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EVALUATION OF IMPACT STRENGTH OF HEAT CURE ACRYLIC RESIN REINFORCED WITH NYLON FIBER MESH WITH AND WITHOUT PRESTRESSING (IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: Acrylic resin prostheses are liable to high levels of forces due to their frequent removal by patients and accidental slippage. Hence, the impact strength of acrylic denture base material is of major significance in providing long-term functional prostheses.
OBJECTIVES: The aim of this study was to evaluate the reinforcing effect of prestressed nylon fiber meshwork and the specimen thickness increase on the impact strength of heat cure acrylic resin.
MATERIALS AND METHODS: 72 specimens were divided into 3 groups (I, II and III) which were heat cure acrylic resin (control), Nylon mesh reinforced acrylic resin and prestressed-nylon mesh reinforced acrylic resin. Each group was formed of 24 specimens, which were further subdivided into 3 subgroups (A, B and C) of different dimensions; 75 mm × 10 mm × 3 mm and 75 × 10 × 4 mm and 75 x 10 x 5 mm. Thus, the specimens were divided into 9 experimental subgroups (n=8 per subgroup). A Charpy's impact tester was used to measure the impact strength of acrylic resin. The data were analyzed using Anova-test ($p \leq 0.05$).
RESULTS: The mean impact strength of groups II and III was higher than the control group I impact strength. The difference between the reinforced groups and control group was statistically significant for all specimen thicknesses.
CONCLUSIONS: The impact strength of heat cure acrylic resin was increased by the incorporation of nylon fiber mesh whether prestressed or not.
KEYWORDS: Prestressing, Nylon meshwork, Acrylic resin, Impact strength, Reinforced PMMA

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INTRODUCTION

Various materials like vinyl resins and vulcanite, etc., were used to fabricate dentures, however, they all had a variety of disadvantages. Polymethyl methacrylate (PMMA) resins have dominated the denture base market since its introduction in 1937 (1). It is widely used because of its desirable attributes and handling characteristics: low cost, easy handling and processing, easy to polish and repair, excellent esthetics and biocompatibility in the oral environment (2).

However, PMMA denture base material is not ideal in every respect and has drawbacks such as insufficient surface hardness, low flexure strength, and low impact strength. Clinically, failure of complete or partial denture prosthesis made from PMMA is most likely in the form of fracture; with the rate reported to be 68% after 3 years of usage. Fracture is either due to fatigue or impact forces (3). Flexure fatigue of acrylic dentures as evidenced by midline fracture is due to the stress concentration around the micro cracks formed in the material due to continuous applications of small forces. Fracture of dentures by impact forces, on the other hand, results from the sudden application of force to dentures. Such types of fractures are more likely due to the accidental dropping of dentures on surfaces during cleaning by patients (4). For maxillary dentures, most fractures are caused by a combination of fatigue and impact, whereas, for mandibular dentures, 80% of fractures are caused by impact forces (5).

Therefore, reinforcement of acrylic prosthesis was obligatory to improve their strength and prevent fractures. There are two approaches for preventing denture fractures; one is to increase the denture thickness of susceptible areas, and the other is to strengthen the denture base material. However, dentures designed to reduce stress by increasing the thickness in the anterior region are not desirable because this reduces the tongue space and thus affects speech (6).

Several methods have been suggested to strengthen the denture base material; the addition of cross-linking agents such as polyethylene glycol dimethacrylate or the chemical modification of a denture base material by copolymerization with a rubber graft copolymer in the form of butadiene styrene (7, 8). Such modification has successfully improved the impact strength but has inversely affected the modulus of elasticity and the rigidity of the denture base. Moreover, these materials are often expensive options to conventional heat-cured acrylic resin reaching up to ten folds the cost (9).

