ORIGINAL RESEARCH

Comparative evaluation of effect of different methods of reinforcements on the fracture toughness of interim fixed partial denture – An in vitro study

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ABSTRACT

Context: There is presently no ideal provisional material suitable for all clinical conditions. A material for the fabrication of multiunit interim prostheses for longer duration of time it can be reinforced with different materials. Which materials is best for increasing the fracture toughness of material is unclear, therefore it is necessary to evaluate effect of different reinforcements and the best material suitable for increasing the fracture toughness of provisional materials.

Purpose: The aim of the study was to evaluate and compare the fracture toughness of chemically cure and dual cure interim fixed partial denture materials with different methods of reinforcement.

Methodology: A stainless steel jig was fabricated with standard specifications. A urethane based dual cure resin (Tuff temp plus) and bis acryl based self cure (Protemp 4) interim restorative materials were used for fabrication of samples. Glass fibers, Braided glass fibers, graphene oxide nanoparticles and stainless steel mesh were used as reinforcement materials. Total 100 samples were fabricated and divided according to interim restorative resins used. Samples were further divided into five subgroups of each group having 10 with each reinforcing material. Unreinforced samples were fabricated as control groups. The fracture toughness values for each sample were measured using Universal testing machine (Dak system inc, series 7200).

Statistical analysis: ANOVA test, Tukey's post hoc test.

Result: All the reinforcements have shown statistically significant increase in fracture toughness values for both the groups. Among all the reinforcements for group I (Tuff temp plus) statistically significant fracture toughness values were obtained with graphene nano particles (519.5±109.91), stainless steel mesh (505.1±108.15), braided glass fibers (382.23±32.3) and Glass fibers (374.9±75.08) in comparison to control group (P<0.05). Whereas for group II all the reinforcements, graphene nanoparticles (574.7±111.86), stainless steel mesh (561.7±28.44), braided glass fibers (443.2±130.05)

and glass fibers (426.6±111.86) showed statistically highly significant values in comparison to control group (P<0.05).
No significant difference was observed in comparison of fracture toughness between group I and group II control and reinforced specimens.
Conclusion: When compared to control groupall the reinforcement materials produce significantly higher fracture toughness for both UDMA resin (Tuff temp plus) and bisacryl (Protemp 4).Reinforcement of both types of resin with graphene oxide nanoparticles and stainless steel mesh provides higher fracture toughness in comparison to glass fibers and braided glass fibers. No statistically significant difference was evident between UDMA and bisacryl resin.
Keywords: Interim fixed partial denture materials, Fracture toughness, Reinforcement materials

INTRODUCTION

Interim crowns or interim partial fixed dental prostheses (FDPs) are essential in prosthodontic therapy. Interim prostheses are those placed between the time of tooth preparation and placement of the definitive prosthesis. The word interim means established for the time being, pending a permanent arrangement.[1]
To be successful, provisional restorations must fulfil biologic, mechanical, and esthetic requirements.[2-8] These restorations should provide pulpal protection, comfort, positional stability, occlusal function, access for cleaning, esthetics, strength, and retention. Prognosis of questionable teeth is evaluated, and therapeutic occlusal vertical dimension is determined.[8-13] They also promote guided tissue healing by providing a matrix for surrounding gingival tissues. Interim fixed partial dentures must preserve abutment position and maintain inter- and intra-arch relationships through the establishment of proximal and occlusal contacts.[2,14-18]Unfortunately, temporary usually connotes laxity.[1]
Because of unforeseen events (e.g., laboratory delays or patient unavailability), an interim restoration may have to function for an extended period. For other patients, a delay in placing the definitive restoration may be intentional (e.g., because the etiologic factors of a temporomandibular disorder or periodontal disease must be corrected). Whatever the intended length of treatment time, an interim restoration must be adequate to maintain patient health. Thus, it should not be casually fabricated on the basis of an expected short term of use.[19,20]
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), polyethylmethacrylates (PEMA), polyvinyl ethyl methacrylates (PVEMA), Bis-GMA resins, bis-acryl resin composites, and visible light-cured urethane dimethacrylate resins.[2,3,4,5,21-23]There is presently no ideal provisional material suitable for all clinical conditions.In selecting a material for the fabrication of multiunit interim prostheses for longer duration of time, the clinician must consider numerous factors in terms of flexural strength, surface hardness, wear resistance, dimensional stability, polymerization shrinkage, colour range and stability, handling properties, repair, and cost.[2,6,12]
Many attempts have been made to strengthen the provisional restorative materials by incorporating with different types of reinforcement.[20-26] Various materials like glass fibers, [3.4]polyethylene glass fibers,[8,12,15]quartz,[13] carbon fibers,[17,19] stainless steel wire or mesh,[21,24] Kevlar fibers[16]are used for reinforcement of provisional restorative materials.
Increase in mechanical properties of reinforced composite restorative materials are primarily dependent upon fiber type, ratio of fiber to matrix resin, fiber architecture i.e., unidirectional, woven or braided and quality of impregnation of fiber and resin.[2,18,22] The position of fiber is

