation and placement of the definitive prosthesis. To be successful, they must fulfill biologic, mechanical, and esthetic requirements.[1] These restorations should provide pulpal protection, comfort, positional stability, occlusal function, access for cleaning, esthetics, strength, and retention.[2,3] During the interval of their insertion, the fate of periodontally involved teeth is assessed.[4,5] Prognosis of questionable teeth is evaluated, and therapeutic occlusal vertical dimension is determined.[3,6-8] They also promote guided tissue healing by providing a matrix for surrounding gingival tissues.[4,6,7] Interim fixed partial dentures (FPDs) must preserve abutment position and maintain inter- and intra-arch relationships through the establishment of proximal and occlusal contacts. These requirements

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initiated our attempts to strengthen these so-called temporary restorations.[9,10]

The terms provisional, interim, or transitional restoration have been routinely used interchangeably in the literature; however, the term "temporary" is controversial and is considered inappropriate by some, as it may be interpreted as one of lesser importance or value.[7,11] Interim prostheses are the prototypes on which functional, occlusal, and esthetic adjustments are made to optimize the definitive treatment. Occasionally, they must function for extended intervals while adjunctive treatment is accomplished.[12] There is presently no ideal provisional material suitable for all clinical conditions. As the complexity of the proposed treatment increases, interim prostheses act as a key diagnostic tool. These materials have many requirements, such as appropriate marginal adaptation, low thermal conductivity, nonirritating to the pulp and gingival tissue, ease of cleaning, contour, alterability, and repair.[8] Long-span interim prostheses require materials that provide greater strength relative to single restorations. Furthermore, long-term interim prostheses require materials that are more durable because of their longer periods of service.[5,13]

Current materials for the fabrication of multiple-unit interim prostheses are, for the most part, resin-based. They differ regarding their mode of polymerization, filler composition, and monomer type. They include autopolymerizing and dual-cured resins, such as polymethyl methacrylates (PMMA), polyethyl methacrylates (PEMA), polyvinyl ethyl methacrylates (PVEMA), Bis-GMA resins, bis-acryl resin composites, and visible light-cured urethane dimethacrylate resins.[14] In selecting a material for the fabrication of multiunit interim prostheses, the clinician must consider numerous factors in terms of flexural strength, surface hardness, wear resistance, dimensional stability, polymerization shrinkage, color range and stability, handling properties, repair, and cost. No interim material meets optimal requirements for all situations.[2]

PMMA possesses color stability and good esthetics. It is easy to handle and repair and is inexpensive; however, it is reported to have multiple deficiencies, ranging from polymerization shrinkage, pulpal and periodontal damage associated with exothermic polymerization, and marginal discrepancies. It is also susceptible to fracture.[3,7] Autopolymerizing acrylic resins provide adequate short-term interim prostheses, whereas heat-processed acrylic resins are better for long-term interim prostheses due to their increased density and strength; however, they require special equipment and involve time-consuming procedures.[15]

Attempts were made to strengthen acrylic resin materials by chemical modification using copolymers and cross linkage, or by inclusion of various organic and inorganic fibers.[9,16] It has been demonstrated that acrylic resin can be strengthened through the addition of structural components of different size distributed in the matrix, thus forming a composite structure.[17] Compared to PMMA materials, composite-based provisionals possess high flexural strength and modulus, due to bulky Bis-GMA monomers.[18]

Young et al[19] compared bis-acryl and PMMA and concluded that the former was superior in many aspects, including a convenient delivery method, which accounted for an accurate and consistent mix. Others disagree, claiming that PMMA resins possess higher flexural strengths than composites.[14] This confusion can be attributed to the lack of standardization during testing and the lack of correlation between various testing methodologies and the functional strengths of interim prostheses in vivo.[20]

Attempts at resin reinforcements differ in material types, quantities, orientation, and inclusion methods.[5,12,15,21–23] The strength and serviceability of any resin is determined by the material's resistance to crack propagation. Fracture toughness or the resistance to crack propagation has been shown to be highest for PMMA, followed by Bis-GMA resin and lastly PEMA. Bis-GMA composite resin materials seem to be more brittle than PMMA and therefore more likely to fracture in long-span FPDs.[24] The development of fibrous composite materials in industry has inspired a new approach to improving the performance of acrylic resins.[25–27] A number of reinforcing fiber types have been investigated, ranging from carbon, glass, aramid, and woven polyethylene, with varying degrees of success.[9,10,28–41]

The fiber-reinforced composite (FRC) material is a combination of fiber and a resinous matrix. The mechanical properties of FRC materials are primarily dependent upon fiber type, length, ratio of fiber to matrix resin, fiber architecture (i.e., unidirectional, woven, or braided), and quality of impregnation of fiber and resin.[28–32] Some manufacturers produce dry fibers that require hand impregnation, while others are machine-impregnated with resin by the manufacturer. These are known as "preimpregnated" FRC materials.[14]