Alternatively, metallic reinforcing agents in the form of cobalt-chromium wires, wires plates, and mesh were used to improve the mechanical properties of PMMA, but denture base fractures reoccurred with metal strengtheners (10). Furthermore, varying amounts of powdered silver, copper, aluminum and ceramic fillers have been incorporated into the PMMA matrix with considerable improvement in the compressive strength (11). However, such additions were not successful due to the lack of interfacial bonding between the metallic fillers and the resin matrix (12).

Many types of fibers such as carbon, glass, nylon and ultra-high-modulus polyethylene fibers have also been employed to reinforce PMMA resin (13). Fibers can be used in three forms, namely, chopped, continuous unidirectional or bidirectional meshwork (10). The fiber reinforcing mechanism has been explained by the principle that a relatively soft ductile polymer matrix is fully capable of transferring an applied load onto the fibers via shear forces at the interface. In such a composite, the fibers will be the main load-bearing constituents while the matrix forms a continuous phase to surround and hold the fibers in place (14).

Nylon Fibers are polyamides and are mainly built on aliphatic chains. The chief advantage of nylon is its resistance to shock and repeated stress. Nylon-reinforced denture bases displayed higher fracture resistance than conventional PMMA (15).

In civil engineering, Concrete resists compressive stresses successfully, but not tensile ones. The problematic compressive/tensile strength ratio of concrete called for the development of the prestressing concept in which a prior stress stage is applied to the structure to optimize its strength and performance (16). The application of a pre-compressed state is obtained by pre-tensioning high-strength steel cables placed inside the molds and pulled with tensile force before casting the matrix phase. Once the concrete has reached the desired compressive strength (which should always exceed the pre-tensioning stress), the tension is released and the cables tend to recover their original length. Because of the adhesion between cables and concrete, the structure is subjected to compression (17). The same prestressing process was applied with nylon fiber mesh and acrylic resin in this study aiming to produce acrylic resins with improved impact strength.

The aim of this study was to evaluate the effect of nylon meshwork fibers addition, with and without prestressing, and specimen thickness increase on the impact strength of heat cure acrylic resin. The null hypothesis was that the inclusion of nylon fiber mesh, whether prestressed or not, will not improve the impact strength of PMMA nor allow it to be used in thinner thickness with better mechanical properties.

MATERIAL AND METHODS

A total of 72 acrylic resin specimens were prepared. They were divided into three equal groups of 24 specimens each. The groups were I, II and III; heat cure acrylic resin (control), mesh reinforced heat cure acrylic resin (Component Supply Company, Florida, USA) (Figure 1) and prestressed-mesh reinforced heat cure acrylic resin respectively. Each group was subdivided into 3 subgroups (A, B and C) of different thicknesses: 75 x 10 x 3 mm, 75 x 10 x 4 mm and 75 x 10 x 5 mm respectively.

Metal dies of the desired specimens' dimensions were fabricated. The dies were coated with a thin layer of separating medium (petroleum jelly), and were embedded in type III dental stone to form molds using the conventional investing technique in dental flasks.

Each metal die was placed in the stone so that only half of its thickness was embedded in the stone of the lower part of the flask while the other half was invested by the stone of the upper part of the flask. This produced a mold cavity divided between the two halves of the flask to allow the placement of the mesh in the middle of the specimen during packing of PMMA. After stone hardening, mold spaces were washed with hot water to remove any debris. Separating medium (sodium alginate) was painted on the stone molds which allowed easy removal of PMMA specimens later on. Three test specimens were polymerized in the flask simultaneously.

For the preparation of control group, heat cure PMMA was mixed conventionally according to the manufacturer's instructions. After reaching the dough stage, PMMA was kneaded and packed into the stone molds. Trial closure was performed under manual dental press. Excess flash was removed during packing, then flasks were clamped and polymerized in denture curing unit by raising water temperature slowly to reach 73 ºC and then long curing cycle was continued. Once polymerization was completed, the denture flasks were allowed to cool slowly at room temperature before deflasking.