one of the crucial factors for reinforcing effect, so than the length and the adhesion. However, excessive fiber concentrations may produce the opposite effect.[4]

Recently nanoparticles are also been used for reinforcement of dental resins to increase the mechanical properties. Graphene oxide is one such material that can be used for reinforcement of composite resins. Graphene oxide nanoparticles are usually used in the form of tubes and sheets.[5] Graphene oxide nanoparticles is known to improve mechanical properties like fatigue resistance, impact strength and transverse strength of resins. It also exhibits operational inconvenience and unsatisfactory aesthetics. [10]

Although these above-mentioned materials are used frequently for reinforcing the provisional restorative materials, which is the best material that can improve the properties of interim restoration, how and where it should be incorporated for best results is unclear.

It is evident that fractures are common in long-span interim FPDs, frequently occurring at connector sites. This study was undertaken to test the efficiency of reinforcing these restorations by adding different reinforcing materials between the abutments spanning the midabutments, connector, and pontic length.

MATERIALS AND METHODOLOGY

1. FABRICATION OF MASTER DIE

A master die of stainless steel was fabricated. It was an analogue of second premolar, second molar and an edentulous span for missing first molar representing fixed partial denture.The distance between the two dies was 10 mm representing missing first molar. One platform was fabricated in the first molar area representing the edentulous ridge for fabrication of pontic.One counter jig was also fabricated such that samples fabricated with 8 mm height from finish line to occlusal surface. Also, samples fabricated had connector height of 4mm and width of 3mm.Occlusal surface of abutment and counter jig was marked with number 1 & 2 so that all the samples were fabricated with same placement of counter jig over master jig each time.

