INTRODUCTION

The material most commonly used for the fabrication of complete denture is polymethylmethacrylate (PMMA) denture base resin. This material is not ideal in every respect and it is the combination of virtues rather than one single desirable property that accounts for its popularity and usage. Despite satisfying esthetic demands it is far from ideal in fulfilling the mechanical requirements of prosthesis. A study by Johnston et al. showed that 68% of acrylic resin dentures break within a few years after fabrication primarily due to impact failure. Many approaches have been used to strengthen the PMMA denture base resin such as incorporation of metal wire. Alternate polymers do exist like vinyl acrylic, polystyrene and acrylic styrene, but have not been shown to produce dentures of greater accuracy with better performance. Modifications on PMMA by the incorporating a rubber phase in the bead polymer has improved the impact strength but resulted in increased cost. The other approach is the reinforcement of PMMA denture base resin with various types of fibers which include glass fiber, sapphire whiskers fiber, aramid fiber, carbon fibers, nylon fibers and polyethylene fiber. However, these fibers break-up the homogeneous matrix of acrylic resin due to poor interface between fiber and resin affecting the mechanical properties. In order to avoid this problem, many studies advocating the surface treatment of fibers have been reported in the literature. Numerous studies have been conducted on individual reinforced fibers to improve the strength of the denture base. It seems that very little work has been carried out to compare between individual reinforced fibers to determine which fiber suits best to improve impact strength of denture base.

In view of above observations, a study was considered to find out how the strength of acrylic resin can be improved by...
using fiber reinforcement and whether surface treatment affect the impregnation of fiber within the resin matrix. Hence, the purpose of this study was to evaluate the effect of reinforcement with untreated and surface treated glass, polyethylene and polypropylene fibers on impact strength of heat polymerized denture base resin.

**MATERIALS AND METHODS**

The materials used in the study are mentioned in Table 1. According to ASTM D4812 standard (standard test method for un-notched cantilever beam impact strength) metal dies with dimensions of $64\text{ mm} \times 13\text{ mm} \times 3\text{ mm}$ were fabricated to prepare the gypsum mold. The specimens were fabricated using standard techniques with mixture of monomer and polymer in ratio of 1:2.4 by weight. The flask was immersed in an acrylicizer (Unident, Mumbai, India) at room temperature for curing. The temperature was raised slowly up to $74^\circ\text{C}$ and held for 2 hours, then raised to $100^\circ\text{C}$ and was maintained for 1 hour. Acrylic specimens were finished and polished. The dimensions and quality of each specimen were verified. A total of 70 specimens were fabricated with 10 specimens for each group ($n = 10$).

The test specimens were grouped as under.

- **Group A**: Control group (Unreinforced specimens)
- **Group B**: Reinforced with glass fibers.
- **Group C**: Reinforced with polyethylene fibers.
- **Group D**: Reinforced with polypropylene fibers.

For Group B, C, and D specimens, before mixing polymer and monomer, 2% by weight of fibers were introduced into the reactor and stirred thoroughly with the polymer powder. Then the polymer powder and fibers were mixed thoroughly to disperse the fibers and the specimens were fabricated as in control group.

In case of Group B specimens, 2% by weight of glass fibers were soaked in silane for 5 minutes and allowed to air dry completely before they were dipped in a methacrylate monomer. In case of Group C and D specimens, Plasma treatment of polyethylene and polypropylene fibers was carried out in the reactor for enhanced adhesion of the fibers to resin matrix. 2% by weight of the fibers were introduced into the reactor and treated with 100 W power for 3 minutes using a flow of $17 \times 10^3 \text{ mm}^3 \text{ min}^{-1}$ of $\text{O}_2$ gas as plasma carrier. The pressure inside the reactor was 0.5 torr. The fibers were then soaked in monomer for 10 minutes. After the fibers were removed from the monomer, excess monomer was allowed to dry. Then the polymer powder and fibers were mixed thoroughly to disperse the fibers and the specimens were fabricated as in control group.