The effectiveness of these strengthening mechanisms varies, with the prime requirement being adequate bond formation between the reinforcing material and the parent resin. In the presence of an inadequate bond, the filler may act as an inclusion body and weaken the prosthesis.[36] In addition, carbon fibers present esthetic problems limiting their use,[10] while glass fibers are difficult to handle due to their fraying and spreading in undesired areas. If they protrude from the interim prostheses, the restorations may be difficult to polish and thus attract bacteria, causing irritation.[9,10,14] Previous studies advocated the use of long continuous fibers, with strands perpendicular to the direction of the applied load, as this orientation seemed to exhibit higher strength and modulus than unreinforced materials.[28,30,31] Vallittu[34] suggested that unidirectional fibers be used to reinforce the joint region between the pontic and the retainer and that woven fibers should be used instead to reinforce crowns and prevent crack formation during occlusal loading.

Samadzadeh et al[27] tested the effects of a plasma-treated polyethylene fiber on the fracture strength of PMMA and bis-acryl resin materials. They noted a significant increase in fracture load for the bis-acryl material only, along with a difference in the pattern of failure for both resins. Nohrström et al[29] analyzed the influence of the position and quantity of fibers on the fracture resistance of interim FPDs using unidirectional and woven glass-fiber reinforcements. They reported that the reinforcing effect of glass fibers became more evident in long spans. Stipho[25] tested the incorporation of 2, 5, 10, and 15% concentrations of glass fibers. She recommended the addition of a low-percentage concentration of glass fibers to reinforce PMMA, claiming that higher concentrations had a weakening

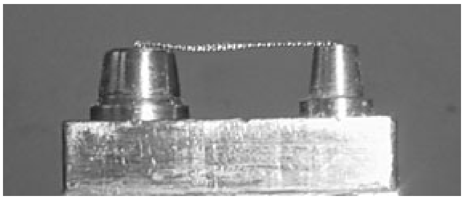

Figure 1 Metal mesh placed between the abutments.

effect. Chung et al[36] confirmed that the incorporation of glass fibers to improve resin strength favored the dispersion rather than the orientation inclusion method, as the even distribution of glass fibers in a single direction was virtually impossible. Saygili et al[37] confirmed these findings in their study showing that the strength of PMMA, PEMA, and bis-acryl resin improved by 20 to 50% after reinforcement with glass and aramid fibers.

It is evident that fractures are common in long-span interim FPDs, frequently occurring at connector sites.[40] This study was undertaken to test the efficiency of reinforcing these restorations by adding either a fine gauze metallic mesh (316-000-00 Dentaurum, Pforzheim, Germany) or a polyethylene fiber between the abutments spanning the midabutments, connector, and pontic length.

Materials and methods

Forty-five resin FPDs were constructed for this study using three resin materials; 15 FPDs were fabricated for each resin type. Three types of commercially available provisional materials were selected representing three main categories of chemically cured resin materials: Protemp II (3M ESPE, Seefeld, Germany), a bis-acryl composite; Snap (Parkell, Farmingdale, NY), a PVEMA; Duralay (Reliance Dental, Worth, IL), a PMMA resin. The three resin groups were further divided into three subgroups of five each depending on their reinforcement type, forming nine subgroups. Two materials were used for reinforcement: a metallic mesh (316-000-00 Dentaurum) and ultra-high modulus polyethylene fibers (UHMPE, DVA Reinforced polyethylene fiber, Dental Ventures of America, Riverside, CA) (Figs 1 and 2). The fibers were silanized by the manufacturer (methacryloxypropyl-trimethoxysilane) to improve adhesion between the fibers and resin materials.

Figure 2 Magnified view of unidirectional preimpregnated FRC.

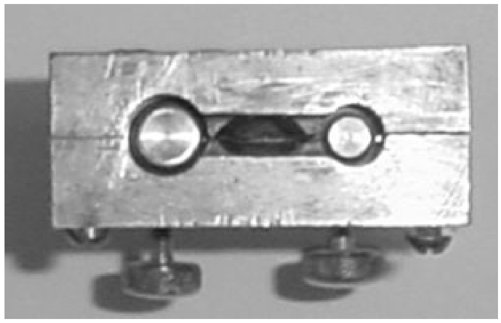

Figure 3 Counter die seated over the stainless steel dies.