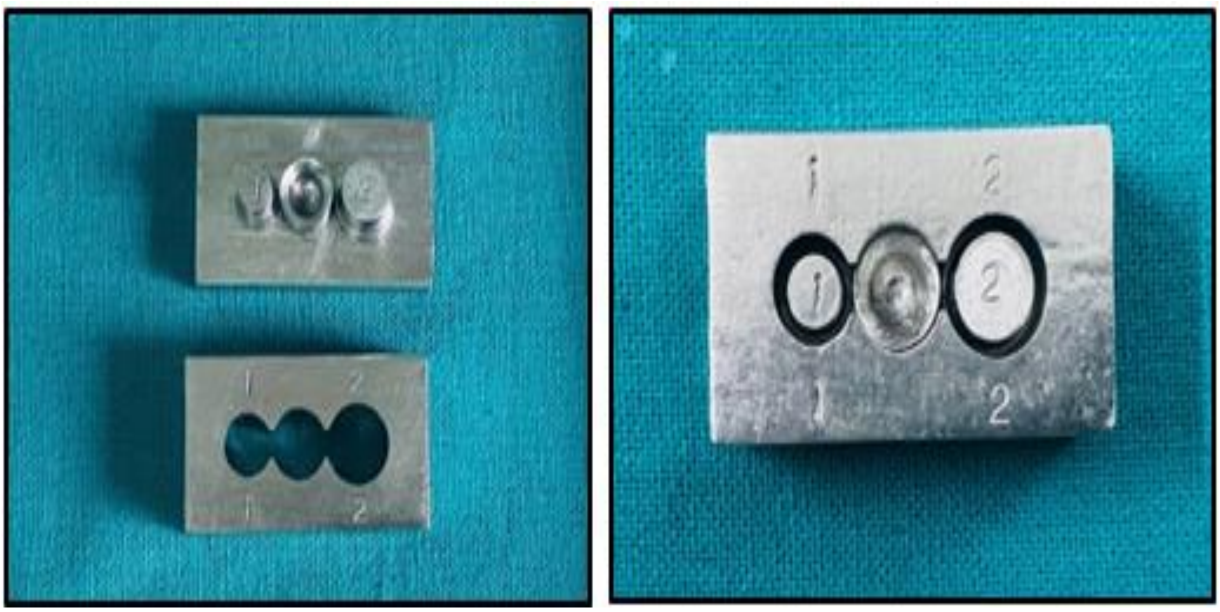


Fig. 1- stainless steel master model

2. GROUPING OF SPECIMENS

100 specimens were fabricated and divided in group 1 & 2 according to provisional restorative materials used and into respective subgroups according to the reinforcement materials used.

Table 1: Grouping of the specimens

Materials / Reinforcement	GROUP I (Tuff temp plus)	GROUP II (Protemp 4)
Control group (n = 10)	I C	II C
Glass fiber (n = 10)	I GF	II GF
Braided glass fibers (n = 10)	I BGF	II BGF
Graphene oxide nanoparticles (n = 10)	I GN	II GN
Stainless steel mesh (n = 10)	I SS	II SS

3. FABRICATION OF CONTROL GROUP SPECIMENS

The specimens were divided into two groups I and group II according to provisional restorative material used.

Group I - Temp Temp Plus (Pulpdent, USA.,LOT-200732, Exp.-31/07/2022)

Group II – Protemp 4 (3M ESPE, India.LOT-7997263, Exp.-05/07/2022)

Fabrication of Group I control specimens (I C group):

For fabrication of control specimen petroleum jelly (Vaseline) was applied on the jig and counter jig master model also on thermoplastic sheet. Tuff temp plus is injected into the mould through 1:1 auto mix gun and cartridge.

After the mould has completely filled with material 1.50mm thermoplastic sheet (Avac R, Jaypee agencies, India.) was placed over the jig and material was cured for 20 seconds using NMD visible light cure unit for each crown.

After complete curing the specimen was retrieved from the mould.

Fabrication of Group II control specimens (II C group):

The procedure for fabrication of Group II control specimens was same as above. Self cure resin, protemp 4 was dispensed through a 1:10 automix gun and cartridge. A thermoplastic sheet was placed above the jig and the material was allowed to cure for 4 min according to manufacturer's instructions.

A total ten specimens were fabricated.

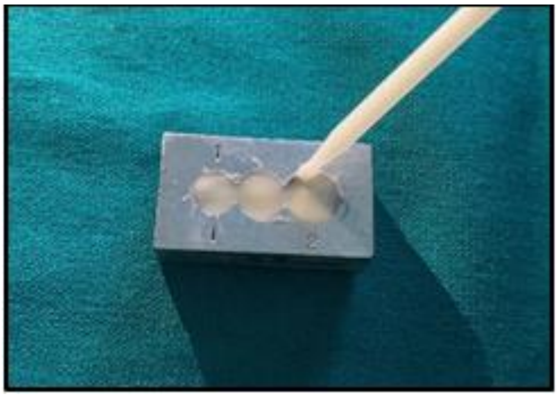


Fig. 2- Injecting provisional material

4. FABRICATION OF SPECIMENS WITH E GLASS FIBER REINFORCEMENT

For reinforcement of E glass fibers into the provisional restorative materials of both groups the fibers were placed in silane coupling agent for coupling with resins matrix. The mould was filled upto occlusal third level. After the fibers were completely soaked in silane coupling agent, they were placed from centre of one abutment to centre of another through pontic area.

Mould was then completely filled with either Protemp 4 or tuff temp plus material and allowed to cure completely as per manufacturer's instructions. After the material has set specimens were retrieved.

