Original Article

An investigation into the transverse and impact strength of a new indigenous high-impact denture base resin, DPI-TUFF and its comparison with most commonly used two denture base resins

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An investigation into the transverse and impact strength of a new indigenous high - impact denture base resin, DPI-TUFF and its comparison with two most commonly used two denture base resins. **INTRODUCTION:** The heat cure denture base resins are extensively used for their excellent properties such as ease of handling, durability and esthetics etc. However, their strength properties are field for ongoing research, leading to various modifications of the resins to improve its strength, which include the high - impact resins. **AIMS AND OBJECTIVES:** A study was carried out to evaluate and compare the transverse and impact strength of a new high - impact denture base resin and it was compared with two most commonly available resins in the market. The materials used were DPI-TUFF, Lucitone 199 and DPI heat cure denture base resins. **MATERIALS AND METHODS:** A total of 120 resin samples were prepared (60 samples for transverse strength and 60 samples for impact strength) from three different materials. The samples were prepared using the short and long curing cycle and tested under dry conditions and after immersion in water for a week. **RESULTS AND DISCUSSION:** The obtained values for transverse and impact strength were subjected to statistical analysis. A student's T-test was performed to determine the difference between the materials selected. **CONCLUSION:** The DPI-TUFF high impact denture base resin appears to be comparatively superior to the other two resins, with mean transverse strength of 115.0 MPa and impact strength of 18.95 kJ/m^2. The dry strength of the samples of the materials tested show that it is greater than after immersion of the samples in water at 37ºC for a week. The long curing cycle shows considerably higher values of transverse and impact strength as compared to short curing cycle.

Key words: Acrylic resins, denture base resins, impact strength, transverse strength

Polymers today occupy a prominent place in the spectrum of materials used by dental profession. Although the properties of acrylic denture base resins are not ideal in every respect, it is the combination of virtues rather than one single desirable property that accounts for this popularity and universal use.

The fracture of acrylic resin denture is rather a common occurrence and causes inconvenience to the patient and embarrassment to the dentist. Denture fracture may occur either inside or outside the mouth. Failure occurs through impact if the denture is dropped. Inside the mouth, the occlusal forces may also cause fracture. Acrylic resin can be mechanically reinforced by incorporating various kinds of fibers. Other modifications of PMMA to improve the existing material include chemical modification to produce graft copolymer called high- impact resins.[1]

The resistance to fracture of acrylic resin denture depends on, among the other factors on flexural strength and impact strength. Due to the variety of materials available in the market many products are a remake of the patented products, which has led to the economical alternatives to these products. Such manufacturers claim their products to have comparable properties to those imported products. Due to the increased concern for quality control and to obtain assured results repeatedly, the evaluation of such newly introduced and currently available products is imperative. This study is one such effort to evaluate and compare the properties related to fracture resistance that is transverse strength

and impact strength of a new high - impact resin DPI-TUFF®, with other commercially available heat cure denture base resins Lucitone 199® and DPI® Heat cure available in the market. Further more this study aims to evaluate and compare the effect of water immersion and the duration of polymerization cycle on these properties. Such a study would add to the similar comparative studies[1-8] that have been conducted to establish the data for comparison and further evaluation.

MATERIALS AND METHODS

Three heat cure denture base resins, commercially available in the market were selected for this study. DPI-TUFF, a newly introduced indigenous high - impact heat cure resin material was selected to evaluate and compare with another high impact resin Lucitone 199. The unreinforced conventional heat cure denture base resin was used as control. Batch numbers and manufacturers for the materials selected for this study [Figure 1] are listed in the following table:

Type	Trade Name	Batch No.	Manufacturer
Conventional heat polymerized acrylic resin	DPI® Heat Cure	P- S43	DPI dental products of India Ltd. Mumbai
Newly introduced High - impact heat cure acrylic resin	DPI-TUFF®	-	DPI dental products of India Ltd. Mumbai
High - impact heat cure acrylic resin	Lucitone 199®	099666	Dentsply, York division, Pa.