Each specimen was conditioned in water for 7 days at $37^\circ\text{C}$ and placed in water at $23^\circ\text{C}$ for 1 hour prior to testing. Specimens were labeled at each end prior to testing so that fractured pieces could be reunited and examined subsequent to testing.

Impact strength testing could be carried out on un-notched and notched specimens but notching would have cut the superficial fibers in the specimens, therefore testing was carried out on un-notched specimens. Testing was done on Izod impact testing machine (Veekay testlab, Mumbai, Maharashtra, India) with a pendulum of S2 scale in air at $23 \pm 2^\circ\text{C}$. Before testing, pendulum was released to freely swing in the air to record the air resistance (AR) encountered by free-swinging pendulum. Air resistance of 0.6 Joules was recorded. The readings were taken on S2 scale where pointer was stabilized after swing. The specimen was clamped in position precisely (Fig. 1). Pendulum was released and reading indicating energy absorbed (EA) to break the specimens on S2 scale was recorded. All the specimens were tested in the same manner. Fig. 2 shows one fractured specimen from each group.

Impact strength of specimen was calculated by using following formula -

$$\text{Impact strength} = \frac{\text{Corrected Readings}}{\text{W}}$$

Where,

- Corrected readings = (EA - AR) in Joules
- W = Test specimen width in meter
- Impact strength = J/m

One fractured specimen from each group was selected for SEM analysis. Specimens were cut 3 - 4 mm in length from the fractured specimens. Specimens were polished with different grades of silicon carbide paper up to 2400 grit, cleaned with alcohol, dried and sputter coated with gold/palladium for 2 min and examined using SEM.

### Table 1. The materials used in the study

| No. | Material                                      | Details                                      |
|-----|----------------------------------------------|----------------------------------------------|
| 1   | Heat cured denture base resin                | Trevalon Dentsply; 640011112, Germany         |
| 2   | Glass fiber (15 to 20 μm in thickness fibrillated and 6 mm in length) | Saint Gobin Vetrotex International;1263050, Chambery France |
| 3   | Polyethylene fibers (18 μm in thickness fibrillated and 6 mm in length) | Lotus polytwist (P) Ltd; 21458-32, Daman, India |
| 4   | Polypropylene fibers (10 μm in thickness and 6 mm in length) | Stealth e3, SI Concrete System; 81032, USA |
| 5   | Silane (Chemical name - Methacryloxypropyltrimethoxysilane) | Z-6030 Dow-Corning; 2530850, USA |
Effect of fiber reinforcement on impact strength of heat polymerized polymethyl methacrylate denture base resin: in vitro study and SEM analysis

Mowade TK et al.

These cut specimens from each group were mounted on SEM buttons using double sided sticking, and labeled. Mounted specimens were kept in the scanning Electron microscope. All the adjustments for focusing the microscope were done on the computer screen and the microscopic view was observed on the screen. The photographs for each group were stored for comparing the different groups.

RESULTS

The statistical analysis was performed using appropriate tests and statistical software (graphpad quickcals and graphpad prism). The data was interpreted at a confidence interval of 95%. The means and standard deviation are mentioned in Table 2.

An ANOVA was used to study whether all fibers reinforcement significantly improved impact strength when compared to unreinforced group. The null hypothesis (H0) in the present study being tested by ANOVA is that there is no difference in impact strength of PMMA resin after reinforcement with different fibers. The alternate hypothesis (H1), in case the null hypothesis is rejected, is that there is difference in impact strength of PMMA resins after reinforcement with fibers. The difference caused may be because of the presence of the fibers in the resin matrix.

