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Effect of Knitting Pattern of PP Mesh on the Flexural Properties of Heat-cured PMMA Denture Base Resin

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ABSTRACT

Heat-cured polymethyl methacrylate is (PMMA) is the most common denture base material and some mechanical properties such as flexural strength and impact resistance etc. may lead to fail, besides its excellent properties. Polypropylene (PP) hernia mesh is a commercially available medical textile used in surgical repair of different types of hernia. It was aimed to investigate the effect of two different knitting patterns of PP meshes on the flexural properties of the PMMA denture base resin when they are used as reinforcement and compare with glass fiber mesh reinforced and no mesh used resins. Knitting patterns of the PP mesh structures were hexagonal honeycomb pattern and square pattern and these were used as single or double layer as reinforcement. 6 groups were established in the study: control group with no mesh and 5 reinforced groups with meshes (glass fiber mesh, single layer honeycomb patterned PP mesh, double layer honeycomb patterned PP mesh, single layer square patterned PP mesh, double layer square patterned PP mesh). A total of 60 samples with the dimensions of 65x10x3 mm, n=10 in each group were fabricated. The flexural strength, maximum deformation, and flexural modulus were determined by three-point bending test. Fracture surfaces were evaluated by scanning electron microscopy. The obtained data were statistically analyzed by two-way ANOVA test with Bonferroni corrections. The single layer square patterned PP mesh group exhibited the highest (76.67 ± 7.64 MPa), and the control group showed the lowest (63.49 ± 7.18 MPa) flexural strength values. The single layer glass fiber mesh group showed the highest (7.13 ± 0.55 mm) and the control group showed the lowest (4.72 ± 0.81 mm) maximum deformation values. The single layer glass fiber mesh group exhibited the highest (2131.87 ± 205.76 MPa), and the control group exhibited the lowest (1582.26 ± 98.63 MPa) flexural modulus values. Significant increase in flexural strength was observed in all polypropylene mesh-reinforced groups compared to the control group except double layer honeycomb patterned PP mesh group ($p < 0.05$). Using PP fiber mesh for reinforcement provide a very favorable aesthetic view and PP fiber mesh is concluded to be a promising material for reinforcement of heat-cured PMMA denture base resins.

Keywords: PMMA denture base resin, Glass fiber mesh, Polypropylene hernia mesh, Reinforcement, Flexural strength

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Introduction

The most commonly used denture base material for production of removable dentures is heat cured polymethyl methacrylate (PMMA) acrylic resin [1]. Due to its favorable properties such as biocompatibility, superior aesthetic view, low water sorption, ease of modification, capability of being repaired, and ease and simplicity in processing achieved a great success in clinical dentistry [2]. Despite these favorable properties, the weakness of PMMA in mechanical properties like low flexural strength (FS), low impact strength (IS) and low surface hardness reduces the clinical longevity of the prosthesis which may end up with patient dissatisfaction [3]. Although the reasons of failure with fracture are well known, acrylic resin fracture is still an unavoidable problem in removable prosthodontics. Reinforcement with additives, copolymerization, improved cross-linking, and plasticization of acrylic resin are some of the strategies applied to overcome this challenge [4].

However, resin substrates with low mechanical strength are susceptible to deformation and impact during the chewing process [5,6]. Therefore, reinforcing materials enhancing the mechanical properties of complete dentures are required. Currently, metal frameworks are primarily used in clinical practice as reinforcements to improve the fracture resistance, volume stability, and precision of complete dentures [5]. However, metal frameworks are comparably heavier because of their high densities and also they are less favorable due to more complicated fabrication processes than resins. Beyond these, metal frameworks are made of alloys which may cause hypersensitivity [7]. Using metal wires or plates as reinforcement within the denture base resin is the most common method for enhancing the mechanical strength. However, adhesion of the resin to the metal framework is low due weak bonding and also exhibit poor aesthetic properties. Nanoparticles or various fiber reinforcements, such as carbon and glass fibers, plyometric polyamide, and ultra-high molecular- weight polyethylene were reported to be used in reinforcing PMMA based denture bases [8-11].