Ten samples each of group I GF and group II GF were fabricated as mentioned above.

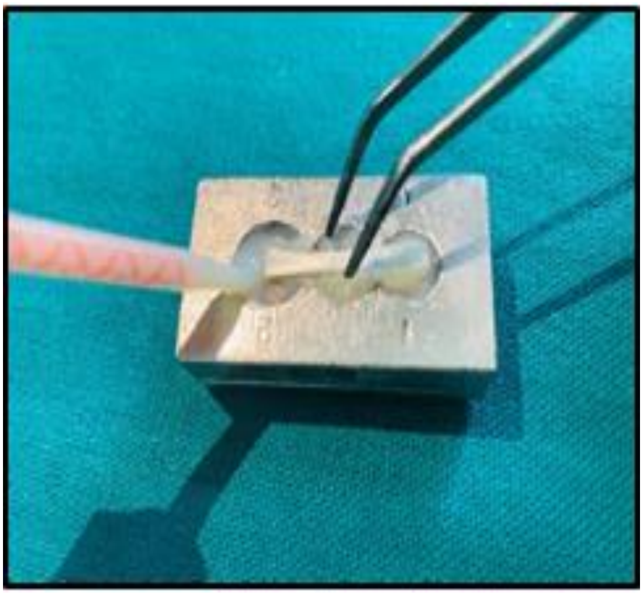


Fig. 3- Incorporation of reinforcement on occlusal third area

5. FABRICATION OF SPECIMENS WITH BRAIDED FIBER REINFORCEMENT

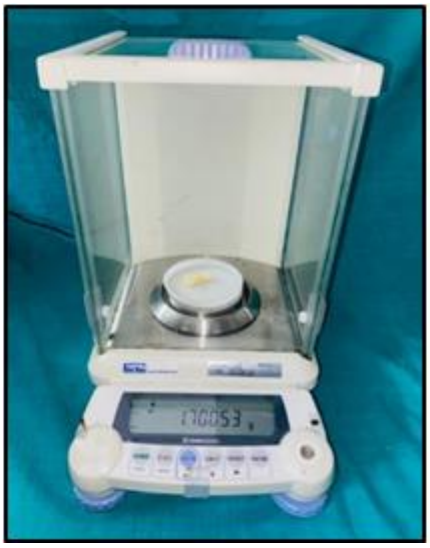
For reinforcement of braided glass fibers (Interlig) into the provisional restorative materials the fibers were cut to a length of 19mm. The fibers were then placed in bonding agent (Orthosolo) for bonding with resin matrix. The mould was filled upto occlusal third level. After the fiberswere completely soaked the bonding agent, they were placed from centre of one abutment to centre of another abutment.

Ten samples each of group I BGF and group II BGF were fabricated as mentioned above.

6. FABRICATION OF SPECIMENS WITH GRAPHENE OXIDE REINFORCEMENT

For reinforcement of graphene oxide into the provisional restorative materials five samples of each control group were weighed in microbalance machine. An average of these weighed specimens was calculated. 0.25wt% of these average values was calculated. The powder was weighed for each specimen. The preweighed graphene powder was placed in silane coupling agent for bonding with resin matrix. The mould was filled upto occlusal third level. After the particles were completely soaked in silane coupling agent, they were placed from centre of one abutment to centre of another abutment with help of hard brush.

Ten samples each of group I GN AND group II GN were fabricated as mentioned above.



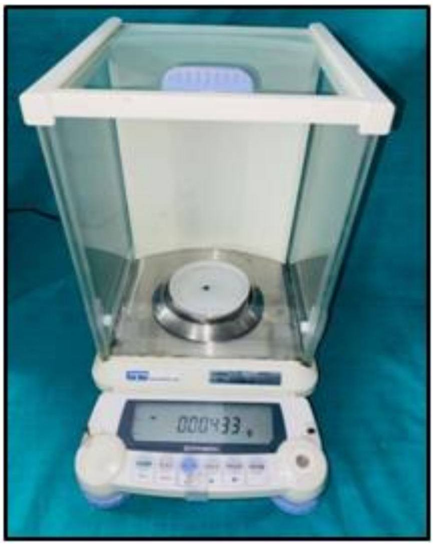


Fig. 4- weighing of control model using microbalance
Fig. 5- weighing of graphene oxide nanoparticles