The results of ANOVA test are shown in Table 3. The “F” value obtained was 172.3 whereas the table value of “F” at 0.05 level of confidence was 2.84. This analysis revealed that the results were statistically significant. Though the difference given by one-way ANOVA was significant, this test showed only collective results of all the means therefore Dunnett’s post hoc test was applied. Dunnett’s post hoc test compared all the reinforcement groups i.e. Group B, C and D with the control i.e. Group A (Table 4). The results revealed that Group B, C and D differed significantly (P<.05) from the control group.

| Table 2. Mean and standard deviation of impact strength of all groups |
|------------------------|------------------|-----------------|------------------|
| No. | Groups | Mean (× 10^-2 J/m) | SD       |
|-----|--------|---------------------|----------|
| 1   | Unreinforced specimens (control group) | 4.245 | 0.1202 |
| 2   | Untreated fiber reinforced specimens | | |
|     | Group B | 5.764 | 0.2764 |
|     | Group C | 7.58  | 0.8046 |
|     | Group D | 8.697 | 0.3994 |
| 3   | Surface treated fiber reinforced specimens | | |
|     | Group B | 6.448 | 0.3426 |
|     | Group C | 9.096 | 0.3864 |
|     | Group D | 9.229 | 0.4714 |

| Table 3. The results of ANOVA test |
|------------------------|------------------|-----------------|------------------|
| Source of variation    | SS  | Df | MS   | F- Ratio | Table value of -F |
|------------------------|-----|----|------|----------|------------------|
| Between groups         | 116 | 3  | 38.66| 172.3    | 2.84             |
| Within groups          | 8.079 | 36 | 0.2244|          |                  |
| Total                  | 124.1 | 39 |      |          |                  |
Effect of fiber reinforcement on impact strength of heat polymerized polymethyl methacrylate denture base resin: in vitro study and SEM analysis

Mowade TK et al.

This showed that reinforcement with fibers i.e. glass, polyethylene and polypropylene increased the impact strength significantly. Since calculated "F" value was more than the value of "F" that was given in the "F" table at difference between the classes and at difference within the classes at 0.05 level of significance, null hypothesis was rejected and alternate hypothesis stating that there was difference in impact strength of PMMA resin after reinforcement with fiber is accepted. This showed that there was improvement in impact strength after fiber reinforcement.

Individual 't' test were performed to compare the mean strength of untreated fiber groups with their respective surface treated fiber groups. The results of 't' test are shown in Table 5. The glass fibers treated with silane compound enhanced the impact resistance significantly compared to the impact resistance given by non-silanized glass fibers (t = 4.9137, df = 18, P=.0001). Plasma treated Polyethylene fibers showed impact resistance significantly higher than the untreated polyethylene fiber (t = 5.3710, df = 18, P=.0001). Plasma treated polypropylene fibers also showed significant difference in the impact resistance compared with the polyethylene fibers of untreated group (t = 2.7229, df = 18, P=.014). This showed that there was increase in the impact strength after surface treatment.

The ANOVA was performed to compare the impact strength of all the fiber reinforced groups i.e. Group B, C, D, Bt, C and Ct (P>.05). The results revealed that all the comparisons were statistically significant except for group D & C (P>.05) and group C & D (P>.05).

The scanning electron micrographs of surface at the fractured end were taken of representative samples from each group. Following observations were revealed.

- Group A: The SEM view of the fractured end of specimen showed rough surface and cracks spread throughout the fractured surface (Fig. 3A).
- Group B: The SEM view showed rough surface and cracks of smaller size than Group A. Glass fibers protruding out from the resin matrix and voids formed due to pulled out fibers were seen. Voids formed due to pulled out of glass fibers from the resin matrix were less as compared to Group B (Fig. 3B).
- Group Bt: The SEM view showed similar rough surface and cracks. Polyethylene fibers, which were fractured cohesively, and some protruding fibers were also seen. Voids formed due to pulled out of polyethylene fibers from resin matrix were less as compared to Group B (Fig. 3C).
- Group C: The SEM view showed rough surface and cracks same as in above groups. Polyethylene fibers protruding through the fractured end and voids formed due to pulled out polyethylene fibers from the resin matrix were also seen (Fig. 3D).
- Group C: The SEM view showed similar rough surface and cracks. Polyethylene fibers, which were fractured cohesively, and some protruding fibers were also seen. Voids formed due to pulled out of polyethylene fibers from resin matrix were less as compared to Group C (Fig. 3E).
- Group D: The SEM view showed rough surface and cracks