Two stainless steel nonanatomic dies representing a second premolar (6 mm in height × 6 mm in diameter) and a second molar (6 mm in height × 9 mm in diameter) were fabricated using a lathe-cutting machine and set at 11 mm apart in a specially designed metal box provided with two slots. This assembly was used as a working model for each interim prosthesis specimen. A milled split counter die of brass was enlarged by 1.5 mm and constructed to fit over the stainless steel dies. It was used during specimen construction to standardize the dimensions of the resin FPD (Figs 1 and 3).

The mesh and the fibers were cut to a predetermined length averaging 18.5 mm, spanning the midabutment span. Finally, the precut fibers were preweighed using an electronic scale, before incorporation in the restoration to represent 3% weight of the resin interim prosthesis. The stainless steel dies and the fitting surface of the brass mold were both coated with separating medium. The chemical cure material was mixed and loaded inside the brass mold, which was seated on the metal dies. Excess material was removed before curing.

The control FPDs were constructed by filling the mold with resin in three increments to minimize shrinkage and porosity. In the reinforced groups, when the resin reached the level of the occlusal surface of the abutments, the preweighed cut fibers (approximately 3%),[25,41] or mesh was inserted between the abutments, then the remaining occlusal third of the resin was filled. Excess resin was removed before complete setting. A glass slab was placed over the assembly until final setting to ensure constant pressure.

Load-to-failure test

Each provisional retainer was seated on its corresponding die within the metal box, which in turn was secured to the lower fixed compartment of the computer-controlled testing machine (Model LRX-plus, Lloyd Instruments Ltd, Fareham, UK) with a load cell of 5 kN. Specimens were loaded compressively with a steel ball (3.7 mm diameter), which was centrally positioned at the midpontic area at a crosshead speed of 0.5 mm/min. Failure was manifested by an audible crack and confirmed by a sudden drop in the recorded load-deflection curve. The load required to fracture the specimens was recorded in Newtons. Stress values in MPa were not calculated because of the complex shape of the specimens.[29] The load-deflection curves were recorded using computer software (Nexygen-4.1, Lloyd Instruments).

Table 1 Summary of regression model

Variable	Source of variation	Sum of squares	df	Mean square	*f*-value	*p*-value
Fracture resistance	Material	56,284.1	2	28,142	8.566	0.002*
	Reinforcement	40,311.8	2	20,155.9	6.135	0.009*
	Material/reinforcement	5555.268	4	1388.817	0.423	0.790
Young's modulus	Material	2,164,813.6	2	1082,406.8	3.592	0.049*
	Reinforcement	1,130,517.8	2	565,258.9	1.876	0.182
	Material/reinforcement	2,462,471.4	4	615,617.8	2.043	0.131

*Significant at $p \leq 0.05$.

Statistical analysis

Data were presented as means and standard deviations (SD). A regression model with two-way ANOVA was used in testing significance for the effect of material type and reinforcement on fracture resistance and Young's modulus. Duncan's post hoc test was used for pairwise comparison between the means when ANOVA test was significant. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with SPSS 14.0® (SPSS, Inc., Chicago, IL) for Windows.

Results

Maximum load

Comparison between the materials

The means, SD, and results of ANOVA and Duncan's tests are presented in Table 1 and Figure 4. There was a statistically significant difference between the three control materials. Duralay displayed the highest mean fracture resistance, followed by Protemp and Snap. As for the fiber-reinforced group, Duralay showed the highest values; however, no statistically significant difference was detected between the values of Protemp and Snap restorations. Furthermore, no statistically significant difference was evident between the fracture resistance of the three mesh-reinforced materials.

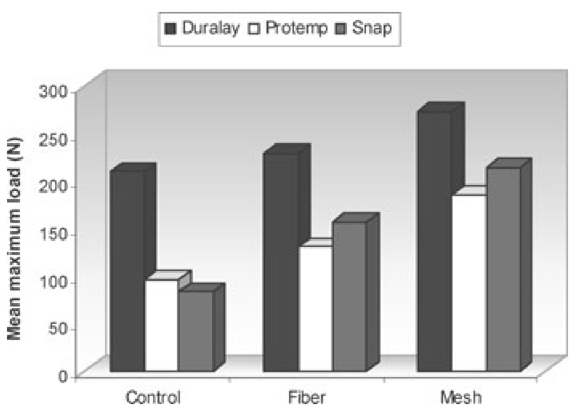

Figure 4 Effect of reinforcement on the fracture resistance of the three resins.

Comparison between the reinforcements

The means, SD values, and results of ANOVA and Duncan's tests are presented in Table 2 and Figure 5. Reinforcement did not show any significant alteration in the fracture resistance of Duralay and Protemp resin subgroups; however, a statistically significant alteration was apparent in the reinforced Snap subgroups. Mesh-reinforced Snap showed the statistically highest mean fracture resistance values. This was followed by fiber-reinforced Snap; the control group registered the lowest mean values.