Preparation of samples for transverse and impact strength

Preformed metal strips for transverse strength and plastic strips for impact strength were fabricated as per the dimensions given below:

Strip for	Dimensions	Standards
Transverse strength	65 x 10 x 3 mm	ADA specification No.12 for testing denture base resins[9]
Impact strength	80 x 12.7 x 3.17 mm	ASTM D 256[10]

a tab of wax (Modelling Wax, Hindustan Dental Products, Hyderabad India Ltd.) was attached at one end of the metal strip to facilitate its removal. The strips were coated with a thin layer of petroleum jelly (Bioline®) and were invested in dental stone in the lower half of the denture flask [Figures 2 and 3], taking care that one half the thickness was embedded in the stone put in base of the flask. This was allowed to set for half an hour and a single layer of separating medium was applied. The second pour was made with dental stone (Kalastone, Kalabhai Dental Products, Mumbai, India) and the flask was held in compression till the final set of dental stone. The denture flask was then opened and the preformed strips were retrieved from the stone. The ensuing steps that followed were similar to one used for processing conventional complete denture.

DPI-TUFF (P:M ratio 24 g: 8 ml), Lucitone 199 (P:M ratio 21 g: 8 ml) and DPI Heat Cure Polymer (P:M ratio of 21 g: 10 ml) was taken in, manipulated according to manufactures' instructions and the material was packed into the mould [Figure 4] in dough stage. Care was taken to avoid porosities due to entrapment of air bubbles. Trial closure was performed. The flask was immersed in water in an acrylizer with automatic controls (KaVo EWL) at room temperature. Test samples were labelled on each end before testing as $D_1, D_2 \ldots D_{20}$ for DPI TUFF, $L_1, L_2 \ldots L_{20}$ for Lucitone 199 and $C_1, C_2 \ldots C_{20}$ for DPI heat cure conventional resin, so that the fractured pieces could be reunited.

Curing of the samples

Two curing cycles were used:

- A short curing cycle where the temperature was slowly raised to 73ºC and held for 90 min followed by boiling at 100ºC for 30 min.
- In the long curing cycle the temperature was slowly raised from room temperature to 73ºC and held for 9 h.

After the completion of the polymerization cycle the flasks were allowed to cool in the acrylizer to room temperature before deflasking.

Finishing and polishing of samples

After deinvesting the samples were retrieved, finished with sandpaper and polished with felt cone in slow speed. Minimal finishing and polishing was required and care was taken to maintain low heat during the procedure.

Treatment of samples for testing under dry and wet conditions

- The non-immersed samples were referred to as dry samples alter being left exposed to air 24 h prior to testing.
- The wet samples, were immersed in distilled water at 37ºC in a thermostat for 1 week before testing.

Evaluation of transverse strength

The specimens were tested for transverse strength with a 3-point-bending test using INSTRON universal testing machine (model No. 8502, Servohydraulic testing, Canton USA) at a crosshead speed of 2 mm/min. and span length of 50 mm. The load was applied centrally on the bar specimen until fracture occurred. The amount of deflection [Figure 5] and the load at fracture were noted. The transverse strength was calculated using the formula:

Transverse strength = $3/2 \times pl/bd^2$

where

p - is the peak load

l - is the span length

b - is the sample width and
d - is the sample thickness

Evaluation of impact strength

For impact testing the samples were tested using an Izod impact tester (RESIL 5.5, CEAST S.p.a, Torino, Italy). The specimens were clamped at one end and a swinging pendulum of 0.5 J was used to break the unnotched specimens [Figure 6]. The absorbed energy by the specimen was noted.

The impact strength was calculated using the formula:

Impact strength = E / b x d

where

E - is the absorbed energy
b - is the sample width and
d - is the sample thickness

The obtained data were tabulated and statistically analysed. The pertinent data has been presented in tabulated form in the chapter of results.