For groups II and III, sheets of meshwork were cut into a length of 70 mm and a width of 50 mm. These sheets were soaked in monomer for 2 minutes and then allowed to air dry. During the packing of PMMA into the molds, a wet sheet of cellophane paper was used to divide the resin dough into approximately two equal halves in thickness to ensure the placement of the meshwork in the middle of the specimen. While for the preparation of Group III specimens, the nylon fiber mesh was attached to the custom made pre-tensioning frame and subjected to tension equivalent to 5 kilograms. The tension produced in the fibers was measured using the universal testing machine prior to embedding the mesh in the resin. Then the prestressed mesh was embedded in PMMA in the dough stage. The mesh remained attached to the frame during the whole curing cycle, with the frame outside the flask to insure metal to metal contact of the flask parts. After curing of acrylic samples, the nylon meshwork ends were cut to separate the mesh from the frame and release the tension.

The specimens of groups II and III were polymerized and recovered in the same manner as group I. Polymerization and deflasking protocols were executed in the same manner as for the control group. After deflasking, the dimensions of all specimens were checked to ensure accuracy using a manual Vernier caliper (model: VER-600M VIS/ Poland), and were notched edgewise in the middle (Figure 2). The geometry of the Charpy V-notch impact specimen was done according to the recommendation of ISO 179-92 (18). Abrasive paper was used to finish the specimens. Specimens of all groups were stored in water for 2 days before they were tested (19).

The test was carried out using a Charpy-type tester (WPM Leipzig, Leipzig, Germany), the pendulum struck the specimens from the unnotched side (Figure 3) and the impact strength (IS) was calculated using the following formula (20):

$IS = (Ec/hb)10^3$

where IS = Charpy impact strength of the unnotched specimen (kJ/m^2); Ec = corrected energy absorbed by breaking the test specimen (J); h = thickness of specimen (mm); and b = the remaining width at the notch base (mm).

Statistical analysis:

Data were fed to the computer and analyzed using IBM SPSS software package version 21.0. Quantitative data were described using range (minimum and maximum), mean and standard deviation for normally distributed data while abnormally distributed data were expressed using median, minimum and maximum.

For normally distributed data, comparison between more than two populations was analysed F-test (ANOVA) to be used. Significance test results are quoted as two-tailed probabilities. Significance of the obtained results was judged at the 5% level. A p-value of less than 0.05 was considered statistically significant.

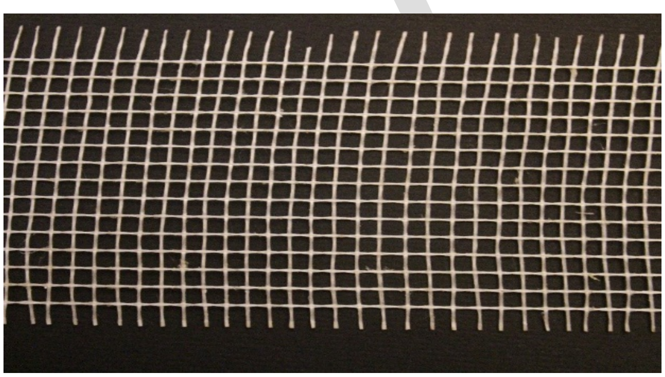

Figure 1: The nylon fiber mesh used in the study.

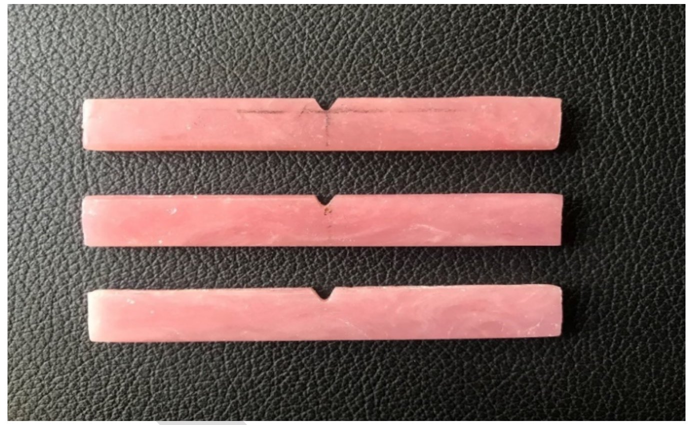

Figure 2: Notched test specimens of different thicknesses before testing.

