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Evaluation of Impact and Flexural Strength of Conventional Heat Cure Polymethyl Methacrylate Resin and High Impact

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Abstract

Denture fractures are very common, reflecting the fact that both impact strength and flexural strength are barely adequate. Its relatively low young modulus compared with metal renders the material flexible even in thick sections used in dentures. The purpose of this study was to find out and evaluate the impact and flexural strength values of certain brands of commercially available denture base resin and suggest their suitability. A total of 60 specimens ($n = 60$) were fabricated using metal dyes and divided into four groups (Group I: PMMA-TREVALON, Group II: PMMA-ACRALYN-HI, Group III: PMMA-TREVALON-HI, Group IV: PMMA-ACRALYN-H) of commercially available denture base resin, with each group containing 15 specimens. All specimens were tested for flexural resistance on the Hounsfield tensometer and for impact strength on Hounsfield balanced pendulum impact machine. Data analysis was done using one-way ANOVA to compare means between the groups. Group IV showed significantly very high impact strength compared to Groups I and II. However, the difference between Groups III and IV was insignificant. Group IV showed significantly very high flexural strength compared to all other groups. Within the limitations of the study, it is observed that Acralyn-H super unbreakable recorded the highest impact and flexural strength.

Keywords: Denture base resin; Flexural strength; Impact strength; PMMA

Introduction

A number of materials have been used in the fabrication of denture bases. Wood, ivory, ceramic, metal, and numerous polymers have been used in denture base applications. Acrylic resin, polymethyl methacrylate (PMMA), was introduced in 1937 by Dr. Walter Wright. It continues to be the material of choice for denture fabrication because of its ease of processing, dimensional stability, accuracy of fit, and improved esthetics [1-5]. It also has certain inherent poor mechanical properties. Denture fractures are very common, reflecting the fact that both impact strength and flexural strength are barely adequate. Its relatively low young modulus compared with metal renders the material flexible even in thick sections used in dentures. Numerous studies have been conducted on methods to improve the characteristics of denture base resin [6-9]. Strength is increased by grafting a rubber-like substance, often styrene, butadiene, or a combination of both chemicals [10,11]. Impact and flexural strength still remain a requisite of denture base material, which needs to be improved in order to overcome the inherent liability to breakage [12-16]. Flexural strength gives an indication of material performance under the conditions of static load while impact strength testing involves a measure of energy absorbed by the material before fracture [17-22]. The purpose of this study is to compare and evaluate the impact and flexural strength values of certain brands of commercially available denture base resin and suggest their suitability.

Materials and Methods

The council on dental materials (1975) has revised the American Dental Association Specification No.12 for denture base resin [7].

1. Impact strength testing
2. Flexural strength testing

Preparation of the Mold

Metal dies were duplicated using highly elastic polyvinyl siloxane duplicating material (Elite Double 8. Zhermack, Italy). The die has a dimension of $60 \times 10 \times 4$ (mm) (length × width × thickness)—rectangular for flexural testing specimens and a dimension of 4.5×7.5 mm (length × diameter) and cylindrical for impact strength testing specimens. Wax patterns thus retrieved were invested with type III dental stone in the lower half of the flask. A mechanical vibrator was used to prevent air trapping during investing. The wax patterns were placed horizontally in the unset dental stone embedding half portion of it. When the dental stone was set, the surface was coated with a thin layer of petroleum jelly. The upper part of the flask was then placed and filled with stone on a mechanical vibrator. One hour after the beginning of the last mix used for pouring the molds, the flask was immersed in boiling water for 4 min. The two halves were then separated. The molds were then flushed with hot household detergent solution to remove any traces of petroleum jelly and were cleaned in boiling water. The molds were allowed to cool so that they could be held in bare hand. At this stage, the stone's surface was painted with one coat of undiluted tin-foil substitute. The molds were maintained at room temperature for 1 h.