RESULTS

Tables 1 and 2 show the mean transverse and impact strength of the three materials tested and the strength values are highest for DPI-TUFF when cured using the long curing cycle and tested under dry conditions.

A student '*t*' test was performed on the observed values [Tables 3 and 4], to compare the differences in strength under dry and wet conditions using the short and long curing cycles. The results showed significant differences in transverse and impact strength between DPI-TUFF and Lucitone 199 and the DPI heat cure resin used as control. Long cured dry samples showed statistically significant difference in transverse and impact strength with DPI-TUFF showing higher values than Lucitone 199.

Table 1: Mean transverse strengths (MPa)°

Materials tested	Dry specimens		Wet specimens	
	Short curing cycle	Long curing cycle	Short curing cycle	Long curing cycle
DPI-TUFF	115 ± 1.8	142.5 ± 4.7	98.49 ± 2.9	112.5 ± 2.8
LUCITONE 199	94.66 ± 4.3	99 ± 1.6	83.14 ± 2.8	89.66 ± 3.3
DPI-HEAT CURE	51.16 ± 2.6	61.56 ± 1.4	52.36 ± 2.5	55.11 ± 3.4

°MPa - Mega pascals

Table 2: Mean impact strengths (kJ/m²)#

Materials tested	Dry specimens		Wet specimens	
	Short curing cycle	Long curing cycle	Short curing cycle	Long curing cycle
DPI-TUFF	18.95 ± 0.6	21.28 ± 1.1	14.8 ± 0.3	16.27 ± 0.4
LUCITONE 199	17.12 ± 0.6	22.23 ± 1.2	15.47 ± 0.3	19.83 ± 0.6
DPI-HEAT CURE	8.83 ± 0.7	12.04 ± 0.7	7.56 ± 0.3	10.1 ± 0.3

#kJ/m² - kilo joules per square meter

DISCUSSION

The fracture of acrylic resins is an unresolved problem in removable prosthodontics despite numerous attempts to determine its causes. Typically the ratio of upper to lower denture fractures is about 2:1 with most common causes of fracture appearing to be poor fit and lack of balanced occlusion. An analysis of the practical situation with respect to the fracture of dentures shows two types of failure: (1) outside the mouth, caused by impact forces, i.e., a high stress rate and (2) inside the mouth, usually in function, which is probably a fatigue phenomenon, i.e., low and repetitive stress rate. Inside the mouth, it is generally flexural failure caused by repeated flexure over a period of time. This type of fracture occurs most often close to midline in maxillary than in mandibular dentures. Acrylic resins have shown to flex in function to a much greater degree than would be expected.[11] Therefore to overcome such disastrous eventualities many modification/s in the conventional denture base resin to improve its strength were introduced.

Modification of the acrylic resin designed to improve the specific properties include plasticization, copolymerization, crosslinking and reinforcement.[7] One such attempt led to the production of high-impact resins

Table 3: Statistical comparison (t-test) of mean transverse strength of different denture-base materials

Materials tested	Dry specimens		Wet specimens	
	Short curing cycle	Long curing cycle	Short curing cycle	Long curing cycle
DPI-TUFF-	115 ± 1.8	142.5 ± 4.7	98.49 ± 2.9	112.5 ± 2.8
LUCITONE	94.66 ± 4.3	99 ± 1.6	83.14 ± 2.8	89.66 ± 3.3
199	S+	S	S	S
LUCITONE 199-	94.66 ± 4.3	99 ± 1.6	83.14 ± 2.8	89.66 ± 3.3
DPI-HEAT	51.16 ± 2.6	61.56 ± 1.4	52.36 ± 2.5	55.11 ± 3.4
CURE	S	S	S	S
DPI-HEAT CURE-	51.16 ± 2.6	61.56 ± 1.4	52.36 ± 2.5	55.11 ± 3.4
DPI-	115 ± 1.8	142.5 ± 4.7	98.49 ± 2.9	112.5 ± 2.8
TUFF-	S	S	S	S