Young's modulus

Comparison between the materials

The means, SD values, and results of ANOVA and Duncan's tests are presented in Table 3 and Figure 6. The three control group resin materials appeared to have similar moduli. As for the fiber-reinforced group, a statistically significant difference was found. Fiber-reinforced Duralay resin showed statistically the highest mean Young's modulus, but no statistically significant difference was found between Protemp and Snap. Regarding the mesh-reinforced group, a statistically significant difference was detected. Mesh-reinforced Duralay had the highest modulus, followed by mesh-reinforced Protemp and Snap, which showed similarly lower mean values.

Comparison between the reinforcements

Reinforcement caused significant alterations in the mean modulus values of Duralay resin subgroups (Table 4, Fig 6). Mesh-reinforced resin displayed the highest mean modulus, but no statistically significant difference was found between fiber-reinforced and control groups. As for Protemp and Snap resin subgroups, both fiber and mesh reinforcements produced no statistically significant change in their moduli.

Discussion

The purpose of this study was to assess the influence of UHMPE-preimpregnated fiber or mesh addition on the fracture resistance and moduli of three resin interim restorations. Many attempts at reinforcement have been reported. Prestipino[21] declared that brittleness in long-span interim prostheses could be reduced by adding metal reinforcements. Powell et al[5] attempted to strengthen PMMA interim prostheses using stainless

Table 2 Fracture resistance of the three resin materials with and without reinforcements (N)

Reinforcement \ Material	Duralay		Protemp		Snap		
Reinforcement	Mean	SD	Mean	SD	Mean	SD	*p*-value
Control	209.9[a]	12.3	95.9[b]	39.2	83.6[b]	20	<0.001*
Fiber	229.3[a]	18.3	130.4[b]	9.4	156.5[b]	15.7	0.046*
Mesh	273	94.6	185.4	96.8	214.5	14	0.414

*Significant at $p \leq 0.05$. Means with different letters are significantly different according to Duncan's test.

steel wires or polyaramid fibers. Others have described various methods of reinforcements by adding metal structures to acrylic resin interim prostheses.[5,12,15,21-23]

Initially Duralay restorations (PMMA) showed higher fracture strength values than the other two resin restorations. This corresponds to the findings of Gegauff and Wilkerson,[24] who stated that fracture toughness was highest for PMMA, followed by Bis-GMA and lastly PEMA. They confirmed that Bis-GMA was more brittle than PMMA and therefore more likely to fracture in long-span FPDs. Koumjian and Nimmo[13] also reported that the bis-acryl materials demonstrated lower strengths than methacrylate resins.

Provisional materials are typically composed of methacrylates or Bis-GMA. Each material is thought to have physical properties unique to its chemistry. A composite material is a combination of two or more distinct components that form a new material with enhanced properties. They encompass a variable category by virtue of the fact that they are chemically composed of a combination of two or more types of materials. Bis-acryl resins are hydrophobic materials similar to Bis-GMA. Controversy exists as to the supremacy of one resin over the other.[13,20,28,42] This inconsistency has been attributed by some authors to material property rather than resin category. Moreover, some, but not all, bis-acryl resins have shown superior strengths over traditional resins.[42]

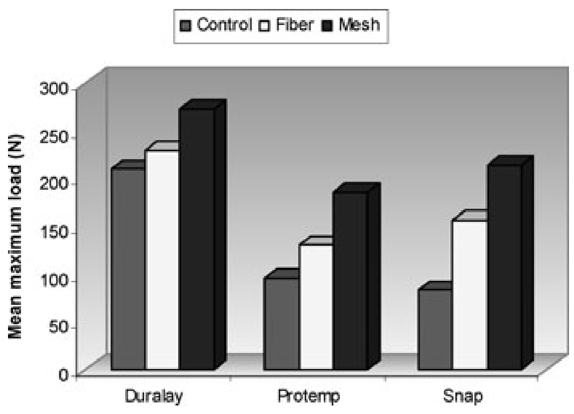

Figure 5 Effect of reinforcements on the fracture resistance (N) within each resin group.