Preparation of PMMA Resin Specimen

Group 1: Conventional heat cure PMMA-TREVALON (Dentsply Ltd, Detray division—Trevalon) ($n = 15$)
Group 2: Conventional heat cure PMMA-ACRALYN-HI (Asian Acrylates-Acralyn-HI) ($n = 15$)
Group 3: High impact heat cure PMMA-TREVALON-HI (Dentsply Ltd, Detray division—Trevalon-HI) ($n = 15$)
Group 4: High impact heat cure PMMA-ACRALYN-H (Asian acrylates-Acralyn-H) super unbreakable ($n = 15$)

The monomer–polymer ratio was maintained at 1:3 by volume for all four groups. The mixed acrylic was handled with latex examination gloves to avoid contamination of the resin with skin oils. On reaching the dough stage, i.e., when it separates cleanly from the sides of the mixing jar, the denture base material was kneaded thoroughly and packed into the mold space. Polythene sheets were used between the denture base material and upper half of the flask during trial closure. After the introduction of the acrylic resin into the flask, the two halves were closed together using the intermittent application of pressure on a bench press. The flask was closed and pressure applied until metal-to-metal contact was achieved. The flask with acrylic resin was allowed to bench cool for 1 h after which it was cured according to the curing cycle used in this study.

Curing Cycle

For Trevalon-HI: 200 ml of cold water was added for every 2 liters of water used and left for 60 min. Low heat was applied to maintain the temperature of water at 68°C for 30 min.

For Trevalon: The clamped flask was immersed in boiling water, the heat was turned off for 20 min, and then the water was reheated and boiled for 10 min.

For Acralyn-H, Acralyn-H Super Unbreakable: The flask was immersed in water in an acrylizer at room temperature. The temperature was raised slowly up to 70°C, held for 11/2 hours, then raised to 100°C, and maintained for half an hour.

After curing, the flasks were allowed to bench cool slowly from the final water bath temperature. The flasks were allowed to cool to room temperature. The acrylic specimens were then retrieved, finished, and polished. The specimens were stored in water for 24 h so that the residual monomer present on the surface of cure specimen could leach out.

Testing of the Specimen

Flexural resistance testing (60 × 10 × 4 mm)

Specimens were tested for flexural resistance on the Hounsfield tensometer (Tensometer Ltd, England). Three-point loading was used to carry out this test. The load applied to the specimens was measured by the movement of mercury in the glass tube. Before starting the test, the mercury level on the scale was measured to zero. Loading was increased gradually at increments of 500 gm and a crosshead speed of 5 mm/min. The loading was continued until the specimens fractured. The breaking load was recorded in kilograms. Flexural strength was calculated using the following formula:

$$FS = \frac{3}{2}\frac{pl}{bd2}$$

p = Load applied
1 = Sample length (60 mm)
b = Sample width (10 mm)
d = Sample thickness (4 mm)

Impact strength testing (4.5 × 7.5 mm)

Specimens were tested for impact strength on Hounsfield balanced pendulum impact machine (England). The specimens to be used were notched to a depth of 2 mm. An angle of 45° was machined across one face at midpoint of the length using a notch cutter. The apparatus was adjusted in accordance with the operating instruction. In testing the standard bar with notch, the specimens were placed on the supports in such a manner that the striking edge hits the center of the specimens. The pendulum was released by depressing the release lever, and the reading of the pointer was recorded on the scale to the nearest subdivision. The pendulum was arrested and returned to release position. The maximum load applied and energy absorbed to break the specimens were noted and the impact strength was calculated:

$$\text{Impact strength} = \frac{\text{Energy}}{\text{Area}}$$

E = Energy absorbed
N = Surface area

Results

Impact and flexural strength were measured using conventional and high impact heat cure PMMA for the four groups. The results are as follows.

Group I: Energy absorbed to break the specimen ranges from 0.068 j to 0.136 j with a mean of 0.104 j. Impact strength ranges from 1.1×10^{-3} J/mm^2 to 2.3×10^{-3} J/mm^2 with a mean of 1.7×10^{-3} J/mm^2 (Figure 1).

Group II: Energy absorbed to break the specimen ranges from 0.068 j to 0.136 j with a mean of 0.095 j. Impact strength ranges from 1.1×10^{-3} J/mm^2 to 2.3×10^{-3} J/mm^2 with a mean of 1.6×10^{-3} J/mm^2 (Figure 1).

Group III: Energy required to break the specimen ranges from 0.136 J to 0.304 J with a mean of 0.244 J. Impact strength ranges from 3.1×10^{-3} J/mm^2 to 6.9×10^{-3} J/mm^2 with a mean of 5.5×10^{-3} J/mm^2 (Figure 1).