Figure 3: Specimen mounted on Charpy's impact tester.

RESULTS:

strength of the reinforced groups II (n=24) and III (n=24) was noticeably higher than that of the control test group I (n=24) for all subgroups A, B and C as seen in tables 1,2 and 3. By using ANOVA-test to compare between the groups I, II and III a highly significant difference was found ($P<0.001$).

In subgroup IIA, the addition of the nylon mesh has improved the impact strength by 141%, and in subgroup IIIA the prestressed mesh has improved it by 130 % in comparison with the control subgroup IA as shown in table 1. While for subgroup IIB, the nylon mesh presence approximately doubled the impact strength, and in subgroup IIIB the prestressed mesh enhanced the impact strength by 44% in comparison with the control subgroup IB as shown in table 2. However, prestressing of meshwork did not produce specimens with higher impact strength in comparison with specimens reinforced with unstressed mesh. No significant difference was found between subgroups II A and III A (table 1), subgroups IIB and IIIB (table 2), and subgroups IIC and IIIC (table 3).

Meanwhile, the increase of specimen thickness did not improve the impact strength of conventional acrylic resin. In the reinforced groups increasing the specimen thickness significantly decreased the impact strength.

	Subgroup I A (n=8)	**Subgroup II A (n=8)**	**Subgroup III A (n=8)**
Range Mean S.D.	6.2-12.7 9.4 2.3	19.6-28.9 22.7 2.9	18.9-27.7 21.7 3
ANOVA P value	19.5 0.001*		
P1	0.0001*		
P2	0.0001*		
P3	0.240		

Table 1: Comparison of the mean impact strength of the three studied subgroups of specimen thickness 3mm
F = ANOVA test
P is significant if ≤ 0.05
* Significant difference
P1 comparison between subgroup IA and IIA
P2 comparison between subgroup IA and IIIA
P3 comparison between subgroup IIA and IIIA

	Subgroup I B (n=8)	**Subgroup II B (n=8)**	**Subgroup III B (n=8)**
Range Mean S.D.	7.8-17.6 12.7 2.7	20.2-27.2 23.2 2.1	13-23.7 18.3 3.8
ANOVA P value	24.3 0.0001*		
P1	0.0001*		
P2	0.002*		
P3	0.003*		

Table 2: Comparison of the mean impact strength of the three studied groups of specimen thickness 4mm.
F = ANOVA test
P is significant if ≤ 0.05
* Significant difference
P1 comparison between subgroup IB and IIB
P2 comparison between subgroup IB and IIIB
P3 comparison between subgroup IIB and IIIB

	Subgroup I C (n=8)	**Subgroup II C (n=8)**	**Subgroup III C (n=8)**
Range Mean S.D.	6.2-16.2 11.4 3.9	17.8-25.6 21.5 2.9	13.6-21.2 17.1 2.5
ANOVA P value	26.25 0.001*		
P1	0.0001*		
P2	0.002*		
P3	0.003*		

Table 3: Comparison of the mean impact strength of the three studied subgroups of specimen thickness 5mm.
F = ANOVA test
P is significant if ≤ 0.05
* Significant difference
P1 comparison between subgroup IC and IIC
P2 comparison between subgroup IC and IIIC
P3 comparison between subgroup IIC and IIIC

DISCUSSION:

Despite the desirable properties of PMMA as a denture base material, fracture of PMMA in service is repeatedly encountered, particularly in the form of maxillary dentures midline fractures (3). This finding is attributable to repetitive flexing forces on maxillary dentures that lead to flexure fatigue (21). Consequently, the need for denture strengthening became inevitable. Polymer reinforcement can be categorized as metallic or non-metallic reinforcing agents. When compared, fiber reinforcement is preferred to metal reinforcement as the later increases the weight of the prosthesis, is difficult to fabricate, and fails to bond with acrylic resin (22).