Modifications in Bis-GMA impart properties that reflect the properties of the added group: that is additional monomer groups may add toughness and flexibility while some composites have additional fillers that increase strength. Moreover, additional groups in some proprietary brands provide more flexible chains than other synthetic resins, which allow for a balance between high mechanical strength and limited elasticity of the composite material. This confirms the fact that the difference in modulus is probably material specific rather than resin category specific.[42]

The stress at which a brittle material fractures is called the fracture strength.[3] The ultimate compressive strength or stress is defined as the maximum stress that a material can withstand before failure in compression. It is determined by dividing the maximum load in compression by the original cross-sectional area of the test specimen.[3] In many studies, the dimensions of the FPDs were identical so the loads at fracture were used to compare the effect of reinforcement on the fracture resistance of the interim prostheses.[5,27,29,39,40,43] In the case of fiber-reinforced restorations, Duralay showed the highest fracture load values followed by both Protemp and Snap. The mechanical properties of FRC materials are primarily dependent upon fiber type, length, ratio of fiber to matrix resin, fiber architecture (i.e., unidirectional, woven, or braided), and quality of impregnation of fiber and resin.[26-32] The fibers used in this study were machine impregnated with silane by the manufacturer to promote bonding. It may be suggested that the fibers increased the mean fracture resistance values of all the tested groups, so the ranking of the control resins was maintained, but the values were higher for all groups due to an adequate bond to all the resin groups.

Flexural strength is the measurement of the strength of a bar supported at each end under a static load, while the developed stress in that case refers to the load divided by the area of the beam.[3] It may vary within material chemical classes and between chemical classes of materials, that is, chemical composition.[42] The modulus is also dependent on the composition of the material.[3] Bis-GMA composite resin materials seem to be more brittle than PMMA, and therefore, more likely to fracture in long-span FPDs.[13,14,20,24,40] This property is most probably the cause of the better performance of Duralay, a PMMA resin.

The fibers had an enhancing effect on the fracture resistance of Snap resin, though not as significant as the mesh. It has been advised that the highest strength for fiber composite could be

Table 3 Young's modulus of the three resin materials with and without reinforcements

Material / Reinforcement	Duralay		Protemp		Snap		
	Mean	SD	Mean	SD	Mean	SD	*p*-value
Control	1709.4	128.6	2326.3	247.4	1118.8	267.3	0.188
Fiber	1850.7[a]	276.5	996.1[b]	262.8	1075.1[b]	93.6	0.002*
Mesh	2069.9[a]	109.2	1262.1[b]	367.9	1174.2[b]	124.4	<0.001*

*Significant at $p \leq 0.05$. Means with different letters are significantly different according to Duncan's test.

obtained by fibers oriented in one direction perpendicular to load application.[43] This fact was considered in this study; in addition, the fibers were preimpregnated with silane and added as 3% weight. The basic requirement for reinforcing resins is an adequate bond as, in the case of an inadequate bond, the filler may act as an inclusion body and weaken the prosthesis.[14,36] Furthermore, it could be postulated that reinforcing materials produced new composite materials with unequal moduli. Initially, the three control resins had equal moduli, even though they belonged to different resin categories; however, both fiber and mesh addition changed their moduli, providing newer systems with different stiffness and bending values.

The fact that fiber and mesh reinforcements did not alter the fracture resistance of Duralay and Protemp resin subgroups disagrees with the findings of Samadzadeh et al,[27] who reported a significant increase in strength for bis-acryl. It is possible that some fiber–resin combinations produce better bonds due to their chemistry or amount of unpolymerized chains. The fibers in this study were treated with silane and not plasma as reported in the previous study. Direct comparison to other studies is not always possible due to differences in material methodology, span length, testing conditions, and specimen configuration. Braden et al[32] reported that UHPPF was far more effective in enhancing impact strength and stiffness than carbon fibers, but less effective in improving flexural strength. The stronger the adhesion between the fiber and the matrix, the greater the strengthening effect. In fact, the presence of poorly bonded fiber at which little load is transferred can be almost equivalent to voids.[44]

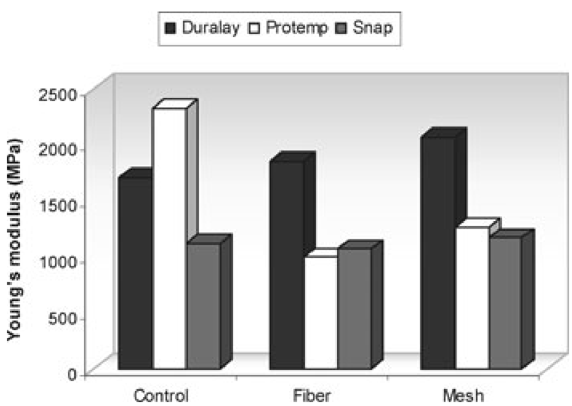

Figure 6 Young's modulus of the three resin materials with and without reinforcements.