Group IV: Energy required to break the specimen ranges from 0.204 J to 0.408 J with a mean of 0.271 J. Impact strength ranges from

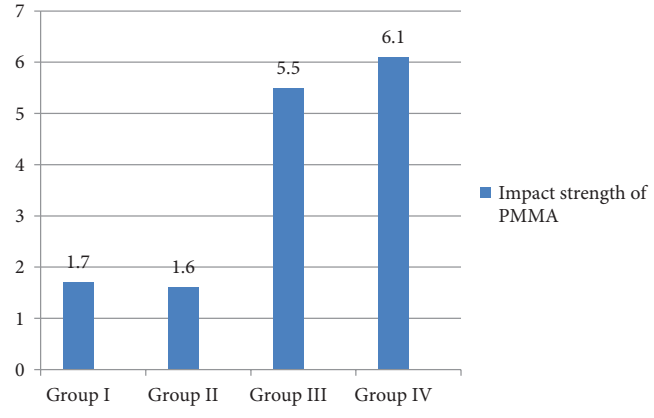

Figure 1: Comparision of mean impact strength of all four groups

4.6×10^{-3} J/mm^2 to 7×10^{-3} J/mm^2 with a mean of 6.1×10^{-3} J/mm^2 (Figure 1).

The mean impact strength values of four groups showed that Group IV had the highest mean impact strength value. This showed that Group IV presented the greatest impact resistance followed by Group III, Group I, Group II. However, the difference between Groups III and IV was insignificant. So Group IV can be considered the most superior among the four groups. It was also seen that Group III and Group IV had impact strength almost three times more than that of Groups I and II.

Flexural Strength

Group I: The force required to fracture the specimen was in the range of 7.2 to 9.0 kg. The range of flexural strength was between 39.73 and 49.66 Mpa with a mean of 46.02 Mpa (Figure 2).

Group II: The force required to fracture the specimen was in the range of 7.2 to 9.5 kg. The range of flexural strength was between 39.73 and 52.97 Mpa with a mean of 47.24 Mpa (Figure 2).

Group III: The force required to fracture the specimen was in the range of 11.7 to 12.7 kg. The range of flexural strength was between 65.11 and 70.63 Mpa with a mean of 68.02 Mpa (Figure 2).

Group IV: The force required to fracture the specimen was in the range of 12 to 14.2 kg. The range of flexural strength was between 66.22 and 78.36 Mpa with a mean of 70.08 Mpa (Figure 2).

The mean flexural strength value of four groups showed that Group IV had the highest mean flexural strength. It was also seen that Groups I and II had flexural strength one and a half times more than that of Groups III and IV (Table 1).

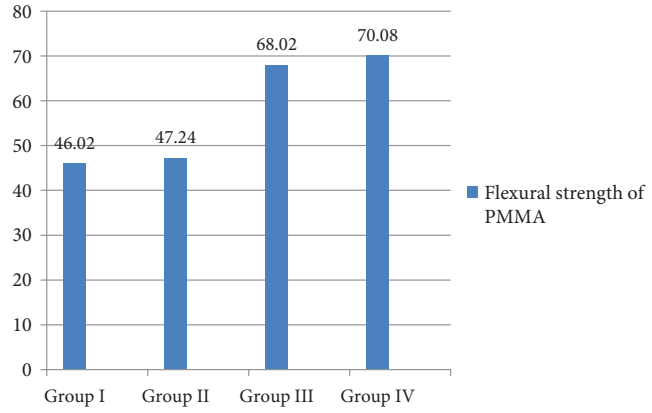

Figure 2: Comparision of mean flexural strength of all four groups

Groups	Flexural strength (mpa)			F. Value ANOVA	Comparision of means	
	Range	Mean	S.D.		Groups compared	Significance
1	39.73-49.66	46.02	3.22	216.8 $p < 0.001$ (vhs)	1-2	NS
2	39.73-52.97	47.24	4.15		1-3	NS
3	65.11-70.63	68.02	2.10		1-4	VHS
4	66.22-78.36	70.08	3.83		2-3	VHS