7. FABRICATION OF SPECIMENS WITH STAINLESS STEEL REINFORCEMENT

For reinforcement of stainless steel into the provisional restorative materials the stainless steel denture metal mesh cut to a length of 19mm and 3mm width. It was then placed in Orthosolo bonding agent for coupling with resins matrix. The mould was filled upto occlusal third level. After the meshwas completely soaked in bonding agent, it was placed from centre of one abutment to centre of another abutment.

Ten specimens each of group were I SS and group II SS were fabricated as mentioned above.

Like this total 100 samples were fabricated. All the samples were inspected for any voids or irregularities on the surface.

8. MEASUREMENT OF FRACTURE TOUGHNESS OF SPECIMENS OF ALL GROUPS

For measurement of fracture toughness values, each provisional retainer was seated on its corresponding die within the metal jig. Specimens were loaded compressively with a steel ball of 3.7 mm diameter, which was centrally positioned at the mid pontic area at a crosshead speed of 0.5 mm/min using universal testing machine. 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 as fracture toughness of the material. The load-deflection curves were recorded using computer software.

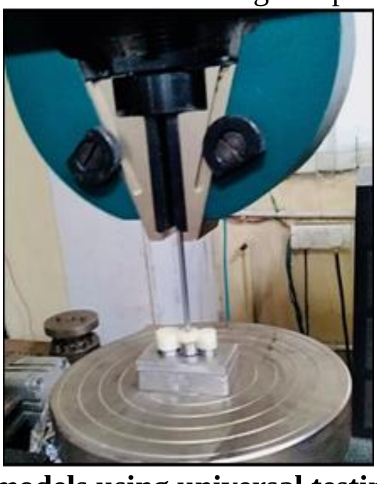


Fig. 6- Testing of models using universal testing machine

RESULT

Fracture toughness of all the samples were measured and statistical analysis was done for comparison of both the groups.**Table 2**shows Descriptive statistics of mean fracture toughness of provisional FPDs (Group I –Tuff Temp Plus) and (Group II – Protemp 4) using different types of reinforcement.

All the reinforcements have shown statistically significant increase in fracture toughness values for both the groups. Among all the reinforcements for group I (Tuff temp plus) statistically significant mean fracture toughness values were obtained with graphene nano particles (519.5), stainless steel mesh (505.1), braided glass fibers (382.23) and Glass fibers (374.9) in comparison to control group ($P<0.05$). Whereas for group II all the reinforcements, graphene nanoparticles (574.7), stainless steel mesh (561.7), braided glass fibers (443.2) and glass fibers (426.6) showed statistically highly significant values in comparison to control group ($P<0.05$).

No significant difference was observed in comparison of fracture toughness between group I and group II control and reinforced specimens.

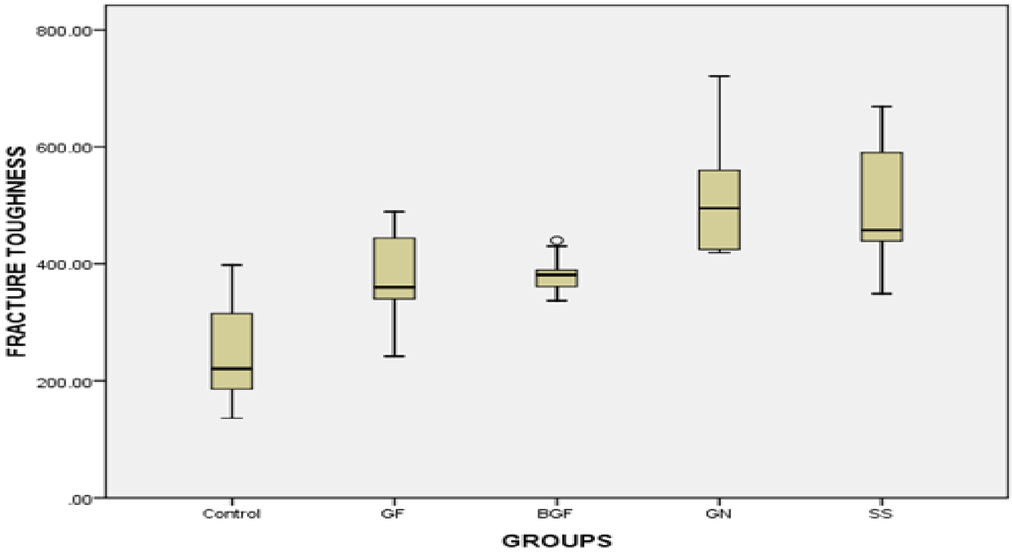
Box plot -1 & 2 shows mean of fracture toughness of control and reinforced specimens within group I and group II respectively.