Glass fiber is one of the materials used as reinforcement in dentistry. Because of its ductility that allows the material to be bent without fracture, researchers have focused on using glass fiber instead of metal frame to enhance the fracture resistance of dentures [10,12-16]. A complete denture fabricated using glass fiber frame has a shorter fabrication time, lighter in weight and exhibit better aesthetic properties compared to using a metal frame. However, only a few experimental and clinical studies have focused on enhancing the mechanical properties of complete dentures reinforced with glass fiber mesh. In particular, the fatigue resistance and long-term prognosis of glass fiber mesh reinforced complete dentures have been rarely studied [5]. Orthopedic casting tape (OCT) which is basically formed by a mesh made from glass fibers and a self curing resin surrounding the mesh, has been used for fracture management of long bones and provides excellent outcomes of immobilization and rigid support in the field of orthopedics. However, their potential in denture reinforcement still needs to be investigated [1]. From the available indexed literature, it was observed that inadequate data is available about the mechanical properties of complete dentures reinforced using glass-fiber mesh. Also, the using OCT as reinforcement of PMMA acrylic resin denture bases is a novel approach to enhance the mechanical strength of complete dentures. Therefore, it is hypothesized that PMMA acrylic resin denture bases reinforced with glass-fiber mesh and OCT can exhibit better fracture loads when compared with the PMMA dentures bases without reinforcement [1].

Poly propylene (PP) fiber is an important member of family of synthetic fibers. It possesses good mechanical and chemical properties such as high-level resilience, elasticity, and tensile strength, durable in acid and similar medium, low density (0.91 g/cm3) and low cost. Due to all of these advantageous features, polypropylene fiber is a suitable candidate for PMMA-based resin reinforcement [17-19]. Polypropylene fibers are available in various forms in the medical market. PP mesh is one of these products; it is a surgical mesh commonly used to repair different types of hernia [19,20].

The aim of this study is to evaluate the effect of addition of single- or double-layer polypropylene hernia meshes with two different patterns on the flexural properties of the heat-cured acrylic resin. Since the meshes used in this study were readily available medical textiles, they were not subjected to any surface treatment in order to compare the solely effect of the PP mesh on flexural properties.

Materials and Methods

Heat-cured PMMA denture base resin (Meliodent, Kulzer GmbH, Frankfurt, Germany) was used. Two different PP meshes; one of the mesh PP-4A (4A Medical, Ankara, Turkey) which was honeycomb patterned (Figure 1A), and the other one PP-Supro (Supro Mesh, Klas Medical, Istanbul, Turkey) which was square patterned (Figure 1B), were used. The PP meshes were obtained in sterile package that is produced for surgical operations. Delta Plus orthopedic cast (Delta Lite Plus, BSN Medical GmbH, Frankfurt, Germany) was obtained in sealed package and washed with ethanol to get rid of the curing resin initiated by air contact. Cleansing with alcohol procedure is as follows, material was cut in dimensions suitable to fit in the mold, immersed in excess amount of ethanol (96% v/v), swung with gentle movements periodically within first two hours and kept in for 24 hours, washed with fresh ethanol and dried prior to use.

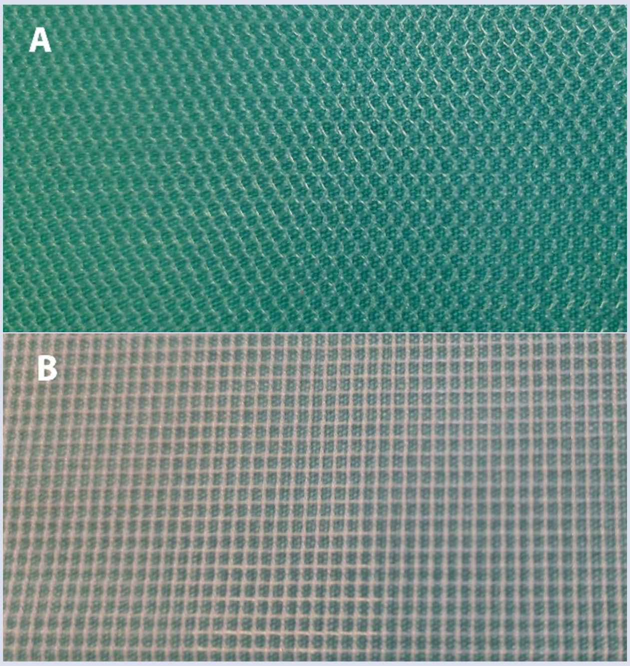

Figure 1. Two different patterned hernia meshes; (A) Honeycomb patterned PP-4A; (B) Square patterned PP-Supro

A total of 6 groups were established in the study: control group and 5 reinforced groups with different meshes. Mesh reinforced groups were, single layer PP-4A group (4A1), two layers PP-4A group (4A2), single layer PP-Supro group (SP1), two layers PP-Supro group (SP2) and single layer Delta - Lite Plus glass fiber mesh washed with ethanol (DPA).