### Table 4. Dunnett’s post hoc test to compare control group with untreated fiber reinforced groups

| Groups compared | P value | Significance |
|-----------------|---------|--------------|
| A - B           | <.01    | Yes          |
| A - C           | <.01    | Yes          |
| A - D           | <.01    | Yes          |

### Table 5. Results of unpaired 't' test between Group - B and Bt, C and Ct, and D and D.

| No. | Groups compared | Mean     | SD       | 't' value | P value |
|-----|-----------------|----------|----------|-----------|---------|
| 1   | Group B         | 5.764    | 0.2764   | 4.9137    | <.0001  |
|     | Group Bt        | 6.448    | 0.3426   |           |         |
| 2   | Group C         | 7.580    | 0.8046   | 5.3710    | <.0001  |
|     | Group Ct        | 9.096    | 0.3864   |           |         |
| 3   | Group D         | 8.697    | 0.3994   | 2.7229    | .014    |
|     | Group Dt        | 9.229    | 0.4714   |           |         |

### Table 6. Results of ANOVA comparing all the untreated and surface treated fiber reinforced groups

| Source of variation | SS  | Df  | MS     | F- ratio | Table value of F |
|---------------------|-----|-----|--------|----------|------------------|
| Between groups      | 105.5 | 5  | 21.1   | 92.24    | 2.45             |
| Within groups       | 12.35 | 54 | 0.2287 |          |                  |
| Total               | 117.8 | 59 |        |          |                  |

### Table 7. Results of Newman-Keuls post hoc test for multiple comparisons.

| Group B    | Group C | Group D | Group Bt | Group Ct | Group Dt |
|------------|---------|---------|----------|----------|----------|
|            | <.001   | <.001   | <.001    | <.001    | >.05     |
similar to that of above reinforcement groups. Polypropylene fibers spread throughout the fractured surface and voids formed due to pulled out fibers were seen. Particles of the acrylate were seen attached to the surface of the fibers (Fig. 3F).

- Group D: The SEM view showed similar rough surface and cracks. Polypropylene fibers, which were fractured cohesively at the level of specimen fracture, and some protruding fibers were seen. Voids formed due to pulled out of fibers from matrix were less as compared to the Group D (Fig. 3G).

DISCUSSION

The glass fiber is an inorganic substance. E glass fibers, based on alumina-lime-borosilicate composition are considered the predominant reinforcement for polymer matrix due to their high mechanical properties, low susceptibility to moisture absorption, resistance to chemicals, thermal stability and high melting point. The other two fibers used in the study were polyethylene and polypropylene which are the two most common members of olefin family. Olefin fiber is a manufactured fiber in which the fiber forming substance is any long chain synthetic polymer composed of at least 85% by weight of ethylene, propylene or other olefin units. These fibers are very lightweight, have high strength and modulus, resistant to deterioration by chemicals, abrasion resistant, resistant to moisture absorption, resilient, and not brittle. Polyethylene fibers, because of its natural color and known biocompatibility, have been extensively studied for reinforcement in denture base PMMA resin over the last two decades. To date, no studies have been reported in the dental literature using polypropylene fiber for reinforcement in denture base. A polypropylene fiber has natural color and good mechanical properties. Because of its excellent biocompatibility it has been used in general surgery for closure of abdominal wounds and in oral and maxillofacial surgery for reconstruction of orbital floor, where there are multiple fragment fractures. The polypropylene reinforced specimens provided good surface finish and polish. American Composite Manufacturers Association suggests polypropylene as one of the reinforcement material for composite resins. Therefore, polypropylene fibers were also used in this study for reinforcement in PMMA.