The means of loads at failure in the present study differed from those registered in some previous studies.[4,34,39] This variation may be attributed to the difference in testing methodology, that is, the model materials on which the fracture resistance test was carried out. Lang et al[40] used cobalt–chromium alloy dies; others tested on stainless steel dies,[38] or epoxy dies.[41,45] Additionally, the various diameters of the ball indenter used in their studies may account for variation. Lang et al[40] used a 12.5 mm steel ball, Fahmy and Mohsen[45] used a 6 mm indenter, and the present study used 3.7 mm. It must also be clarified that the fracture-resistance test in this study was performed while the interim restorations were seated on metal dies as performed by Nohrström et al,[29] Hamza et al,[38,39] and Lang et al,[40] as an alternative to other testing conditions in which the interim prostheses were cemented to their dies.[4,34]

No cementing medium was used, which accentuated the brittle behavior of the materials by not transferring stresses to the supporting structures. A former study noted that cementation increased the fracture resistance of restorations by transferring stresses more evenly to the abutments. Another study reported omitting the use of provisional cement due to its poor bonding to metal abutments.[46] Wang et al[2] compared six resins in their study and found that Protemp had the same transverse strength as the other four resins tested. Snap, however, failed to give readings, as it exhibited extreme plastic deformation due to its rubbery nature. This was not apparent in the present study.

No statistically significant difference was evident between the fracture resistance of the three mesh-reinforced materials. Mesh addition significantly increased the fracture resistance of Snap. This was probably due to the formation of a new composite material, which performed as well as the two other mesh-reinforced resins, negating its initial low performance values. This result agrees partially with the results of previous researchers who attempted to strengthen interim prostheses by metal reinforcements;[5,12,15,21-23] however, the strengths of Duralay and Protemp were not improved.

Mesh-reinforced Snap restorations showed higher fracture-resistance values than fiber and unreinforced restorations. The fine mesh seemed to have bonded better to Duralay resin than did the fibers, forming a new composite material that endured higher fracture loads, making it perform better than the Duralay and Protemp resin, which initially showed higher values. The fine mesh possessed microirregularities, which

Table 4 Effect on Young's modulus (N/mm^2) of reinforcements within each resin group

Material / Reinforcement	Duralay		Protemp		Snap	
	Mean	SD	Mean	SD	Mean	SD
Control	1709.4[b]	128.6	2326.3	247.4	1118.8	267.3
Fiber	1850.7[b]	276.5	996.1	262.8	1075.1	93.6
Mesh	2069.9[a]	109.2	1262.1	367.9	1174.2	124.4
p-value	0.039*		0.105		0.756	

*Significant at $p \leq 0.05$. Means with different letters are significantly different according to Duncan's test.

probably enhanced mechanical retention by interlocking and providing an increased surface area as compared to fiber reinforcement, which depends mostly on chemical bonding. The higher flow of Snap resin may have promoted bonding by entering within the fine mesh and binding in it as opposed to Duralay and Protemp, which both possess thicker consistency.

The elastic modulus represents the stiffness or rigidity of a material within the elastic range.[3] Generally, in restorations, the two most important mechanical properties for reinforcing fibers are strength and stiffness or rigidity of materials. A high modulus is necessary for fiber-reinforced FPDs, as it offers more support to brittle composites. This situation is similar to metal frameworks supporting porcelain in metal ceramic prostheses.[35,44,47,48] Initially, the three resin materials appeared to have similar moduli; however, after fiber and mesh additions, a statistically significant difference was displayed between the three subgroups. Fiber- and mesh-reinforced Duralay resin showed statistically higher modulus values, while both reinforced Protemp and Snap resins showed no change. This increase in modulus would make Duralay resin develop higher rigidity, allowing less bending, thereby increasing its fracture resistance. This was evident by the numeric increase in mean fracture resistance value (Table 2) but did not appear to be statistically significant. Braden et al[32] reported that UHPPF increased stiffness but was less effective in improving flexural strength.

The results of this study are consistent with those of Gratton et al,[14] who recommended the use of PMMA for multiunit, long-term interim FPDs. Gegauff and Wilkerson[24] concluded that fracture toughness was highest for PMMA, followed by Bis-GMA and PEMA. Fracture toughness may therefore more accurately determine the probability of failure of an interim fixed prosthesis in clinical practice.