PMMA resin was fabricated as reported before [19]. Briefly, ideal powder-liquid mixing ratio was used as 25 g powder and 10 ml liquid and complete wetting was observed. Acrylic paste was cast using a mold made of chromium designed with the dimensions of 65x150x3 mm. Then, the mold was pressed in the hydraulic press device (GLS, Gulersan Lubrication Equipment Industry and Trade Co. Ltd., İstanbul, Turkey) for 5 minutes and the excess acrylic was removed. Then, the polymerization was completed by making temperature and time adjustments in accordance with the manufacturer's instructions. Three point bending test specimens were cut in 65x10x3 mm dimensions using a laser cutting machine (LazerFix Laser Technology, Konya, Turkey) in order to match dimensions described in ISO 178 standard. All specimens were stored in distilled water for 24 hours. In this way, residual monomers were removed.

Flexural properties of the control and mesh reinforced groups were determined by three point bending test in accordance with ISO 178 standard. A representative image of the test specimens before and after three-point bending test and tensile test was shown in Figure 2. Three point bending tests were performed on a total of 60 samples in 6 groups and n=10 samples for each group using a universal testing machine (Autograph AGS-X, Shimadzu, Japan) at a compression rate of 3 mm/min cross head speed. Samples placed between the shoulders having a gap of 50 mm. All tests were carried out at room temperature.

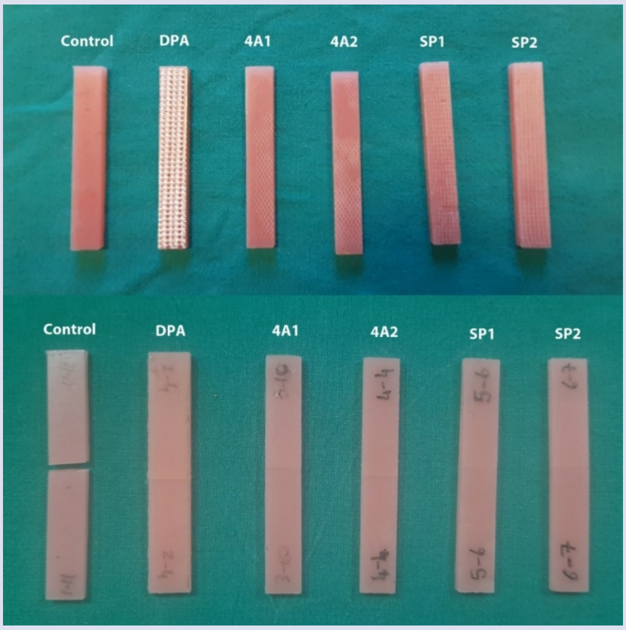

Figure 2. Representative image of the test specimens before and after three point bending test

Results and Discussion

The basis of using PP fiber mesh for reinforcement of the PMMA resin was the unique properties of PP such as low density, resistance to corrosion, high mechanical stability, moisture repellence, resilience and elasticity [21,22]. In this study, three different mesh reinforcements were set in five groups: woven glass fiber mesh group, two PP mesh groups based on mesh pattern and number of layers used, and two PP mesh groups based on another mesh pattern and number of layers used, within the heat polymerized PMMA resin. A control group, PMMA resin with no fiber mesh additive was used for the comparisons with each mesh-reinforced group. Flexural loading is an important parameter for dental prosthetic materials as it mimics the conditions they are exposed to in the oral environment [17,23]. Three-point bending test was used to measure the flexural properties of the prepared acrylic samples. For this purpose, specimens were cut into 65x10x3 mm dimensions and kept in distilled water from fabrication to testing period in order to avoid potential reduction in flexural strength that is previously reported [13,24].

Three Point Bending Test

Test results for between subject effects obtained by one-way ANOVA analysis of three point bending test results for three flexural properties as flexural strength (MPa), maximum deformation (mm) and flexural modulus (MPa) are summarized on Table 1. Mean with standard deviations and scoring on significance of the tested variables obtained by comparisons of three point bending test results are presented as Table 1 (in group comparison). Test results obtained by three-point testing were plotted and presented in Figure 3. According to the test results, any type of mesh use for reinforcement exhibited a significant change in all flexural properties of the ($p<0.001$).