Table 2: Descriptive statistics of fracture toughness of provisional FPDs (Group I –Tuff Temp Plus) and (Group II – Protemp 4) using different types of reinforcement.

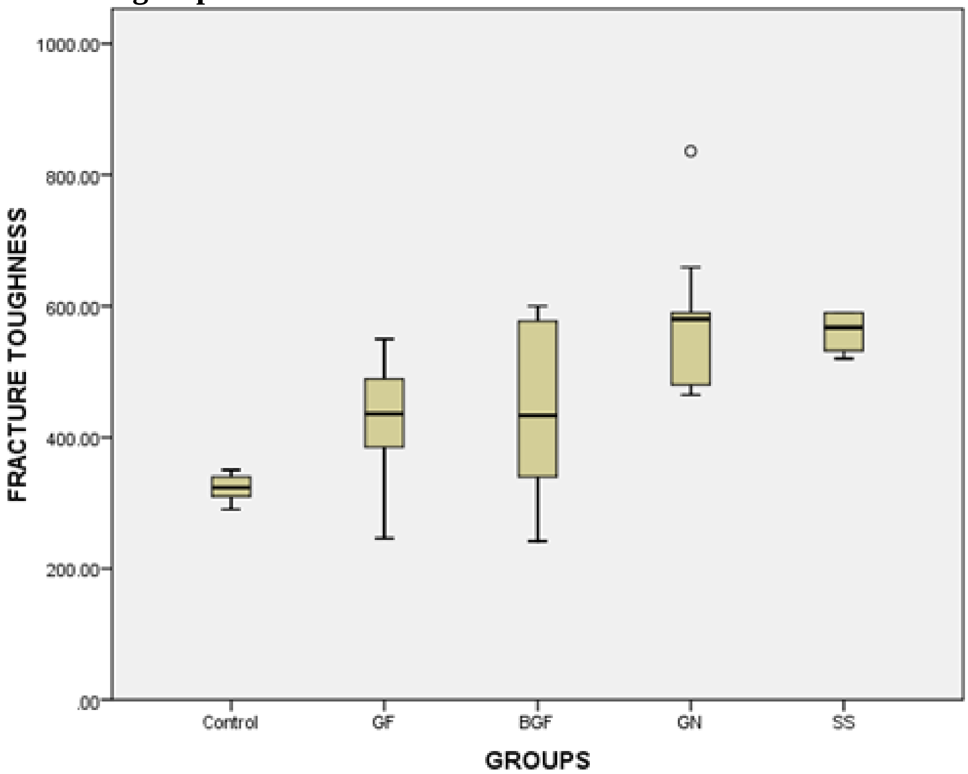
Materials / Reinforcements	Group I (Tuff temp plus)	Group II (Protemp 4)
	Mean	Mean
Control group	245^{Aa}	322^{Ba}
Glass fibre	374.9^{Ab}	426.6^{Bb}
Braided Glass fibre	382.3^{Ab}	443.2^{Bb}
Graphene oxide nanoparticles	519.5^{Ac}	574.7^{Bc}
Stainless steel mesh	505.1^{Ac}	561.7^{Bc}

^{a,b,c} statistically significant difference between different reinforcements methods (within same group).^{A,B}statistically significant difference between two groups (within the same reinforcement method.) ($p>0.05$)

Graph 1: Box plot showing mean of fracture toughness of control and reinforced specimens within Group I.