The pattern of failure for the reinforced restorations was totally different from the control group. Instead of two separate segments, the reinforced restorations failed but remained attached. The fracture failure of interim prostheses has been classified into two main categories: partial failure (unseparated fracture), which is a favorable mode of fracture where the prosthesis remains intact, and catastrophic failure (separated fracture), where there is complete separation of the restoration, and requires fabrication of a new prosthesis. It was found that the first type occurred with reinforced materials, which agrees with the findings of others.[27,47]

The site of reinforcement selected in this study enhanced fracture resistance in only one group, but future trials should be attempted at tension sites at the cervical part of the pontic where there seems to be the most stress.[21] One has to take into consideration that resins are very often tested as beams, whereas interim FPDs do not have uniform dimensions. Connectors have smaller dimensions and are not rigidly connected to abutment teeth, as these allow rotational movement of retainers during loading.[5] Moreover, abutment teeth are not rigidly anchored in the maxilla or mandible, and flexible mounting should be considered during testing to simulate the periodontium.[43]

For multiunit, complex, long-term interim FPDs, PMMA resins remain the material of choice. Preimpregnated fiber systems with defined fiber concentrations and carefully determined coordinated material combinations may be used for provisional reinforcement. Finally, the metallic mesh used in this study should be considered for further investigation, as it was developed for use in orthodontics, but its fine mesh design promoted bonding to resin. Furthermore, it provides easier handling and precise placement during interim construction than do fibers.

Conclusions

1. Initially, Duralay restorations (PMMA) had higher fracture-resistance values than Protemp (Bis-GMA) and Snap (PEVMA) resin.
2. Fiber and mesh reinforcements did not alter the fracture resistance of Duralay and Protemp resin restorations; however, they greatly increased the fracture resistance of Snap, mesh significantly more than fiber.
3. No statistically significant difference was evident among the fracture resistance of the three mesh-reinforced resin FPD restorations.
4. Initially the three resin materials appeared to have similar moduli. Fiber and mesh reinforcement increased the modulus of Duralay resin but did not alter the moduli of Protemp and Snap resin subgroups.