Table 1. Mean and standard deviations for three flexural properties and their significance obtained by three point bending test

Groups	Flexural strength (MPa) Mean ± SD	Maximum deformation (mm) Mean ± SD	Flexural Modulus (MPa) Mean ± SD
Control	63.49 ± 7.18^{c}	4.72 ± 0.81^{y}	$1582.26 \pm 98.63^{\beta}$
DPA	67.71 ± 2.93^{bc}	7.13 ± 0.55^{x}	$2131.87 \pm 205.76^{\alpha}$
4A1	72.48 ± 6.57^{ab}	6.57 ± 0.65^{x}	$2054.50 \pm 97.07^{\alpha}$
4A2	70.72 ± 7.71^{abc}	6.36 ± 1.25^{x}	$2045.72 \pm 76.70^{\alpha}$
SP1	76.67 ± 7.64^{a}	7.04 ± 1.12^{x}	$2051.59 \pm 91.29^{\alpha}$
SP2	74.64 ± 4.57^{ab}	6.62 ± 0.68^{x}	$2105.56 \pm 62.21^{\alpha}$

a,b,c: Comparison of flexural strength values between groups; x,y: Comparison of maximum deformation values between groups; α,β: Comparison of flexural modulus values between groups. Values with different superscript letters indicate significant differences.

It is evident by the results presented on Table 1 that a significant increase in flexural strength was achieved for single-layer polypropylene-Supro group (SP1) which exhibited the highest (76.67 ± 7.64 MPa) flexural strength, while the control group exhibited the lowest (63.49 ± 7.18 MPa). Compared to the control group, significantly higher flexural strength was observed in all polypropylene mesh reinforced groups except the 4A2 group ($p < 0.05$). Although, a slight decrease in average flexural strength values was observed for double layer PP mesh usage, it did not reveal significance ($p > 0.05$). DPA glass fiber mesh group did not show a significant difference in flexural strength compared to control. The reason for this behavior was concluded to be the poor adhesion of PMMA matrix on to glass fibers together with the void spaces between the fibers forming the bundle.