Graph 2: Box plot showing mean of fracture toughness of control and reinforced specimens within group II.



DISCUSSION

This study compared the fracture toughness of two materials commonly used to fabricate provisional restorations namely Tuff temp plus, a urethane dimethacrylate resin and Protemp 4, a bis-acryl composite. It also compared the fracture toughness of the two materials when reinforced with glass fibers, braided polyethylene fibers, graphene oxide nanoparticles and stainless steel mesh.

In this study bis-acryl based auto polymerizing resin and Urethane dimethacrylate based dual cure resin materials have been used. Bis acryl composite resin materials have proven commercially popular because of the ease of use,low polymerization shrinkage, low exothermic reaction, reduced tissue toxicity, handling properties and superior mechanical properties including hardness, flexural strength and modulus of elasticity.[7]

Advantages of the UDMA monomer when compared to Bis-GMA include a reduced viscosity, increased filler loading and greater toughness due to the flexibility of the urethane linkages. Studies have shown that when evaluating only the monomer systems UDMA based resin composites have improved mechanical properties compared to composites prepared from Bis-GMA.[7]

In the present study, higher flexural toughness was observed with bis acryl resins. Although no statistically significant difference (P>0.05) was seen between fracture toughness values of Tuff temp plus and Protemp 4.

Similar to this study, **Saisadan D et al (2016)[8],Binalrimal SR et al (2018)[9]**and**Naik B et al (2017)[10]**concluded thatbis acryl resin showed higherflexural toughness as compared to UDMA and PMMA resins.

The possible reason for these results can be bi functional substrate of bis-acryl composites that provides cross linkage with one another and form monomer chain cross linkage leading to increase in impact strength and toughness. They also contain inorganic fillers to increase their abrasion resistance.[11]

In contrast to this study, **Pooncha V et al (2013)[12] and Kerby et al (2013)[7]**concluded that urethane dimethacrylate resin showed higher mechanical properties than bisacryl resin.

This could be due to the flexibility ofthe urethane linkage and long chain molecular backbone between methacrylate end groups. Whereas, polymers made with Bis-GMA or uretahane based monomer system tend to be hydrophilic because they contain polar hydroxyl group and carbamate (urethane) linkages, respectively that can form hydrogen bonds with water. Water sorption can lead to reduction in mechanical properties such as flexural strength and modulus of elasticity of bisacryl resin.[7]

In this present study, both glass fibers have shown significant difference in fracture toughness values than its respective control groups both in group I and II. However, no statistically significant difference was seen between glass fibers and braided glass fibers reinforcements.

In anin vitro study by **Gupta B et al (2011)[13]** the interim fixed partial dentures reinforced with silane treated glass fibers exhibited significantly increased fracture resistance as compared to interim fixed partial dentures reinforced with non silane treated glass fibers. This indicates better adhesion of silane treated fibers to polymer matrix. Similarly, **Kamble et al (2012)[14]**, **Greets et al (2008)[3]**, **Hamza TA et al (2004)[15]**, **Chung K et al (1998)[16]**and **Solnit et al (1991)[17]**concluded that silane impregnated glass fibers reinforcement produce significantly higher flexural strength.

Glass fibers are most often used for reinforcing polymers because of their good esthetic qualities and good bonding of glass fibers to polymers via silane coupling agents. Glass fiber has high alumina and low alkali and borosilicate, this leads to superior fracturetoughness[13], higher mechanical properties, low susceptibility to moisture absorption and hence relatively good long term stability against water, resistance to chemicals, thermal stability and high melting point, and easy manipulation.[13,18]

Silane or organofunctional trialkoxysilane coupling agents form a large group of organic compounds that essentially contain a silicon atom or atoms. Silanes can function as mediators and promote adhesion between dissimilar, inorganic and organic matrices through dual reactivity.[13]

Uzun G et al (1999)[19]and **Kolbeck et al (2002)[20]**concluded that glass fibers in braided form showed significant increase in fracture toughness of resin.