The reinforcement groups with untreated glass, polyethylene and polypropylene showed statistically significant increase in the impact strength compared to the control group specimens. This might be attributed to the presence of reinforced fibers which carry the load along their length to provide strength and stiffness to the specimen in one direction, resulting in higher absorption of energy compared with un-reinforced specimens. Increase in impact strength shown by polyethylene and polypropylene fibers was much higher than that shown by glass fiber. This might be attributed to the inherent brittle property of glass compared to polyethylene and polypropylene fibers, which have more strength and stiffness.

Findings in this study agree in principle with the findings reported by Smith that had shown improvement in mechanical properties after reinforcement by discrete glass fibers in the resin.

---

Fig. 3. SEM view of specimens. A: Group A, B: Group B, C: Group Bt, D: Group C, E: Group Ct, F: Group D, G: Group Dt.
Vallittu et al., Vallittu and Narva, Uzun et al., Kim and Watts, Karacaer et al. are the other authors who are in agreement with the increase in impact strength after reinforcement with glass fibers. Increase in impact strength of polyethylene fiber reinforcement was coinciding with the findings reported by Gutteridge who studied different weight percentage of polyethylene fiber in chopped form and found significant improvement in impact strength and also Ladizesky et al. who showed improvement in impact strength of polyethylene reinforced group compared to unreinforced group.

Glass fibers, polyethylene fibers and polypropylene fibers are hydrophobic in nature and have low surface energy so their compatibility with PMMA is poor. Untreated fibers could act as inclusion bodies in the acrylic resin mixture and instead of strengthening actually weaken the resin by breaking up the homogeneous matrix. In order to improve the adhesion between resin and the fibers, surface modification has to be done. Some of the techniques followed are silane treatment of glass fibers, plasma treatment of polyethylene fibers using oxygen, Helium or Argon gas, chromic acid treatment of polyethylene fibers and plasma treatment of polypropylene fibers. The glass fibers used in this study were silane treated and polyethylene and polypropylene fibers used were plasma treated.

Table 5 shows the comparison of Group Bt, Ct, and Dt with Group B, C, and D respectively. There was significant improvement in impact strength after surface treatment of glass fibers which may be attributed to the effect of silane coupling agent, which chemically bonds inorganic glass fibers to the organic resin matrix and may make the mixture more homogenous resulting in strong PMMA resin. Improvement in impact strength after silane treatment of glass fiber correlates with that of the findings reported by Solnit and Vallittu.

There was also significant improvement in impact strength of Groups C and D compared to Groups C and D, which might be because of improved surface energy and surface wettability produced by plasma treatment which etches (micro-etching) the fibers so that they can bond mechanically with the matrix phase. Plasma is a partially ionized gas that contains ions, electrons and other neutral species at many different energy levels. Treating a polymer with plasma also introduces the functional group on the surface of fibers thereby making the surface polar, which improves the surface energy of the fibers and its compatibility with other materials.

Improvement in impact strength after plasma treatment of polyethylene fiber coincide with that of Ladizesky et al., who showed increased in impact strength of PMMA after plasma treatment of fibers but contradicts Gutteridge who showed no significant difference between untreated and plasma treated fiber specimen group. Plasma treatment of polypropylene fiber was advocated because of its increased surface energy, wettability and compatibility to other materials after plasma treatment.

When all the fiber reinforcement groups were compared (Table 6), Group D showed highest mean impact strength values followed by Group C, D, C, B and Group B. Impact strength values of plasma treated polypropylene, plasma treated polyethylene and untreated polypropylene groups were approximately double to that of unreinforced control group. Thus these fibers can be effectively used to reinforce denture base to minimize denture fracture.

From the literature it appears that reinforcement is optimized when fibers are laid down in a strategic fashion, running parallel to the surface of denture base. In this way their contribution to reinforcement is maximized, as fibers at right angle to the surface produce no beneficial effect. However, technical difficulties of ensuring that fibers were aligned correctly might overweight the possible advantage, by complicating the technique to such an extent that it becomes impractical. This study has showed that a significant effect is produced by random orientation of fibers in the specimens. Presumably, some fibers are oriented to produce beneficial effect and others are of little or no benefit. The ease and simplicity of their inclusion would make this technique more acceptable for widespread use, avoiding the necessity of interruption of packing procedures and time consuming placement of oriented fibers or woven filaments.