In this study, nylon fibers were chosen due to their aesthetic properties and reported efficiency in enhancing the flexure and impact strength of PMMA when used in chopped form (23-25). Besides nylon is easier to use as it does not require compound preparatory procedures such as Silane-coupling procedures or plasma that are obligatory to use with glass or ultra-thin modulus polyethylene fibers (26, 27). To date, no study in the dental literature has tested the use of nylon in mesh form on the mechanical properties of acrylic resin.

Fibers in mesh form were chosen for the study for their simple and precise placement in the PMMA compared to continuous parallel fibers. Previous studies mentioned the difficulty of positioning continuous parallel fibers in PMMA as the individual fibers get dispersed when the flask is pressed (28-30).

Monomer preimpregnation of fibers enhances the value of woven fiber products by improving resin adaptation to the fibers and increasing the strength of the polymer fiber system. Specimens were stored in water for 2 days in this study prior to testing as different storage periods were mentioned in dental literature ranging from few hours to several weeks (23, 31-34). The samples were stored in water to allow water saturation as acrylic resin in use is always in a wet environment either intraorally or even when not in use patients store them in water and water absorption affects its strength (33).

To mimic the impact forces dentures are exposed to in clinical use, two types of tests have been used to in researches; Izod or Charpy test. The main difference between these tests is that in the Charpy test the specimen is braced at both ends and pendulum strikes at midpoint of the specimen. While with the Izod test the specimen is held at a single end and struck by the pendulum weight at the other end. The majority of studies have used the Charpy impact test for testing the impact strength of PMMA (7, 9, 35-37). Although impact strength test can be performed on unnotched or notched specimens, notched specimens were used in this study to mimic the effect of frenal notches on acrylic dentures, as the presence of these notches was proven to greatly reduce the impact resistance of acrylic resin (35, 36).

The results of the current study proved that the addition of nylon fibers has significantly improved the impact strength of the specimens in comparison with the control group for all thicknesses. This finding is in agreement with the results published by Dogan et al (24). Although the presence of the fiber mesh, whether pre-tensioned or not, had a significant effect on the impact strength of PMMA, pre-tensioning has failed to produce specimens with higher impact strength in comparison with specimens with the mesh reinforced group. This can be explained by the elongation of the fibers after application of tension which has decreased the width of the mesh, consequently compromising the fiber orientation and spatial distribution within the specimen.

The use of fibers in woven form has proved capable of strengthening the impact strength of PMMA. These results are in agreement with the findings reported by previous studies using woven fiber materials other than nylon (10, 28, 38). This can be attributed to the fact that the fibers are in the direction perpendicular to the force so they act as a shock absorbent and dissipate the force uniformly to the polymer matrix (30).

Increasing sample thickness did not have an enhancing effect on impact strength values in comparison to thinner samples for both control and test groups. This eliminates the desire to fabricate denture bases with thicker midlines for the sake of mechanical enhancement, as the results of this study have proven that the increase of thickness had no positive effect on the impact strength. The presence of fiber reinforcement in the form of mesh has proved an additional benefit as most tested samples remained connected by the fibers after loading. The mesh acted as a binder of the two fractured parts of the specimen which can assist in future repairs of broken dentures.

CONCLUSIONS:

The reinforcement of heat cure acrylic resin by prestressed or non-stressed nylon mesh can significantly enhance its impact strength.

No significant difference exists between the impact strength of heat cure acrylic resin reinforced with nylon mesh and that reinforced with prestressed nylon mesh.

Increasing the thickness of heat cure acrylic resin had no positive effect on the impact strength.

Nylon mesh reinforced acrylic resin can be used to provide denture bases of thinner thickness and desirable impact strength.

CONFLICT OF INTEREST:

The authors declare that they have no conflicts of interest.

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