The glass fibers are available in unidirectional and woven form.[15] Accurately placed and orientated impregnated fibers (unidirectional glass fiber) showed increased flexural strength. The increase was due to transfer of stress from the weaker polymer matrix to the fibers that have a high tensile strength. The stronger the adhesion between the fiber and the matrix, the greater the strengthening effect.[21]

Also, the preimpregnation of the fiber bundles or weaves with polymer made the glass fiber reinforcement easy to use, namely, the reinforcement did not fray and was easy to place in the desired region of the construction.[13]

Another method of reinforcing the provisional restoration is by the use of stainless steel mesh reinforcement. The stainless steel reinforcement groups in the study showed significantly higher fracture toughness values than control specimens.

In a study conducted by **Geerts et al (2008)[3]**, the glass fibers and stainless steel reinforcement produced significantly higher fracture toughness. In similar studies by **Viswambaran et al(2011)[22], and Vallittu et al(1998)[23]**it was found that the strength of PMMA resin was significantly increased when reinforced with stainless steel wire.

The fine mesh possesses irregularities which enhance mechanical retention by interlocking and providing increased surface area as compared to fiber reinforcement, which depends mostly on chemical bonding.[2]

Although different materials have been used as reinforcements in provisional composite resin materials there is not much evidence regarding the use of graphene oxide nanoparticle to increase fracture toughness of composite resins.

Very few literatures are available on reinforcement of graphene. In this study, an attempt has been made to increase the fracture toughness of provisional composite restorative materials by using graphene oxide nanoparticles as reinforcing agent. In the present study, graphene oxide nanoparticles showed statistically high significant difference ($P<0.01$) in fracture toughness values of both groups as compared to other reinforcements.

Lee et al (2018)[5] suggested that incorporating nanographene oxide significantly enhanced the flexural strength which was observed by 3-point bending test. According to **Larson et al (1991)**[24] the use of carbon graphite fibers served as a promising reinforcement for long span provisional fixed partial denture. These fibers increased the mechanical properties of acrylic resins, thus making it able to endure greater stresses created during mastication.

In the present study, 3-point bending test was performed to evaluate the fracture toughness of specimens.**Fahmy et al (2009)**[2]**, Kapri A (2014)**[25]**, Viswambaran et al. (2011)**[22]and **Gupt et al (2017)**[26] in their studies performed 3-point bending test in order to test the fracture toughness of provisional restorations.

3 point bending test follows the engineering beam theory, which states that when a beam is loaded mid-span between two supporting points, the applied load induces tension at the bottom and compression at the top. Similarly in loading the fixed partial denture from the occlusal surface, the occlusal side of the fixed partial denture undergoes compressive stress and the under surface of the pontic undergoes tensile stress.[13]

All the reinforcements have increased the fracture toughness of both the interim restorative resins. Thus, these reinforced materials can be used for fabrication of long-term interim restorations.

LIMITATIONS

The present study was not a clinical one and was done in an in vitro condition. The effect produced by reinforcement materials can have a slight effect in the oral environment. In this study oral environment was not simulated, also the thermocycling was not performed. There was no luting agent used for cementation of fixed partial denture was done. Further studies can be carried out in clinical conditions to verify the outcome of present study in clinical situations.

CONCLUSION

Within the limitations of the study, according to results and methods used in this study, following conclusions can be drawn.

1. Glass fibers, braided glass fibers, graphene oxide nanoparticles and stainless steel produce significant increase in fracture toughness for both UDMA (Tuff temp plus) and bisacryl (Protemp 4) interim restorative materials.
2. Graphene oxide nanoparticles and stainless steel mesh provided higher fracture toughness in comparison with control group for both UDMA (Tuff temp plus) and bisacryl (Protemp 4) interim restorative materials.
3. Reinforcement with glass fibers and braided glass fibers provides statistically similar increase in fracture toughness for both UDMA (Tuff temp plus) and bisacryl resins (Protemp 4) interim restorative materials.
4. No statistically significant difference was evident on fracture toughness between UDMA (Tuff temp plus) and bisacryl (Protemp 4) interim restorative materials.

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