Any increase in fiber incorporation beyond 3% by weight will affect the flow of the dough. 4% by weight of fibers represents a large volume of material to be wetted by monomer during mixing and may produce dry friable dough. This will provide no beneficial effect on strength. For this reason a standard 2% by weight of each type of fiber was added to each specimen in this study.

The SEM of unreinforced specimens showed larger cracks for causing the specimen fracture compared to all the fiber reinforced groups where cracks were small. This might be because of presence of fibers preventing the crack propagation and change in direction of cracks resulting in smaller cracks between the fibers. This can be correlated to the increased impact strength of fiber-reinforced specimens compared to the unreinforced specimens where there is unobstructed crack propagation. The voids formed due to pulled out fibers from the resin matrix were less in the surface treated glass polyethylene and polypropylene fibers compared to their respective untreated fiber counterparts. This might be because of better adaptation of fibers to the resin matrix after surface treatment. Untreated fiber specimens showed more of the protruding fibers compared to surface treated group where fibers fractured cohesively at the fractured interface of the specimen which might be due to improved adhesion between fiber and resin matrix after surface treatment increasing adhesive strength between fiber and resin matrix above the cohesive strength of fibers.

The particles of acrylate on the surface of the untreated polypropylene fibers compared to the smooth surface of other untreated fibers might be because of better adaptation of
untreated polypropylene fibers to the resin compared to the other untreated fibers. This finding can be correlated to the high impact strength of untreated polypropylene fiber reinforced group compared to the other untreated groups.

In the study, each individual reinforced group has produced improved impact strength than the control. This technique can be clinically used for construction of complete dentures and distal extension partial dentures, especially in cases like patients with poor neuromuscular control. It is advisable to reinforce the denture with polypropylene or polyethylene fiber because of its superior impact resistance capability. Further work is clearly required to investigate the effect of fibers on oral mucosa, whether or not they project from the resin following wear and how various cleaning and polishing procedures affect the surface.

CONCLUSION

Impact strength is an important property of denture base resin and fiber reinforcement is an effective and economical method to increase fracture resistance of denture bases. The present study showed that reinforcement with 2% by weight of glass, polyethylene and polypropylene fibers substantially increased the impact strength of PMMA resin and the surface treatment of the fibers further increased the impact strength significantly. Reinforcement with plasma treated polypropylene fiber showed the highest impact strength, hence can be used clinically to reinforce the denture bases to minimize the denture fracture. The random orientation of the fibers is technically easier and can be followed in the dental laboratory routinely.