Table 1: Comparative statistics of flexural strength

Discussion

PMMA resin, which is widely used today as a denture base material, has many advantages, but it also has certain inherent poor mechanical properties. Fractures may occur during use because of unsatisfactory transverse strength, impact strength, and flexural resistance. This study evaluated the impact and flexural strength of heat cure denture base resins. The resistance to fracture of acrylic resin dentures depends on the flexural and impact strength. Flexural strength gives an indication of material performance under conditions of static load. The flexural strength of a material is a combination of compressive tensile and shear strengths. As tensile and compressive strengths increase, the force required to fracture the material also increases. Impact strength may be defined as the energy required to fracture a material under an impact force. Impact strength testing involves testing under dynamic loading conditions and involves a measure of energy absorbed by the material before fracture [23-26]. The fracture of denture arises usually out of the mouth and a high strain rate fracture also occurs due to the denture being dropped on the floor or bent during cleaning. In the mouth, the fracture of denture occurs in as a result of a fatigue phenomenon, i.e., low and repetitive stress rate. The advent of modern rubber-dispersed phase acrylates have reduced the incidence of denture fractures. The causes of complete denture fractures are more often related to design faults. Stress concentration occurs in a loaded part where the surface contour changes sharply. A stress concentration may be a large change in the surface contour such as a frenum notch or reproduction of rugae on the denture or a scratch on the denture. All dentures are notched to a greater or lesser degree. These notches are placed in the denture to allow freedom of movement for a fibrous attachment in close proximity to denture border. A prominent frenum attachment has little function and is not beneficial to the completely edentulous patient. So it is advisable to eliminate the frenum at the time of extraction of anterior teeth because the notch acts as a point of stress concentration, which ultimately leads to denture fracture.

The ratio of upper to lower denture fracture is about 2:1. Maxillary denture fracture is due to:

- Excessively thin sections
- Marked frenal notch especially anteriorly
- Old dentures on ridges that have continued to resorb
- Open-faced (gum fitted) dentures
- Occlusal problems due to the presence of natural teeth in opposing jaw

Mandibular dentures with thin sections are prone to fracture, and this may be exaggerated by the anatomical situation or by the modification of a denture when soft lining is placed. Midline fracture of a denture base is a flexural fatigue failure resulting from cyclic deformation of base during function. A fracture is the result of initiation and propagation of a crack, and this requires the presence of stress raiser or point of localized stress. Sharp changes in contours, pinholes, inclusions, deep scratches, and residual processing stresses may all cause stress intensification. This is due to the poor mechanical property exhibited by PMMA. Thus, with the suitable design together with the use of correct polymer, the likelihood of fracture is greatly reduced. The modification of PMMA through the addition of certain chemicals resulted in a high-impact, high-strength resin. PMMA has been modified by the addition of certain chemicals, fibers, and inserts. The incorporation of fibers like carbon fibers, [4,15,21,22] aramid fibers, [2,15] glass, [15,18,25,26] polyethylene, [5,11,12,15,16,22] and metal inserts had certain drawbacks. To overcome the problems associated

with these materials, a high-impact, high-strength resin is used. The acrylic is reinforced with rubber that contains butadine-styrene grafted with methyl methacrylate dispersed in poly (MMA) matrix [26]. This modification increases the impact strength, which is accompanied by the increase in transverse deflection. These materials are particularly useful for patients who have a history of breaking dentures during cleaning as a result of careless handling. This study showed that Group IV recorded the highest impact strength values followed by Group III, Group I, and Group II. For flexural strength testing, Group IV recorded the highest strength values followed by Group III, Group II, and Group I. Here, we also see that the higher the energy absorbed to fracture the specimen, the greater the impact strength and higher will be the flexural resistance. It has been observed that the use of high impact denture base resin improves the mechanical properties. Dentures can be made much stronger and more resilient under flexural fatigue or impact stress conditions. With the use of high impact resins, the chances of denture fractures could be substantially eliminated.

Conclusion

The highest impact strength recorded was with Acralyn-H (super unbreakable) heat cure denture base resin, about 4 times as high as conventional denture base resin. Trevalon-HI has an impact strength 3 times as high as conventional denture base resin. The highest flexural strength recorded was with Acryalyn-H (super unbreakable) heat cure denture base resin, about 1½ times as high as conventional denture base resin; Trevalon-HI has flexural strength about 1½ times as high as conventional denture base resin.

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