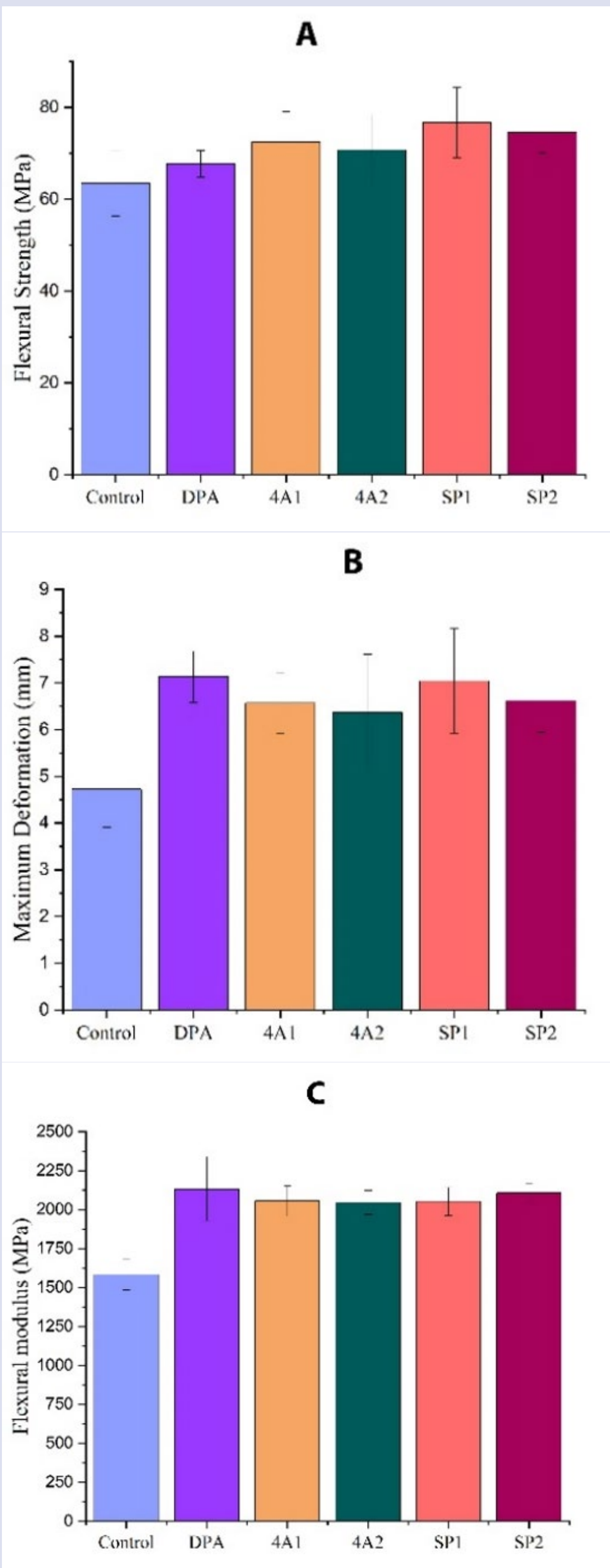

Figure 3. Flexural properties of samples obtained by three point bending test

As a result, this void space may lead the PMMA matrix to form a weak point where fracture starts and propagate from. The knitting pattern of the PP mesh did not exhibit significant difference on flexural strength where the average values of the square patterned SP1 and SP2 PP mesh groups were greater than 4A1 and 4A2 PP mesh groups.

All of the mesh reinforcements resulted with a significant increase in maximum deformation of the test specimens ($p < 0.05$). The single-layer DPA glass fiber mesh group showed the highest (7.13 ± 0.55 mm) maximum deformation, while the control group showed the lowest (4.72 ± 0.81 mm) maximum deformation. All of the mesh-reinforced groups did not exhibit a significant difference comparing their maximum deformation values in between ($p > 0.05$). PMMA resin showed a brittle fracture character, and a more ductile fracture was observed by using any type of mesh reinforcement.

Using any type of fiber mesh for reinforcement resulted with a significant increase in flexural modulus values ($p < 0.05$), but these mesh reinforcements did not exhibit a significant difference comparing each other. The single-layer DPA glass fiber mesh group exhibited the highest (2131.87 ± 205.76 MPa) flexural modulus values, while the control group exhibited the lowest (1582.26 ± 98.63 MPa) flexural modulus values. Significantly higher flexural modulus values were obtained in all mesh reinforced groups than the control group.

SEM Analysis

SEM images of the fracture surfaces were obtained from test specimens that were used for thee point bending tests, and presented in Figure 4 with two different magnifications (100X and 1000X). A brittle fracture was observed for the control group and fracture patterns in the form of a river lines were formed in the direction almost parallel to the force applied (Figure 4A1 and 4A2). The length of these lines was in the range of 10 µm to 40 µm long and these river line patterns were mainly located close to the surface where the force applied and lying along the mid part of the specimen. Fisheye patterns which were formed as a result of the tensile forces occurred perpendicular to the direction of the force applied, were observed to be distributed around mid to bottom part of the specimens. Brittle fracture created a rough fracture surface.

The SEM image of the DPA glass fiber mesh confirmed that alcohol washing was successful in removing the self-curing resin surmounting the glass fiber mesh, and clear and separate glass fiber bundles can easily be recognized (Figure 4B1). Although a brittle fracture was also exhibited by these samples, the fiber mesh structure provided a more ductile fracture to the PMMA resin. The void space between the glass fibers, which form the knitted mesh and could not be filled with PMMA during pack and press process, may be the reason for comparatively lower flexural strength exhibited by DPA mesh reinforcement compared to PP mesh reinforced groups.