#kJ/m² - kilo joules per square meter

Table 4: Statistical comparison (t-test) of mean impact strength of different denture-base materials

Materials tested	Dry specimens		Wet specimens	
	Short curing cycle	Long curing cycle	Short curing cycle	Long curing cycle
DPI-TUFF-	18.95 ± 0.6	21.28 ± 1.1	14.8 ± 0.3	16.27 ± 0.4
LUCITONE	17.12 ± 0.6	22.23 ± 1.2	15.47 ± 0.3	19.83 ± 0.6
199	S	S	S	S
LUCITONE 199-	17.12 ± 0.6	22.23 ± 1.2	15.47 ± 0.3	19.83 ± 0.6
DPI-HEAT	8.83 ± 0.7	12.04 ± 0.7	7.56 ± 0.3	10.1 ± 0.3
CURE	S	S	S	S
DPI-HEAT	8.83 ± 0.7	12.04 ± 0.7	7.56 ± 0.3	10.1 ± 0.3
CURE-DPI-	18.95 ± 0.6	21.28 ± 1.1	14.8 ± 0.3	16.27 ± 0.4
TUFF-	S	S	S	S

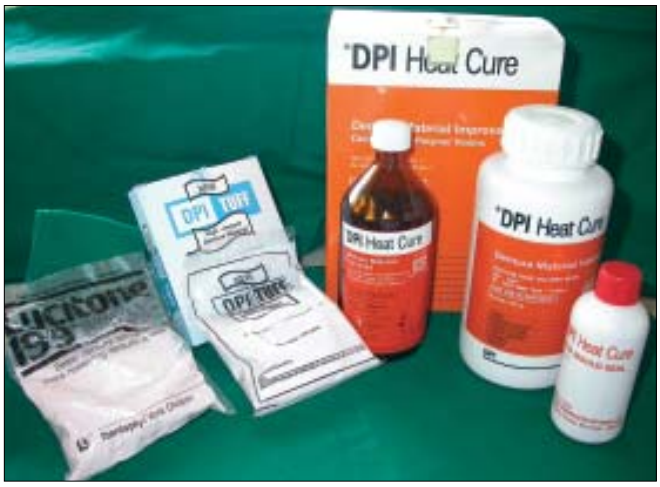

Figure 1: Materials used in the study: DPI - TUFF®, Lucitone 199® and DPI® Heat Cure denture base resins

Figure 2: Preformed dies invested in dental stone for preparation of samples for transverse strength

Figure 3: Preformed plastic strips invested in dental stone for preparation of samples for Impact strength

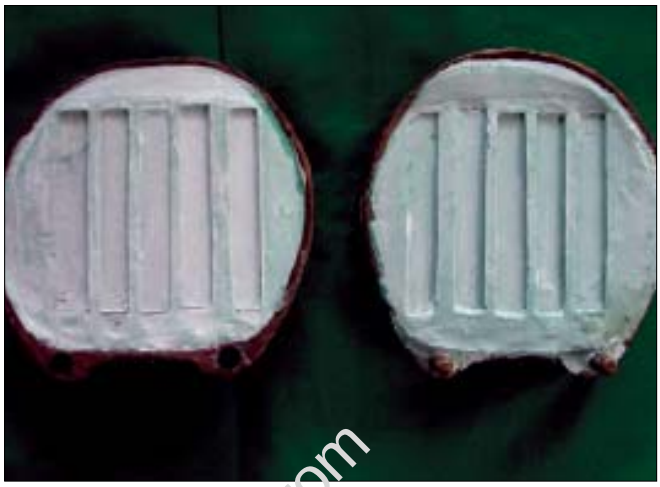

Figure 4: Mold space obtained after removal of strips used to pack the resin for preparation of samples for transverse strength