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References

1. Rosenstiel SF, Land MF, Fujimoto J: Contemporary Fixed Prosthodontics (ed 4). St. Louis, Mosby, 2006, pp. 466-504
2. Wang RL, Moore BK, Goodacre CJ, et al: A comparison of resins for fabricating provisional fixed restorations. Int J Prosthodont 1989;2:173-184
3. Powers JM, Sakaguchi RL: Craig's Restorative Dental Materials (ed 12). St. Louis, Mosby, 2006, pp. 58-60, 204
4. Luthardt RG, Stossel M, Hinz M, et al: Clinical performance and periodontal outcome of temporary crowns and fixed partial dentures: a randomized clinical trial. J Prosthet Dent 2000;83:32-39
5. Powell DB, Nicolls JI, Yuodelis RA: A comparison of wire and Kevlar-reinforced provisional restorations. Int J Prosthodont 1994;7:81-89
6. Lowe RA: The art and science of provisionalization. Int J Periodontics Dent 1987;7:64-73
7. Driscoll CF, Woolsey G, Ferguson WM: Comparison of exothermic release during polymerization of four materials used to fabricate interim restorations. J Prosthet Dent 1991;65: 504-506
8. Vahidi F: The provisional restoration. Dent Clin North Am 1987;31:363-381
9. Vallittu PK, Lassila VP, Lappalainen R: Acrylic resin fiber composite: Part 1. The effect of fiber concentration on fracture resistance. J Prosthet Dent 1994;71:607-612
10. Larson WR, Dixon DL, Aquilino SA, et al: The effect of carbon fiber reinforcement on the strength of provisional crown and bridge partial denture resins. J Prosthet Dent 1991;66: 816-820
11. Freiderick DR: The provisional fixed partial denture. J Prosthet Dent 1975;34:520-526
12. Amet EM, Phinney TL: Fixed provisional restorations for extended prosthodontics treatment. J Oral Implantol 1995;21:201-206
13. Koumjian JH, Nimmo A: Evaluation of fracture resistance of resins used for provisional restorations. J Prosthet Dent 1990;64:654-657
14. Gratton DG, Aquilino SA: Interim restorations. Dent Clin North Am 2004;48:487-497
15. Davidoff SR: Heat processed acrylic resin provisional restorations: an in-office procedure. J Prosthet Dent 1982;48:673-675
16. Amin AE: The effect of polyaramide fiber reinforcement on the transverse strength of a provisional crown and bridge resin. Egypt Dent J 1995;41:1299-1304
17. Panyayong W, Oshida Y, Andres CJ, et al: Reinforcements 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;12:353-366
18. Ireland MF, Dixon DL, Breeding LC, et al: In vitro mechanical property comparison of four resins used for fabrication of provisional fixed restorations. J Prosthet Dent 1998;80:158-162
19. Young HM, Smith CT, Morton D: Comparative in vitro evaluation of two provisional restorative materials. J Prosthet Dent 2001;85:129-132
20. Osman YI, Owen CP: Flexural strength of provisional restorative materials. J Prosthet Dent 1993;70:94-96
21. Prestipino V: Visible light cured resins: a technique for provisional fixed restorations. Quintessence Int 1989;20: 241-248
22. Emtiaz S, Tarnow DP: Processed acrylic resin provisional restoration with lingual cast metal framework. J Prosthet Dent 1998;79:484-488
23. Hazelton LR, Brudvik JS: A new procedure to reinforce fixed provisional restorations. J Prosthet Dent 1995;74:110-113
24. Gegauff AG, Wilkerson JJ: Fracture toughness testing of visible light and chemical-initiated provisional restoration resins. Int J Prosthodont 1995;8:62-86
25. Stipho HD: Effect of glass fiber reinforcement on some mechanical properties of autopolymerizing polymethyl methacrylates. J Prosthet Dent 1998;79:580-584
26. Freilich MA, Meiers JC, Duncan JP, et al: Fiber-Reinforced Composites in Clinical Dentistry. Chicago, Quintessence, 2000
27. Samadzadeh A, Kugel G, Hurley E, et al: Fracture strength provisional restorations restored with plasma-treated woven polyethylene fiber. J Prosthet Dent 1997;78:447-450
28. Goldberg AJ, Burstone CJ: The use of continuous fiber reinforcement in dentistry. Dent Mater 1992;8:197-202
29. Nohrström TJ, Vallittu PK, Yli-Urpo A: The effect of placement and quantity of glass fibers on the fracture resistance of interim fixed partial dentures. Int J Prosthodont 2000;13:72-78
30. Altieri JV, Burstone CJ, Goldberg AJ, et al: Longitudinal clinical evaluation of fiber reinforced composite fixed partial denture: a pilot study. J Prosthet Dent 1994;71:16-22
31. Deboer J, Vermilyea SG, Brady RE: The effect of carbon fiber orientation on the fatigue resistance and bending properties of two denture resins. J Prosthet Dent 1984;51:119-121
32. Braden M, Davy KW, Parker S, et al: Denture base poly(methyl) methacylates reinforced with ultra-thin modulus polyethylene fibers. Br Dent J 1988;164:109-113
33. Ladizesky NH, Cheng YY, Chow TW, et al: Acrylic resin reinforced with chopped high performance polyethylene fibers properties and denture construction. Dent Mater 1993;9:128-135
34. Vallittu PK: The effect of glass fiber reinforcement on the fracture resistance of a provisional fixed partial denture. J Prosthet Dent 1998;79:125-130
35. Vallittu PK: Comparison of the in-vitro resistance of an acrylic resin removable partial denture reinforced with continuous glass fibers or metal wires. J Prosthet Dent 1996;5:115-121
36. Chung K, Lin T, Wang F: Flexural strength of a provisional resin material with fibre addition. J Oral Rehabil 1998;25:214-217
37. Saygili G, Sahmali SM, Demirel F: The effect of glass and aramid fibers on the fracture resistance of provisional restorative materials. Oper Dent 2003;28:80-85
38. Hamza TA, Rosenstiel SF, El-Hosary MM, et al: The effect of fiber reinforcement on the fracture toughness and flexural strengths of provisional restorative resins. J Prosthet Dent 2004;91:258-264
39. Hamza TA, Rosenstiel SF, El-Hosary MM, et al: Fracture resistance of fiber-reinforced PMMA interim fixed partial dentures. J Prosthodont 2006;15:223-228
40. Lang R, Rosentritt M, Behr M, et al: Fracture resistance of PMMA and resin matrix composite-based interim FPD materials. Int J Prosthodont 2003;16:381-384
41. Gutteridge DL: The effect of including ultra high modulus polyethylene fiber on the impact strength of acrylic resin. Br Dent J 1988;164:177-180
42. Haselton DR, Diaz-Arnold AM, Vargas MA. Flexural strength of provisional crown and fixed Partial denture resins. J Prosthet Dent 2002;87:225-228
43. Agarwal BD: Fracture toughness of fiber-reinforced composites. In Cheremisinoff NP (ed): Handbook of Ceramics and Composites, vol 1. New York, Marcel Dekker, 1990, pp. 269-305

44. Cogswell FN: An introduction to thermoplastic materials. In Cogswell FN (ed): Thermoplastic Aromatic Polymer Composites. Oxford, Butterworth Heinemann, 1992, pp. 1-9
45. Fahmy NZ, Mohsen SA: Effect of storage of provisional restorations in artificial saliva on the vertical marginal gap and fracture resistance. Egypt Dent J 2006;53: 697-712
46. Pashley DH: Dynamics of the pulpo-dentin complex. Crit Rev Oral Biol Med 1996;7:104-133
47. Vallittu PK: Flexural properties of acrylic resin polymers reinforced with unidirectional and woven glass fibers. J Prosthet Dent 1999;81:318-326
48. Herakovich C: Mechanics for Fiber Composites. New York, Wiley, 1998, pp. 402-448

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