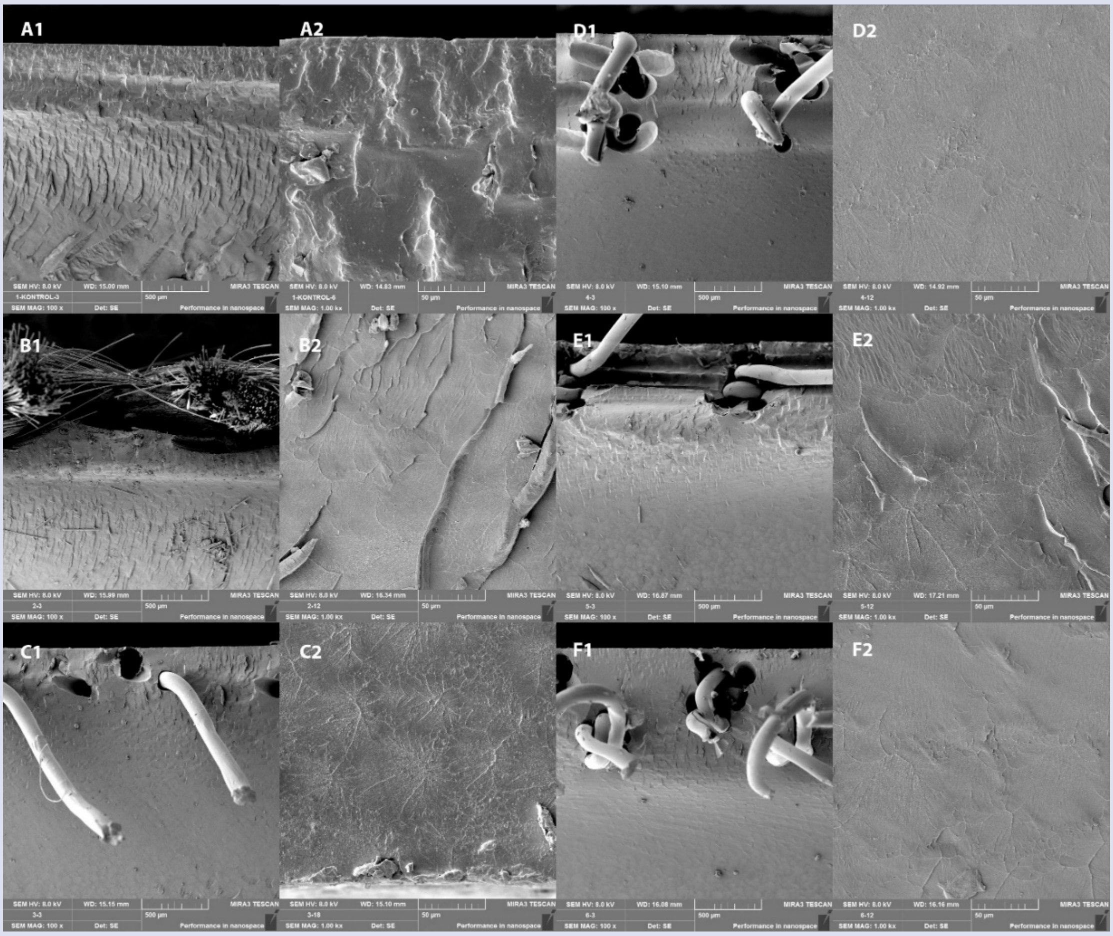

Figure 4. SEM images of the samples from test groups: (A) Control, (B) DPA, (C) 4A1, (D) 4A2, (E) SP1, (F) SP2 - with different magnifications: (1) 100×, (2) 1000×

The SEM images of the 4A1 group revealed that the PMMA matrix tightly fit with the PP fibers, and the minimal void spaces observed around the fibers were formed by the plastic deformation of the PP fibers during the mechanical test or during the separation of the fractured fragments for SEM sample preparation. Fisheye patterns were observed in the middle and lower parts of the fracture. Smooth and clean stripping of the fibers that belong to the mesh structure demonstrated the poor adhesion of the PMMA matrix on to the fibers (Figure C1).

Although double layer PP mesh was used in both 4A2 and SP2 groups, it was observed that the PMMA matrix filled the gaps between PP fibers tightly (Figure D1 and F1). These images also demonstrated that hills and plateaus formed along the borders of the fiber layers during fracture. This behavior was observed only with the double PP mesh layered PMMA resins, that can be associated with the weaker spots formed during filling of the voids by PMMA during pack and press process. Both of these double PP mesh layered samples were fractured from the borders of the knots of the fibers and these knots forms the weak spots for fracture. It was concluded that using multiple PP mesh layers are better be used with a suitable distance between them to avoid the formation of weak spots.

Conclusions

In this study, it was aimed to investigate the potential use of single or double layered PP hernia meshes with two different knitting patterns as reinforcement for heat-cured PMMA denture base resins by comparing them with glass fiber mesh reinforcement and no-mesh used control. Single layer square knitting patterned PP mesh reinforced resin exhibited the highest flexural strength, while DPA glass fiber mesh reinforced resin exhibited the highest maximum deformation and flexural modulus. Using any type of PP mesh except double layer honeycomb knitting patterned PP mesh reinforced group provided a significant increase in flexural strength of the PMMA resin. In this study, each kind of reinforcement was used without any surface treatment for enhancement of fiber-matrix adhesion, since surface treatment is an another parameter that is also dependent to multiple variables. Further enhancement in fiber-matrix adhesion can be achieved by using the methods for surface modification of the fibers. From the aesthetic point of view, it was evident that using PP fibers for reinforcement provide a very favorable view even for double layer usage, PP fiber mesh is a promising material for reinforcement of heat-cured PMMA denture base resins.

Conflicts of interest

All authors declare that they have no conflict of interest.

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