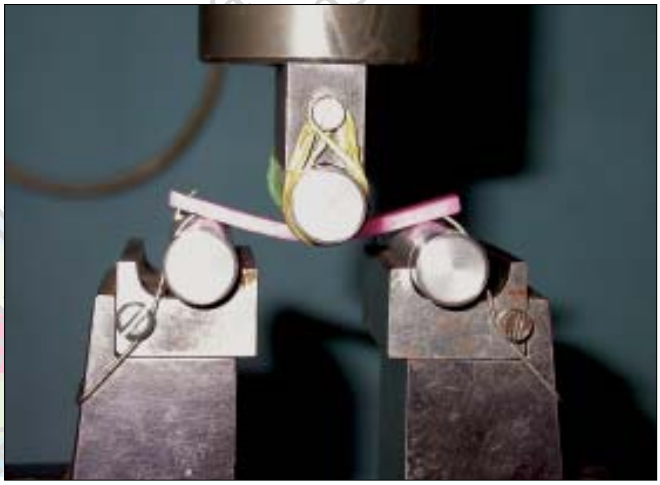

Figure 5: Transverse bend test in progress

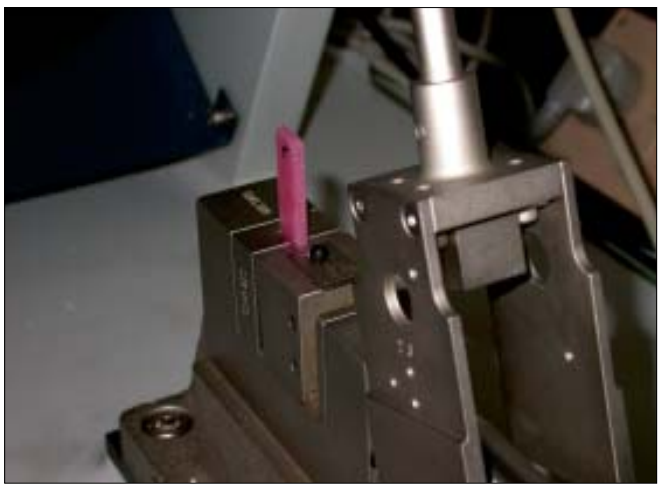

Figure 6: RESIL Impact tester (Izod test)

that contain copolymers of low molecular weight butadiene- styrene-b copolymer-. The exact nature of this inclusion is regarded as manufacturers' trade secret and requires extensive research into chemical engineering.

In order to investigate the effectiveness of modifiers

or fillers in denture base resins or to compare the performance of different products, various mechanical tests can be performed. The commonly used methods in literature to predict the fracture resistance is transverse (flexural) strength[3-5,8] and impact strength.[1,5,6] For this study, these two properties were chosen because of their influence on the selection of a denture base resin material.

The sample preparation followed here was similar to the one adopted by *John J. and Associates.*[12] Here preformed metal/plastic strips were directly invested into dental stone to form stone moulds for fabrication of test samples. To avoid errors in dimensions, distortion and expansion of mould space, ease of preparation and minimal finishing required after deflasking, were the criteria for preference of investing the metal/plastic strips over the wax patterns.

The samples' dimension of 65 x 10 x 3 mm were prepared as per the ADA specification No. 12 to test the transverse strength of denture base resins,[9] where a three point bend test was carried out using Instron Universal testing machine with predictability. The transverse strength of a material is a combination of compressive, tensile and shear-strengths. As the tensile and compressive strengths increase in reinforced resins, the force required to fracture the material also increases. For the impact strength test an Izod Impact tester was utilized. There are basically two types of tests, Charpy and Izod tests for evaluation of impact strength. Depending on the loading configuration, specimen dimensions and presence of notches and their geometry, these tests can result in different values.[13] The Izod impact test used for this study utilizes the specimens dimension of 80 x 12.7 x 3.17 mm according to the ASTM D 256.[10] Although there is a good correlation between the two tests, the absolute values differ from each other,[13] however the aim here was not to evaluate the absolute values of the materials but a comparison between the materials selected. Unnotched samples were cantilevered and a swinging pendulum was used to break the specimens. The reduction in swing of the pendulum or the energy absorbed by the material was measured.