REFERENCES

1. Johnston EP, Nicholls JI, Smith DE. Flexure fatigue of 10 commonly used denture base resins. J Prosthet Dent 1981;46:478-83.
2. Ruffino AR. Effect of steel strengtheners on fracture resistance of the acrylic resin complete denture base. J Prosthet Dent 1985;54:75-8.
3. Vallittu PK, Lassila VP. Effect of metal strengtheners’ surface roughness on fracture resistance of acrylic denture base material. J Oral Rehabil 1992;19:385-91.
4. Smith DC. Recent developments and prospects in dental polymers. J Prosthet Dent 1962;12:1066-78.
5. Gutteridge DL. The effect of including ultra-high-modulus polyethylene fibre on the impact strength of acrylic resin. Br Dent J 1988;164:177-80.
6. Solnit GS. The effect of methyl methacrylate reinforcement with silane-treated and untreated glass fibers. J Prosthet Dent 1991;66:310-4.
7. Vallittu PK. Glass fiber reinforcement in repaired acrylic resin removable dentures: preliminary results of a clinical study. Quintessence Int 1997;28:39-44.
8. Berrong JM, Weed RM, Young JM. Fracture resistance of Kevlar-reinforced poly(methyl methacrylate) resin: a preliminary study. Int J Prosthodont 1990;3:391-5.
9. Goldberg AJ, Burstone CJ. The use of continuous fiber reinforcement in dentistry. Dent Mater 1992;8:197-202.
10. Vallittu PK, Lassila VP, Lappalainen R. Acrylic resin-fiber composite-Part I: The effect of fiber concentration on fracture resistance. J Prosthet Dent 1994;71:607-12.
11. 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;51:119-21.
12. Vallittu PK, Vojtkova H, Lassila VP. Impact strength of denture polymethyl methacrylate reinforced with continuous glass fibers or metal wire. Acta Odontol Scand 1995;53:392-6.
13. Matthews E, Smith DC. Nylon as a denture base material. Br Dent J 1955;98:231-7.
14. Gutteridge DL. Reinforcement of poly (methyl methacrylate) with ultra high modulus polyethylene fibers. J Dent 1992;20:50-4.
15. Ladizesky NH, Pang MK, Chow TW, Ward IM. Acrylic resins reinforced with woven highly drawn linear polyethylene fibres. 3. Mechanical properties and further aspects of denture construction. Aust Dent J 1993;38:28-38.
16. ASTM international. Designation: D 4812-99, Standard test method for un-notched cantilever beam impact resistance of plastics (test method under jurisdiction of ASTM committee on plastics D-20). Annual Book of ASTM Standard; March 1999,14:02.
17. Anusavice KJ. Philips’ science of dental materials. 11th ed. St. Louis; Elsevier; 2003. p. 733-4.
18. John J, Gangadhar SA, Shah I. Flexural strength of heat-polymerized polymethyl methacrylate denture resin reinforced with glass, aramid, or nylon fibers. J Prosthet Dent 2001;86:424-7.
19. Ladizesky NH, Chow TW. The effect of interface adhesion, water immersion and anatomical notches on the mechanical properties of denture base resins reinforced with continuous high performance polyethylene fibres. Aust Dent J 1992;37:277-89.
20. Paula E Silva E, Rosa EL, Barbosa SV. Tissue reactions of polypropylene mesh used in maxillofacial trauma. Braz Dent J. 2001;12(2):121-5.
21. Braden M, Davy KW, Parker S, Ladizesky NH, Ward IM. Denture base poly(methyl methacrylate) reinforced with ultra-thin modulus polyethylene fibers. Br Dent J 1988;164:109-13.
22. Ladizesky NH, Cheng YY, Chow TW, Ward IM. Acrylic resin reinforced with chopped high performance polyethylene fiber properties and denture construction. Dent Mater 1993;9:128-35.
23. Smith DC. The non-metallic denture base-recent developments. Dent Pract 1957;8:73-80.
24. Vallittu PK, Narva K. Impact strength of a modified continuous glass fiber-poly(methyl methacrylate). Int J Prosthodont 1997;14:102-8.
25. Uzun G, Hersek N, Tinçer T. Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resin. J Prosthet Dent 1999;81:616-20.
26. Kim SH, Watts DC. The effect of reinforcement with woven E-glass fibers on the impact strength of complete dentures fabricated with high-impact acrylic resin. J Prosthet Dent 2004;91: 274-80.
27. Karacaer O, Polat TN, Tezvergil A, Lassila LV, Vallittu PK. The effect of length and concentration of glass fibers on the mechanical properties of an injection- and a compression-molded denture base polymer. J Prosthet Dent 2003;90:385-93.
28. Vallittu PK. Comparison of two different silane compounds used for improving adhesion between fibres and acrylic denture base material. J Oral Rehabil 1993;20:533-9.
29. Clarke DA, Ladizesky NH, Chow TW. Acrylic resins reinforced with highly drawn linear polyethylene woven fibres. 1. Construction of upper denture bases. Aust Dent J 1992;37:394-9.
30. Ramos V Jr, Runyan DA, Christensen LC. The effect of plasma-treated polyethylene fiber on the fracture strength of poly-methyl methacrylate. J Prosthodont 1996;76:94-6.