In an article by Zappini *et al.*[13] shows that presence of notch sensitivity reduces the impact strength values. This explains the relatively high values obtained for the impact strength measurement in various groups in this study (Izod impact strength of unnotched samples of Lucitone 199 showed 17.12 kJ/m^2). However, the unnotched values are within the range as observed in previous studies.[1,14] And it was further found that, the loss of impact strength due to presence of surface defects was higher in high impact resins than in conventional resins. To rule out this variation unnotched specimens were used.

It was observed that the mean transverse and impact strength for all three materials tested using the long curing cycle,[15,16] under dry conditions showed higher transverse and impact strength values which were statistically significant. The samples tested using short and long curing cycle under wet conditions showed decreased transverse and impact strength, with the short cured wet samples showing the least strength. This clearly shows that the mean transverse and impact strength reduced when tested after immersion in water for 1 week. The decrease in strength was more so, for the group of short cured wet samples than the group of long cure wet samples. Thus the dry strength appears to be higher than the wet strength and long curing cycle is preferred over the short polymerization cycle for these materials tested.

Another parameter for comparison in this study was transverse and impact strength under dry and wet conditions. The samples were immersed in water for a week prior to testing. A study conducted by Dixon *et al*[2] in 1992 showed that, a week immersion in water was necessary to saturate the samples and 30 day water storage was necessary to maximize the plasticizer effect of water. The results of this study were in concurrence with that study. The absorption of water by acrylic resin is of considerable importance since it is accompanied by dimensional changes.[17]

From the above discussion of results as well as the statistical analysis it is evident that after immersion in water the denture base resins compared, were more prone to fracture than when they are tested dry. Further more the use of long polymerization cycle increases the transverse and impact strength values of these materials as compared with the use of short polymerization cycle, observed more so with the high impact materials DPI- TUFF and Lucitone 199.

Clinical implications

1. In this study it was observed that the dry strength of samples was higher than that of the samples tested after immersion in water. This could probably reduce the chances of fracture during accidental dropping of the denture while polishing and before insertion of denture.
2. Secondly the denture may be more prone to fracture after use in mouth for considerable period of flexing or accidentally dropped during or after its removal from the mouth.
3. Lastly, although the use of long polymerizing cycle is time consuming, it results in dentures with more fracture resistance as compared with the use of short polymerizing cycle.

The variations in strength values of the materials selected have been tested under static loading in simulated oral conditions. Fatigue testing of the denture base materials under dynamic loading using the denture base configurations in simulated oral conditions, using

saliva or its substitutes is an area for further research. Well-controlled clinical studies and further *in-vitro* studies are necessary to correlate the findings and examine those variables that influence the fatigue behaviour of the denture polymers. Although the samples were prepared according to the standards and with a high degree of reproducibility, the results are bound to vary if any of the variables are altered.

CONCLUSION

The mechanical behavior of a denture in service depends not only on the strength of the material but also on the design and construction, on the effect of residual stresses and on the conditions of loading. This knowledge is essential for the interpretation of laboratory results obtained to produce comparative data on different materials. Factors like different powder/liquid ratios, homogenous copolymer beads, differences in water uptake may also affect the mechanical properties.

Clinically a resin material exhibiting a lower transverse strength may be more prone to fracture during function as a denture base, than would a resin with higher transverse strength. This potential for fracture may increase due to water sorption, further decreasing their strength. The polymers therefore behave differently in air and after immersion in water; the present data justifies this observation.

Finally, the laboratory test results for any resin are not necessarily equivalent to clinical findings, even though efforts are made to simulate the clinical conditions in laboratory experiments. The data obtained in this study for transverse and impact strength, pertain to the conditions in which they are tested with any changes in the materials and methodology of testing, the strength values obtained are subject to change.

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